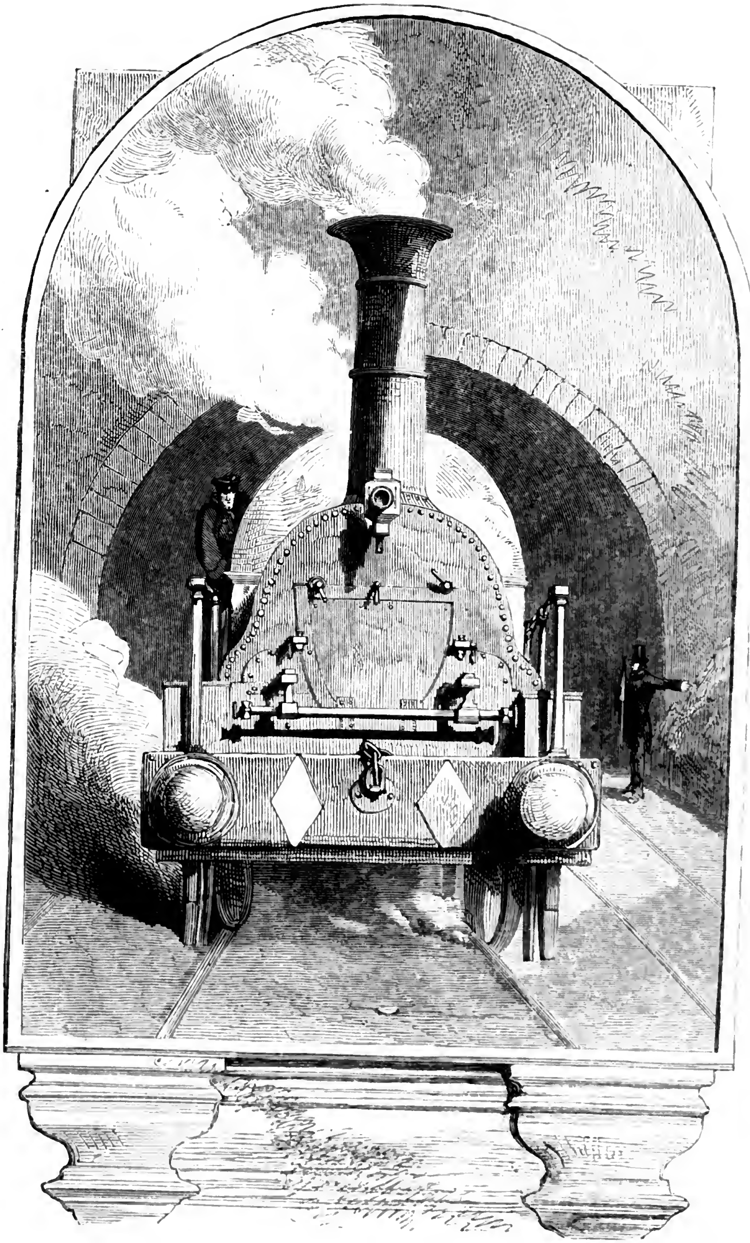
James Metcalfe
July 20th
1857



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THE

STEAM-ENGINE,

ITS HISTORY AND MECHANISM:

BEING

Descriptions and Illustrations

OF THE

STATIONARY, LOCOMOTIVE, AND MARINE ENGINE.

For the Use of Schools and Students.

BY ROBERT SCOTT BURN,

EDITOR OF THE "ILLUSTRATED LONDON DRAWING-BOOK;" "MECHANICS AND MECHANISM;"
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LONDON:

H. INGRAM AND CO.,

MILFORD HOUSE, MILFORD LANE, STRAND;

AND

W. S. ORR AND CO., AMEN CORNER, PATERNOSTER ROW.

1854.

LONDON:
PRINTED BY LEVEY, ROBSON, AND FRANKLYN,
Great New Street and Fetter Lane.

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INTRODUCTORY CHAPTER.

THE PROPERTIES OF STEAM.

BEFORE entering upon the consideration of the historical and mechanical details of the steam-engine, it will be necessary to explain as briefly as possible the nature and properties of steam. It is but just, however, to state, that the new theory of *heat*, now being submitted to the test of experiment, will modify very much the theory of the steam-engine. Until the new views, however, have been conclusively affirmed, it would be premature here to specify them; we shall therefore confine ourselves to a statement of the theory of the steam-engine as generally received.

When a quantity of water is heated until it arrives at a certain fixed temperature, an elastic fluid or aqueous vapour is evolved; this is called steam, and resembles in many of its properties common air. Like air, it is elastic, capable of being reduced in bulk by compression; the pressure which it exerts in the vessel into which it is compressed being exactly in proportion to the amount of compression. (See volume on *Natural Philosophy* in this series.) Like air, steam is also capable of an increase of volume or bulk; this expansion reducing the pressure on the vessel in which it is allowed to expand just in proportion to the amount of expansion. The first property of steam now mentioned is termed its *elasticity*, the second its *expansibility;* although, having these properties in common with fluid gases, steam is distinguished by the term of aqueous vapour, inasmuch as it differs from a gas, which retains permanently its gaseous condition under ordinary circumstances; while steam requires to be kept at a uniform temperature, otherwise it changes its condition, and returns to its original form of liquid. This property, by which steam is readily converted into water, is of immense importance; by virtue of this property the power of steam is made available in what are termed condensing engines, and offers the readiest means of forming a vacuum in the cylinder, into which comparatively little force is required to press the piston.

When a quantity of water is placed in a boiler, and heat applied to it, a circulation of the particles of water immediately commences; those nearest the bottom, receiving a certain quantity of heat, expand and rise upwards; the colder portion taking their place, and becoming heated in their turn, rise; small air-bubbles become formed at the bottom after the above process has gone on for a certain time; these bubbles contain aqueous vapour; these rise upwards, and on coming in contact with the colder portions above, are cooled or condensed, and give out their heat to the surrounding particles. This process continues until the whole mass becomes of a uniform heat, and a fixed temperature has been arrived at. After this, however long the heat might be applied to the boiler, the water would not increase in temperature; but the rising of the steam-bubbles would become so rapid that the whole mass would be in a state of agitation, and a vapour would be evolved in large quantities; this vapour, as before stated, is steam, and is invisible, like common air. The fixed temperature already alluded to is what is termed the *boiling-point.* Under the ordinary atmospheric pressure at the level of the sea, the boiling-point of fresh water is 212° Fahrenheit, that of salt water being somewhat higher, or about 213·2°: in the generation of steam of a high pressure the boiling-point varies, increasing in proportion to the pressure. With a pressure of 16 lbs. to the square inch, the temperature at which the water boils is 216·3°; at 18 lbs. to the inch, 222·7°; at 20 lbs., 228·4°; at 25 lbs., 240·9°; at 30 lbs., 251·4°; at 35 lbs., 260·6°; at 40 lbs. to the square inch, 268·8°; at 50 lbs., 282·7°; at 55 lbs., 288·8°. When steam is generated under a pressure of 15 lbs. to the square inch, it is termed "steam of one atmosphere;" when generated at 30 and 45 lbs. to the square inch, it is said to be of the pressure of steam of two and three atmospheres respectively.

One of the most striking peculiarities of steam is the enormous increase of its bulk, as compared with that of the water from which it is generated.

The proportion of increase will be best remembered by the statement, that under the ordinary pressure of the atmosphere, or 15 lbs. to the square inch, a cubic inch of water will produce a cubic foot of steam; and as there are 1728 cubic inches in a foot, the increase of volume of steam is 1728 times. Under an increase of pressure the volume of steam is diminished: under a pressure of 30 lbs. the volume is only one-half; taking the "relative volume of steam" raised at a pressure of 15 lbs. at 1669, steam at 20 lbs. would have a volume of 1281; at 25 lbs., of 1047; of 30lbs., or double the ordinary pressure, of 882; at 35 lbs., 766; at 40 lbs, 678; at 45 lbs., 609; and at a pressure of 50 lbs. steam would have the relative volume 554. We have before stated, that steam is capable of being reduced from a state of vapour by being reduced in temperature; this temperature is always the same as that of the water from which it is raised. By gradually reducing the temperature of steam the vapour will be condensed, and be reconverted into water: a cubic foot of steam under the ordinary pressure occupying the space of about a cubic inch of water.

In raising steam, a large amount of caloric is absorbed which is not observable by the thermometer; this is termed "latent heat." By this is meant the amount of heat required to evaporate a given quantity of water compared with that necessary to bring the water to the boiling-point. Thus it is found that to evaporate a certain quantity of water into steam at 212°, it will take $5\frac{1}{2}$ times as much heat as would raise the water from 32°, or the freezing-point, to 212°, the ordinary boiling-point; this excess of caloric, however, is not indicated by the thermometer,—hence the term *latent heat*. The latent heat of steam is generally reckoned at 1000°, the temperature of the steam being 212°; the sum therefore of the sensible heat, that is, the temperature indicated by the thermometer, 212°, and the latent heat 1000°, is equal to 1212°. The total amount of the indicated and latent heat at all temperatures is a "constant sum:" thus if the pressure is increased at which the steam is raised, so as to give a temperature of 300°, the latent heat is 912°; if 500°, 712°, and so on. It is from this property of steam that so much fuel is expended in raising it. The mechanical effect produced by the evaporation of a cubic inch of water is generally calculated as being sufficient "to raise a ton weight one foot high;" from this, however, is to be deducted loss from friction and other causes. In the body of the work will be found exemplifications of the properties of steam, and of the duty and the power of steam-engines ; we therefore hasten to the consideration of the general subject.

In arranging the materials and illustrations of our work, we have been guided by the same principles which dictated the method of elucidation in our volume, *Mechanics and Mechanism*, in the present series. We have aimed at presenting practical details rather than elaborate theories ; not deeming these unnecessary, but conceiving that for the purposes of our treatise, and for the classes for which it is more particularly designed, correct illustrations and descriptions of the mechanical arrangements constituting the different varieties of steam-engines now in use will be more generally useful than expositions of strictly theoretical rules and mathematical formulæ, which serve in many cases to confuse rather than to enlighten the uninitiated reader, to deter rather than to induce the pupil to proceed in his investigations. The work necessarily assumes the form of a mere compilation ; but in addition to consulting the best authorities, and endeavouring to place the results of this in as attractive and regular a form as possible, we are indebted for some of our valuable illustrations to the editor of the *Practical Mechanic's Journal*, by whose courtesy we have been enabled to enrich our pages. From the number of the illustrations, and the method of arrangement, we venture to hope that our work will form in some measure a useful auxiliary in an Educational Series.

THE HISTORY

OF

THE STEAM-ENGINE.

CHAPTER I.

HISTORICAL NOTICES OF THE APPLICATION OF STEAM, FROM HERO, 130 B.C. TO SMEATON, 1772 A.D.

As before stated in our introductory remarks, the ancients are known to have had an acquaintance with the utility of the power of steam and heated air, and had devised certain contrivances in which this power was developed. These contrivances were, as may be supposed, applied to no purpose of utility, but served more as the means of exciting the wonder of the populace, as the miraculous production of their priesthood, and as forming part of the mysteries of their worship. Thus, one of the contrivances of the well-known Hero of Alexandria, who flourished 130 years before Christ,—the first personage who figures in the stereotyped history of the steam-engine,—was for the purpose of causing wine to flow from the hands of images placed beside the altar; and was effected as follows: "A steam-tight vessel or vase containing wine is placed within each image, the altar being made hollow, and partially filled with water; bent tubes reaching from the space in the altar above the water to the space in the vases above the wine; and other tubes are taken from the vases, below the level of the wine, to the hands of the images. Matters being thus prepared, when you are about to sacrifice," says Hero, "you must pour into the tubes a few drops lest they should be injured by heat, and attend to every joint lest it leak; and so the heat of the fire mingling with the water will pass in an aërial state through these tubes to the vases, and pressing on the wine, make it pass through the bent syphons until, as it flows from the hands of the living creatures, they will appear to sacrifice, as the altar continues to burn." In another contrivance, the force of the vapour of water was perhaps more obviously shown. In fig. 1, a caldron or vase *a* has a pipe *c* fitted to it, terminated by a small cup *d*. On the caldron being partially filled with water, and fire applied beneath it, the steam, issuing from the jet with considerable velocity, raises and supports the ball *e* so long as the steam is kept up. But the principal contrivance for which Hero is famed, and one which in itself comprises nearly all the requisites of a complete prime-mover, is that known as the "Æloipile."

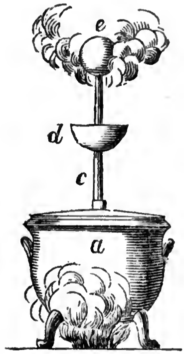

fig. 1.

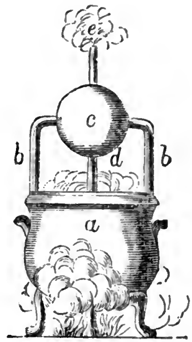

fig. 2.

This invention is, moreover, all the more remarkable and worthy of notice, from the fact that in recent times it has been introduced into practice as an efficient and economical steam-engine. Fig. 2 will explain the arrangement of its parts, and its operations. Let *a* be a caldron or vessel partially filled with water and placed on a fire; two pipes *b b* communicate with the interior of this, and are bent at the top at right angles; a hollow ball *c* revolves on the arms *b b*, and has two pipes *e d* placed at the opposite ends of its diameter; the ends of these pipes are made up, but apertures are made in the opposite sides of each. The steam rising through the tubes *b b*, passing into the hollow ball *c*, is ejected through the apertures in *e d;* the reaction of the opposite jets of steam on the surrounding air causes the globe *c* to rotate with rapidity on its axis, "as if it were animated from within by a living spirit." In fig. 3 the relative arrangements of the jets from the tubes *b c* is shown; the globe *a* revolving in the direction of the arrows. In these contrivances the properties of steam expansion and contraction are made known. It is somewhat remarkable—as taking the era of the introduction of steam and heated air as a motive-power much further back than is generally supposed—that Hero states that he made himself acquainted with the labours of his predecessors and contemporaries in connexion with pneumatical contrivances, and that many of those which he describes in his *Spiritalia seu Pneumatica* were not of his own invention; thus inducing the belief that this power was known for ages previously, although its operation, doubtless, was only known to the priests. All authorities agree in thinking that the knowledge of the power of steam was more widely disseminated than is generally believed. That this power was applied chiefly, if not exclusively, by the priesthood, for the purpose of exciting a belief in their worshippers of the supernatural intervention

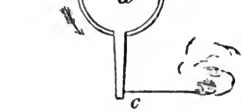

fig. 3.

which at times they could command, is also pretty conclusively ascertained. What schoolboy has not read of the mysterious Memnon, whose mystic utterance of sounds has even yet, in these utilitarian days, "a distinct and mysterious interest, for no myth of the most graceful mythology is so significant as its story." Yet the "seven mystic vowels, which are the very heart of mysteries to us," are said to have been produced by some of those pneumatic contrivances which Hero describes. "When the secrets of the waning faith," says an elegant writer, "were revealed by the votaries of a rival belief, the celestial harmony was then said to be produced by vapour, rising from water concealed in a cavity of the statue, being made to pass through a tube having a small orifice fashioned in a manner similar to that of an organ. As long as the fluid was heated by the rays of the sun, mysterious sounds were heard by the assembled worshippers, which died gradually away as the solar influence was withdrawn from the gigantic idol."

At this stage of our progress an inquiry will naturally arise—how is it, that with all the ingenuity of the ancients, so fertile and so suggestive a power should have been allowed to remain developed only in the devices of priestcraft, and not adapted to the purposes of a more varied and general utility? The cause of this apparent neglect may be traced to the same sources which influenced the obscurity which has hid from later times the arts of antiquity. Another cause may be in the following, so well put by an able writer: "The ancient philosophers esteemed it an essential part of learning, to be able to conceal their knowledge from the uninitiated. And a consequence of their opinion that its dignity was lessened by its being shared with common minds, was their considering the introduction of mechanical subjects into the regions of philosophy a degradation of its noble profession; insomuch that those very authors among them who were most eminent for their invention, and were willing by their own practice to manifest unto the world their artificial wonders, were notwithstanding so infected by this blind superstition, as not to leave any thing in writing concerning the grounds and manner of these operations; by which means it is that posterity hath unhappily lost, not only the benefit of those particular discoveries, but also the proficiency of those arts in general. For when once learned men did forbid the reducing of them to vulgar use and vulgar experiment, others did thereupon refuse these studies, as being but empty and idle speculations; and the divine Plato would rather choose to deprive mankind of these useful and excellent inventions, than expose the profession to the vulgar ignorant." For centuries no attention seems to have been paid to the development of the power of steam; at least, history is a blank as to any notices thereof. Nevertheless, there are sufficient indications of the fact that its power was not altogether unobserved by philosophers and men attached to science; many in their writings hinting at the power to be derived from "vapour," and alluding confidently as to the capability of huge "engines" being forced into motion by the power of this agent. About the year 1121, according to William of Malmesbury, "there were extant in a church at Rheims, as proofs of the knowledge of Gerbert, a public professor in the schools, a clock constructed on mechanical principles, and a hydraulic organ in which the air, escaping in a wonderful manner by the force of heated water, fills the cavity of the instrument, and the brazen pipes emit modulated tones through multifarious apertures."

On the revival of learning throughout Europe, the dissemination of the writings of the ancient philosophers doubtless attracted attention to many of these contrivances. There is some probability attached to the supposition that the invention of Blasco de Garay, a sea-captain, introduced into notice in 1543, was founded upon or derived from one of these. His invention was designed for the propulsion of vessels, and appears to have been very efficient. Unfortunately no record is known to exist from which a knowledge of its parts can be ascertained. The following is the only account extant: "Commissioners were appointed by the Emperor Charles the Fifth to test the invention at Barcelona, on the 17th June, 1543; and the result was, that a ship of 200 tons burden was propelled by the machine at a rate of three miles an hour." The moving force was obtained from a boiler containing water,—liable, as was said, to explosion; and paddle-wheels were the propelling power. Strange as it may appear, no further result was obtained from this trial, and the invention was lost sight of. Towards the close of the sixteenth century numerous expedients and mechanical contrivances for raising water were described in published works; these being based in principle on the contrivances detailed by Hero. Baptista Porta, in 1606, the well-known inventor of the camera-obscura, published a commentary on Hero's *Pneumatica*, in which he describes the arrangement which is illustrated in fig. 4. Let *a* be a furnace, and *b* a small boiler or receptacle for the water to be heated; on the steam rising up the tube *c*, which is continued nearly up to the top of the air-tight box *d d* containing water, it presses on the surface of the water and forces it out through the tube *e*, which is continued down nearly to the bottom of the box *d d*. This contrivance, although the author made no application of it for the purpose of raising water, is worthy of notice, if only for containing within itself the first known germ of an important distinction in steam-mechanism, namely, the adaptation of a separate vessel for containing the water to be raised, from that in which the steam or vapour was generated. Baptista Porta gives this arrangement merely as carried out in an experiment on the relative bulks of water and steam.

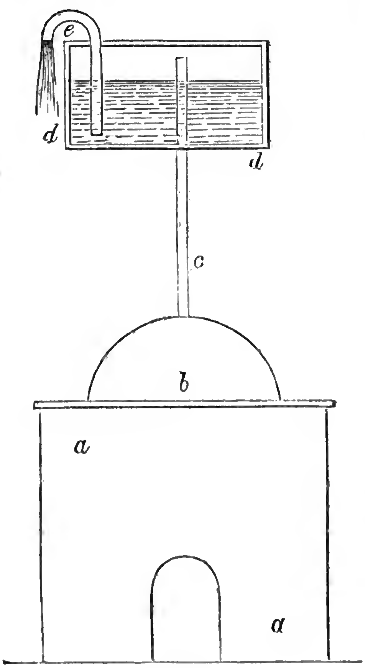

fig. 4.

Solomon de Caus, in a work dated Heidelberg, in 1615, entitled, *Les Raisons des Forces mouvantes avec diverses Machines tant utiles que plaisantes*, amongst a variety of insignificant and fanciful theories and descriptions, gives an arrangement by which water is raised above its level.

In fig. 5 we give an illustration of De Caus' theorem on this point. Let *a a* be a ball of copper, having a pipe *c* by which to partially fill *a a* with water; another pipe *b b* reaching nearly to the bottom of the globe is also provided. On placing the globe on a fire and carefully stopping up the vent *c*, the steam or vapour pressing on the water in *a a* presses it up the tube *b b*. He also details the following illustration of the force of steam. "Take a ball of copper of one or two feet diameter and one inch thick, which being filled with water by a small hole, subsequently stopped by a peg so that neither air nor water can escape, it is certain that if the said ball be put over a great fire so that it may become very hot, it will cause so violent a compression that the ball will be shattered in pieces. It, however, required no experiment of this stamp to prove the force of steam; the ancients were by no means ignorant of this; indeed they went so far as to attribute earthquakes to the force of pent-up vapours derived from subterranean heat. And Alberti, in 1412, notices the effects of pent-up vapour —dreaded by the lime-burners of that period—on the stones: "for when they come to be touched by the fire, and the stone grows hot, it turns to vapour, and bursting the prison in which it is confined with a tremendous noise, blows up the whole kiln with a force altogether irresistible."

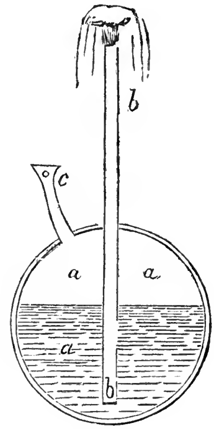

fig. 5.

M. Arago, in his anxiety, we presume, to claim the merit of the discovery of the invention of the steam-engine to a countryman of his own, attributes to De Caus a higher and more philosophical knowledge of the capabilities of steam than one would suppose he was in possession of, merely from his recital of the above experiment; and states that the ideas of the ancients respecting the force of steam had never reached any thing like the numerical appreciation realised by such experiments as those of De Caus. On this point we cannot do better than quote from the able treatise on the steam-engine edited by John Bourne, Esq., C.E.: "We confess that we are at a loss to understand wherein this numerical appreciation can consist; for although De Caus or Rivault may have ascertained that steam will burst a cannon-ball or bomb, they never ascertained what sort of ball or bomb steam will *not* burst; so that they did not establish any limit to the power of steam, but only showed that it is capable of very powerful effects."

In 1629, in a work published by Giovanni Branca, a description is given of a contrivance in which the force of steam was used as the actuating power. The water is heated in a vessel the upper part of which is fashioned like a head; from the lips of this a pipe or tube issues, which directs the steam against the vanes or boards of a wheel, made somewhat like an undershot wheel; this is made, by the impinging of the steam on the floats or vanes, to rotate rapidly. The wheel is placed horizontally, as *b*, fig. 6; in the vertical axis of this a small trundle *c* is placed, which actuates the face-wheel *d*, and gives motion ultimately to stampers for compounding drugs in mortars. It is believed by some writers that this machine was actually in use for the above purpose; by others, however, this idea is discarded. And it is doubtful whether Branca was the real inventor, as his book is avowedly "a collection of machines invented by others; and

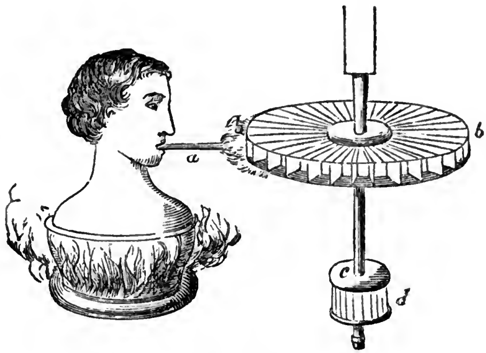

fig. 6.

this mode of moving a wheel by steam is probably, therefore, an idea of which he is the mere illustrator." He was, however, a "man of taste, as well as a person of ingenuity."

From the period now arrived at, up to the middle of the seventeenth century, history has no record as to the advances of the improvement of the steam-engine. All the contrivances hitherto published seem to have been more the result of closet study than every-day practice; more to be looked upon as the playthings of our philosophers than the purposed inventions of the practical mechanic. To this, however, De Garay's steam-boat propeller may perhaps be an exception; nevertheless it can be classed only as an experiment—questionless a successful one—and the barren results of which, in all probability, arose from some inherent defect in its principle or construction. At all events, up to the interesting period we now approach, no useful application of steam to the practical purposes of every-day life had yet been successfully introduced.

In 1663 the Marquis of Worcester, a nobleman who had undergone many changes of fortune in the civil wars of England, published a work entitled "A Century of the Names and Scantlings of such Inventions as at present I can call to mind to have tried and perfected, which, my former notes being lost, I have, at the instance of a powerful friend, endeavoured now, in the year 1655, to set down in such a way as may sufficiently instruct me to put any of them in practice." Amongst the numerous devices which he enumerates, the following is the one which is closely connected with our present subject: "An admirable and most forcible way to drive up water by fire; not drawing or sucking it upward, for that must be, as one philosopher calls it, *infra sphærum activitatis*, which is not at such a distance: but this way hath no bounds if the vessel be strong enough; for I have taken a piece of a whole cannon whereof the end was burst, and filled it three-quarters full, stopping and screwing up the open end, as also the touch-hole, and making a constant fire under it. Within twenty-four hours it burst, and made a great crack; so that having a way to make my vessels so that they are strengthened by the force within them, and one to fill after the other, I have seen the water run like a constant fountain-stream forty feet high. One vessel of water rarefied by fire driveth up forty of cold water; and a man that tends the work has but to turn two cocks, that one vessel of water being consumed, another begins to force and refill with cold water, and so successively; the fire being tended and kept constant, which the selfsame person may likewise abundantly perform in the interim between the necessity of turning the said cocks." The connection between this, the sixty-eighth proposition of the Marquis, and the two following, being the ninety-eighth and one hundredth, has been pretty conclusively established by a writer in the second volume of the *Glasgow Mechanic's Magazine:* "An engine so contrived," says the proposition, "that working the *primum mobile* forward or backward, upward or downward, circularly or cornerwise, to and fro, straight upward or downright, yet the pretended operation continueth and advanceth, none of the motions above mentioned hindering, much less stopping, the other; but unanimously and with harmony agreeing, they all augment and contribute strength unto the intended work and operation; and therefore do I call this a semi-omnipotent engine, and do intend that a model thereof be buried with me." The next proposition is as follows: "How to make one pound weight to raise an hundred as high as one pound falleth, and yet the hundred pounds descending doth what nothing less than one hundred pounds can effect."

"Upon so potent a help as these two last-mentioned inventions, a water-work is, by many years' experience and labour, so advantageously by me contrived, that a child's force bringeth up a hundred feet high an incredible quantity of water, even two feet diameter, so naturally, that the work will not be heard into the next room; and with so great care and geometrical symmetry, though it work day and night from one end of the year to the other, it will not require forty shillings' reparation to the whole engine, nor hinder one day's work; and I may call it the *most stupendous work* in the whole world : and not only with little charge to drain all sorts of mines, and furnish cities with water, though never so high-seated, as well as to keep them sweet, running through several streets, and so performing the work of scavengers, as well as furnishing the inhabitants with sufficient water for their private occasions,—but likewise supplying rivers with sufficient to maintain and make them portable from town to town, and for the bettering of lands all the way it runs. With many more advantages, and yet greater effects of profit, admiration, and consequence; so that deservedly I deem this invention to crown my labours, to reward my expenses, and make my thoughts acquiesce in the way of further inventions." "The *primum mobile*," says a writer of authority on the steam-engine, "is here evidently the force of steam, that, flow in whatever direction it may, is still capable of exerting the same mechanical power; and the movements, however numerous, can be made not to interfere with each other. The fall of a pound weight raising a hundred pounds weight clearly refers to a mechanism like a piston: one weighing a pound attached to a lever would raise one hundred pounds as high as one pound falleth; and were the weight of water to fall on a water-wheel, for instance, as is now often practised, it would raise a quantity very nearly equal to its own weight, and to the same height from which it fell. A child's force, too, would be sufficient to turn a cock even of a large engine; and the small noise made by this description of machinery, and its working day and night without intermission or impairing its power, are circumstances in the use of the machine now familiar to every person. It would be difficult to give a *clearer* description of the action of a steam-engine in general terms, without a special explanation of its minutiæ and principles. In this case, however, it obviously was the intention of Lord Worcester to conceal both." No drawing of this form of engine is extant, by which a notion of its arrangements can be obtained. Diagrams have, however, been given by various writers, detailing arrangements by which the effects as noticed by the marquis could be obtained. These, of course, are perfectly hypothetical; nevertheless, as a matter of some curiosity, we append a diagram illustrative of an arrangement proposed by Mr. Stuart, in his work *Historical and Descriptive Anecdotes of the Steam-engine*, a work abounding in interesting matter (in fig. 7). Steam is supplied to the receivers *a b* by a steam-pipe proceeding from a boiler; the steam is admitted alternately to the receivers *a b* by means of a cock placed at *e*. The receivers are connected with the deduction pipe *i* by a pipe *m*, containing valves opening outwards from each receiver; another pipe *n u* connects the cistern with the receivers; by means of the cock at *n* the communication between the cistern and each receiver may be interrupted at pleasure. The steam from the boiler passes into the receiver *a*, previously filled with water; pressing on its surface, it forces the water through the pipe *m* up the pipe *i*, which conveys it to its destination. After the water is expelled from the receiver *a*, the cock *e* is turned, which admits the steam into the receiver *b*; simultaneously the cock *n* is turned, which admits water from the cistern into *a*; the steam pressing on the surface of the water in *b*, forces it up the pipe *i*; on the whole of the water being expelled, the cock *e* is turned, shutting off the communication with the boiler from *b*, but opening it to *a*. Unless, however, the boiler from which steam is supplied is provided with means for filling it with water at intervals, to compensate for that evaporated during the process of working, it is evident that the continuity of action of the engine would be interrupted. An eminent authority therefore considers that there could not have been in this kind of engine "any feed-pump: in the absence of that instrument, two boilers must have been indispensable to make the action of the engine continuous." It will be interesting to trace briefly the evidence which has been collected in support of the opinion that the Marquis of Worcester had actually carried his engine into practical effect, this being with many a debatable point. In looking over the preposition of his celebrated work, it will be observed that he speaks of having "*seen* the water" raised; of "*having a way* to make his vessels." Again, although the marquis's veracity may be doubted in these incidental notices, it is worthy of note that a manuscript

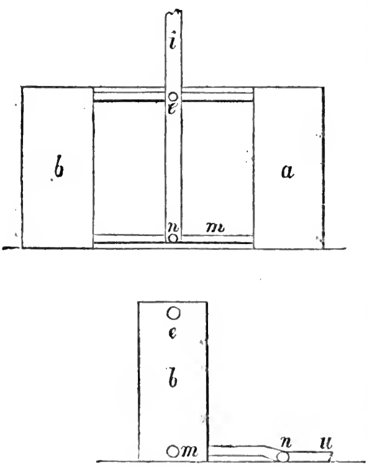

fig. 7.

found after his death bore this heading: "The Lord Marquis of Worcester's ejaculatory and extemporary thanksgiving prayer, when first with his *corporeal eye he did see* finished a perfect trial of his water-commanding engine, delightful and useful to whomsoever hath in recommendation either knowledge, profit, or pleasure." Other corroborative evidence might be given, but it is deemed sufficient to append a very conclusive statement of one who was neither influenced by prejudice or interest. The evidence to which we allude is that given by Cosmo de Medicis, Grand Duke of Tuscany, who visited England about the period of the invention, and whose movements during his travels were duly recorded by his secretary. Under date May 28th, 1699, is the following entry: "His Highness, that he might not lose the day uselessly, went again after dinner to the other side of the city, extending his excursion as far as Vauxhall, beyond the palace of the Archbishop of Canterbury, to see an hydraulic machine invented by my Lord Somerset, Marquis of Worcester. It raises water more than *forty geometrical feet* by the power of *one man only*; and in a very short space of time will draw up *four vessels* of water through a tube or channel not more than a span in width, on which account it is considered to be of greater service to the public than the *other* machine at Somerset House." "This, therefore, is superior in its operations to *another machine* by a *different machanic, and applied to the same purpose*." The following is the entry in the Duke's journal of the other machine to which allusion was made in the first entry: "His Highness went to see an hydraulic machine raised upon a wooden tower in the neighbourhood of Somerset House, which is used for conveying the water of the river to the greatest part of the city. It is put in motion by *two* horses, which are continually going round; it not being possible that it should receive its movements from the current of the river, as in many other places where the rivers never vary in their course." "Nothing can be more satisfactory," says Mr. Stuart, "than this last notice. The water in the hydraulic machine at Vauxhall, by the most easy inference, was *not* elevated by a water-wheel, otherwise the Grand Duke would not have omitted so striking a deviation from that at Somerset House. The effect was equal to that of another worked by two horses; and a tyro in mechanics would at first sight say, that no combination of machinery could accomplish that work by one man which it required the power of twelve men to do in another. From all the circumstances, therefore, it appears to us clear, that this great effect was produced by some sort of a steam-engine: the very identical 'most stupendous water-commanding engine;' 'the semi-omnipotent engine;' the 'admirable and most forcible way to drive up water by fire.'"

The introduction of this, the first "feasible" scheme for producing useful effects by the power of steam, may be said to be the turning-point in the history of the steam-engine. From this time the march of progressive improvement was rapid and uninterrupted; invention followed invention, improvement succeeded improvement, until the steam-engine arrived at its present potent condition.* From this stage of our labours we shall cease

* Sir Samuel Morland in 1683 submitted to Louis XIV. of France a plan for raising water by the aid of steam. The following notice is extracted from a Ms. in the British Museum. "The principles of the new power of fire invented by the Chevalier Morland in the year 1682, and presented to his most Christian Majesty 1683.—Water being evaporated by the power of fire, the vapour shortly acquires a greater space (near 2000 times)

to record the crude and visionary speculations of the philosopher or enthusiast; but have the more useful and pleasant task of describing the practical results of the application of the labours and ingenuity of our engineers and mechanics.

It is supposed by some engineers, that the method of raising water by steam, on the principle of atmospheric pressure (or the vacuum), was not unknown to the Marquis of Worcester; and that it is not improbable but that in the engine mentioned by the Grand Duke of Tuscany this agency was taken advantage of. This is, of course, mere conjecture; but in an invention next in chronological order, now to be noticed, atmospheric pressure, or the formation of a vacuum, was a distinguished feature. The engine to which we allude is that so well known as "Savery's." The period of the introduction of this engine may be looked upon as the commencement of the *practical* era; the very mode in which the inventor ushered it into the world, and presented its claims to consideration, proved this. In place of clothing his description in the studied mysticism of words, which up to this period had been the endeavour of all those who had preceded Savery in describing inventions in connexion with the subject, he, on the contrary, fully explained the principles of its action and the details of its arrangements; and instead of giving exaggerated statements of its power and economy, he practically detailed the reasons why he believed it to be a cheaper method of raising water from mines than any other plan then in operation; and earnestly invited parties interested to inspect the machine in operation, and form their own opinion as to its working value. Very little is unfortunately known of this ingenious man. From his title of Captain it has been conjectured that he was a seafaring man; probably this arose from his having been the inventor of an improved method of moving ships in a calm. It is doubtful whether he was or not; indeed, the latter is likely the case, as, in one of his papers describing an invention of his, he remarks: "I believe it may be made useful to ships; but I dare not meddle with that matter, and leave it to the judgment of those who are the best judges of maritime affairs." This does not read like the statement of one who was a practical seaman. Mr. Stuart conjectures, with greater probability, that he was the director or proprietor of a mine, and as such was known by the title which is even now appropriated to the same officer.

than the water occupied before; and were it to be always confined, would burst a piece of cannon; but being well regulated according to the laws of gravity, and reduced by science to measure, to the weights and balance, then it carries its burden peaceably (like good horses), and thus becomes of great use to mankind; particularly for the elevation of water, according to the following table, which marks the number of pounds which may be raised 1800 times per hour, by cylinders half full of water, as well as the different diameters and depths of the said cylinders." Although no account is obtainable of the contrivance for raising water said to have been submitted by Morland to the King of France, the above extract is sufficient evidence of his being acquainted with the power of steam, and as to the value of its application to useful purposes. The table referred to in the above notice need not be given here; it bears with it the evidence of much care having been taken in the experiments necessary to obtain the given results, which may be said to possess considerable accuracy. It is but just, however, to notice that it is quite an open question whether Morland ever really submitted any plan for raising water by steam, as has been said. One historian of authority states that there is no distinct evidence as to his having done so; and in his book published in 1685, describing all sorts of machines for raising water, he makes not the slightest mention of his being in possession of any such plan.

In 1698 he obtained a patent from William the Third "for raising water, and occasioning motion to all sorts of mill-work, by the impellant force of fire;" and in 1699 he exhibited a model of his engine before the Royal Society, a description and illustration of which is given in their *Transactions*, vol. xxi. p. 228. In 1702 he published a work entitled *The Miner's Friend*, written in a lively and interesting style, and containing a full and circumstantial account of the arrangements and operation of the engine. The following is the description, which is worthy of a place here, as an example of mechanical description, and as giving a notion of the merits of Savery as an inventor. In fig. 8, which is a per-

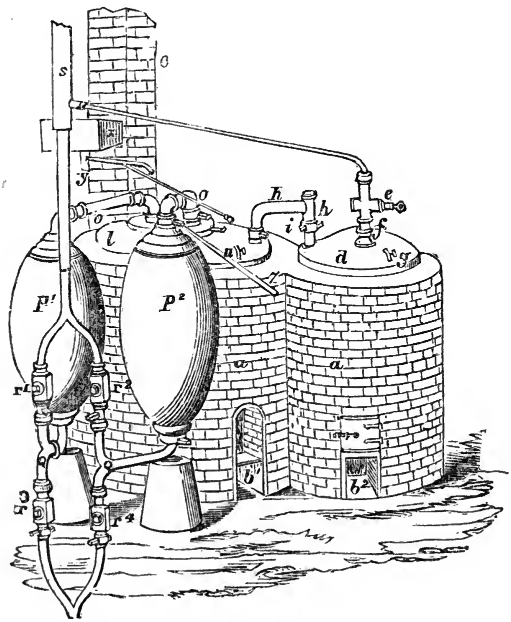

fig. 8.

spective view of the whole apparatus, "*a a* are the furnaces which contain the boilers; *b* 1, *b* 2, the two fire-places; *c*, the funnel or chimney, which is common to both furnaces. In these two furnaces are placed two vessels of copper, which I call boilers; the one large, as *l*, the other small, as *d*. *d*, the small boiler contained in the furnace which is heated by the fire at *b* 2; *e*, the pipe and cock to admit cold water into the small boiler to fill it; *f*, the screw that covers and confines the cock *e* to the top of the small boiler; *g*, a small gauge-cock at the top of a pipe going within eight inches of the bottom of the small boiler; *h*, a larger pipe, which goes the same depth into the small boiler; *i*, a clack or valve at the top of the pipe *h* (opening upwards); *k*, a pipe going from the box above the said clack or valve in the great boiler, and passing about an inch into it. *l l*, the great boiler contained in the other furnace, which is heated by the fire at *b* 1 ; *m*, the screw with the regulator which is moved by the handle *z*, and opens or shuts the apertures at which the steam passes out of the great boiler into the steam pipes *o o* ; *n*, a small gauge-cock at the top of a pipe which goes halfway down into the great boiler ; *o*, *o*, steam-pipes, one end of each screwed to the regulator, the other ends to the receivers *p* 1, *p* 2, to convey the steam from the great boiler into these receivers ; *p* 1, *p* 2, copper vessels called receivers, which are to receive the water which is to be raised ; *q*, screw joints by which the branches of the water-pipes are connected with the lower parts of the receivers ; *r* 1, *r* 2, *r* 3, *r* 4, valves or clacks of brass in the water-pipes, two above the branches *o*, and two below them ; they allow the water to pass upwards through the pipes, but prevent its descent ; there are screw-plugs to take out on occasion, to get at the valves *r* ; *s*, the forcing pipe, which conveys the water upwards to its place of delivery, when it is forced out from the receivers by the impellant steam ; *t*, the sucking pipe, which conveys the water up from the bottom of the pit, to fill the receivers by suction ; a square frame of wood, or a box with holes round its bottom in the water, encloses the lower end of the sucking pipe, to keep away dirt and obstructions ; *x*, a cistern with a buoy-cock coming from the force-pipe, so as it shall always be kept filled with cold water ; *y*, a cock and pipe coming from the bottom of the said cistern, with a spout to let the cold water run down on the outside of either of the receivers, *p* 1, *p* 2 ; *z*, the handle of the regulator, to move it by, either open or shut, so as to let the steam out of the great boiler into either of the receivers."

In working the engine, " the first thing is to fix the two boilers of the engine in a good double furnace, so contrived that the flame of the fire may circulate round and encompass the boilers to the best advantage, as you do coppers for brewing. Before you make any fire, unscrew the two small gauge pipes and cocks, *g*, *n*, belonging to the two boilers, and at the holes fill the great boiler *l* two-thirds full of water, and the small boiler *d* quite full ; then screw in the said pipes again, as fast and tight as possible, and light the fire under the large boiler at *b* 1, to make the water therein boil ; and the steam of it, being quite confined, must become wonderfully compressed, and therefore will, on the opening of a way for it to issue out (which is done by pushing the handle *z* of the regulator as far as it will go from you), rush with a great force through the steam-pipe *o* into the receiver *p* 1, driving out all the air before it, and forcing it up through the clack *r* into the force-pipe, as you will perceive by the noise and rattling of that clack ; and when all the air is driven out, the receiver *p* 1 will be very much heated by the steam. When you find it is thoroughly emptied, and is grown very hot, as you may both see and feel, then pull the handle *z* of the regulator towards you, by which means you will stop the steam-pipe *o*, so that no more steam can come into the receiver *p* 1, but you will open a way for it to pass through the other steam-pipe, *o*, and by that means fill the other receiver, *p* 2, with the hot steam, until that vessel has discharged its air, through the clack *r* 2, up the force-pipe, as the other vessel did before.

" While this is doing, let some cold water be poured on the first-mentioned receiver, *p* 1, from the spout *y*, by which means the steam in it being cooled and condensed, and contracted into a very little room, a vacuum or emptiness is created ; and consequently the steam pressing but very little, if at all, on the clack r 3 at the bottom of the receiver p 1, there is nothing there to counterbalance the pressure of the atmosphere on the surface of the water at the lower part, v, of the sucking-pipe t; wherefore the water will be pressed up, and ascend into and fill the receiver p 1, by what is commonly called suction: the water as it rises lifts up the clack or valve r 3, which afterwards falling down again, and shutting close, hinders the descent of the water that way. The receiver p 2 being by this time emptied of its air, push the handle of the regulator from you again, and the force of the steam coming from the great boiler will be again admitted through o, and will act upon the surface of the water contained in the receiver p 1, which surface only being heated by the steam, it does not condense it, but the steam gravitates or presses with an elastic quality like air, and still increasing its elasticity or spring until it counterpoises, or rather exceeds, the weight of the column of water in the receiver and pipe s, which it will then necessarily drive up, through the passage q r, into the force-pipe s. The steam takes up some time to recover its power; but it will at last discharge the water out at the top of the force-pipe s, as it is represented in fig. 8. After the same manner, though alternately, the receiver p 2 is filled with water by means of the suction, and then emptied by the impellant force of the steam, whereby a regular stream is kept continually running out at top of the force-pipe s; and so the water is raised very easily from the bottom of the mine, &c., to the place where it is designed to be discharged. I should add, that after the engine begins to work, and the water is risen into and hath filled the force-pipe s, then also it fills the little cistern x, and by that means supplies the spout or pipe y y, which I call the condensing pipe, and which by its handle can be turned sideways over either of the receivers, *and is then open*; by this spout cold water is conveyed from the force-pipe, to fall upon the outside of either of the receivers when thoroughly heated by the steam, in order to cool and condense the steam within, and make it suck (as it is usually called) the water up out of the well into that receiver. It is easy for any one that never saw the engine, after half an hour's experience, to keep a constant stream; for on the outside of the receiver you may see how the water goes out as well as if the receiver were transparent; for as far as the steam continues within the receiver, so far is that vessel dry without, and so very hot as scarce to endure the least touch of the hand; but as far as the water is withinside of the said vessel, it will be cold and wet where any water has fallen on it, which cold and moisture vanish as fast as the steam in its descent takes place of the water. But if you force all the water out of the receiver, the steam, or a small part thereof, will go through the clack r 1 or r 2, and will rattle that clack so as to give notice to move the handle of the regulator, and then the steam begins to force the water out from the other receiver p 1, without the least alteration of the steam, only sometimes the stream will be rather stronger than before, if you pull the handle before any considerable quantity of steam be got up the clack r; but it is much better to let none of that steam go off, for that is but losing so much strength; and it is easily prevented by pulling the regulator some little time before that receiver which is forcing is quite emptied. This being done, turn the cock o, or condensing pipe y, of the cistern x, over the empty receiver, so that the cold water proceeding from x may run down through y, which is never opened but when turned over one of the receivers, but when it stands between them is tight and stanch. This cold water, falling on the outside of the receiver, by its coolness causes that steam which had such great force just before to condense and become an empty space, so that the receiver is immediately refilled by the external pressure of the atmosphere, or what is vulgarly called suction, whilst the other receiver is emptying by the impellant force of the steam; which being done, you push the handle of the regulator from you, and thus throw the force into the other receiver, pulling the condensing pipe over the receiver *p* 2, causing the steam in that vessel to condense, so that it fills while the other empties; the labour of turning these two parts of the engine, viz. the regulator and condensing water-cock, and tending the fire, being no more than what a boy's strength can perform for a day together, and is as easily learned as their driving of a horse in a tub-gin."

The method by which Savery managed to keep up the supply in the large boiler, for the purposes of evaporation, is highly ingenious, and is indicative of his inventive powers. Let *a*, fig. 9, represent the small

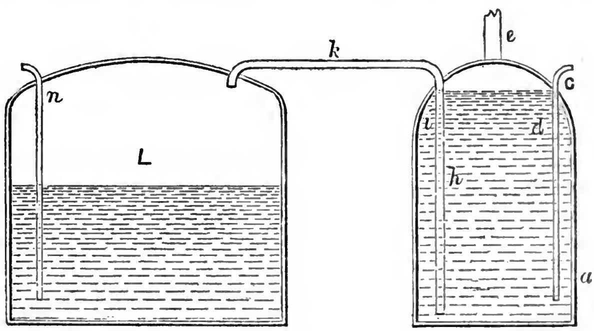

fig. 9.

boiler, which is supplied with water from the force-pipe *s* by the pipe *e*, supplied with a stop-cock (fig. 8); a pipe, *h*, descends within eight inches of the bottom of the boiler, and is provided with a valve, *i*, opening upwards; this pipe is connected with the large boiler *l*. The following is the operation, as described in the inventor's own words: "When it is thought fit by the person tending the engine to replenish the great boiler (which requires about an hour and a half or two hours to the sucking one foot of water), he turns the cock *e*, so that there can be no communication between the force-pipe *s* and the small boiler *d*, and putting in a little fire under the small boiler at *b* 2 (fig. 8), the water will then grow presently hot; and when it boils, its own steam, which hath no vent out, will gain more strength than the steam in the great boiler. . . . The water in the small boiler, being depressed by its own steam pressing on its surface, will force the water up the pipe *h*, through *k*, into the great boiler *l*; and so long will it run, till the surface of the small boiler *d* gets to be as low as the bottom of *h*; and then the steam and water will run together, and by its noise, and rattling of the clack *i*, will give sufficient assurance to him that works the engine that the small boiler hath emptied and discharged itself into the greater one *l*, and carried in as much water as is then necessary; after which, by turning the cock *e* again, you may let fresh cold water out of the force-pipe *s* (see fig. 8) into the lesser boiler *d*, as before; and thus there will be a constant motion and continual supply of the engine, without fear or disorder. And inasmuch as from the top of the small boiler *d* to the bottom of the pipe *h* there is contained about as much water as will replenish the great boiler *l* one foot, so you may be certain it is replenished one foot of course." Captain Savery also introduced a contrivance by which the depth of the water in the boilers could be ascertained; this he termed a "gauge-cock," the principle of which is illustrated in fig. 9, at *c*, *n*, which are pipes continued down to within eight inches of the bottom of the boilers. When the attendant is desirous of knowing when the great boiler wants replenishing, he opens the stop-cock in connection with the pipe *n*: if water issues from it, the supply of water is sufficient; if steam issues from it, it is an evidence that the boiler requires a supply of water. By the cock *c* it is easily ascertained whether the small boiler requires a supply of cold water from the force-pipe *s*. This contrivance of the gauge-cock is still in use to the present day, the best evidence as to the practical value of Savery's ingenuity.

Such is a description of Savery's celebrated "fire-engine," an invention remarkable alike for the judiciousness of its arrangements, and the practical purposes for which, at the period, it was introduced. Considerable discussion has arisen as to whether Savery really invented the engine, or derived his ideas from other sources, as the invention of the Marquis of Worcester. Desaguliers details an evidently got-up story of Savery having bought up the copies of the pamphlet of the marquis, with a view to do away with all evidence of priority of invention on the part of the marquis. There is no evidence that this was done by Savery: on the contrary, all evidence goes to prove the fact that it was extremely unlikely for him to endeavour to detract from the fame of the marquis by way of gaining for himself a reputation. The buying up the pamphlets of the marquis would have been a useless labour, for it is altogether improbable that all recollection of an engine erected at Vauxhall, as reported by the Grand Duke of Tuscany, should have vanished from the minds of many who would have witnessed its action then alive; moreover many of the contemporaries of the marquis were then alive, at the period when Savery introduced his engine, some of them also members of the Royal Society, before which Savery, as we have seen, displayed a model of his engine. But the ingenuity of the arrangements of the engine itself conveys with it, we think, the undoubted stamp of originality. One honour—and that a high one—can at all events be ascribed to Savery without dispute, and that is of being the person who introduced into extended use an invention calculated to be of high practical value; and this labour, the work of which the world is not slow to estimate highly, he performed in the face of what he termed the "oddest and almost insuperable difficulties," with a perseverance and indomitable courage entitled to the highest commendation; and after all, he who, in spite of the opposition of prejudice and interest, succeeds in introducing into extended use inventions calculated to be of service in the promotion of the interests of humanity, is entitled to a higher reward, and to have the value of his labours judged of from a higher standard, than he whose services are confined to the mere discovery or elaboration of a mechanical or philosophical invention.

In the volume on *Natural Philosophy* in this series the subject of "atmospheric pressure" has been fully explained. Toricelli, after the death of Galileo, discovered that the flowing of water (open to the atmosphere) into any vacuous space is owing to the pressure of the atmosphere, which acts upon all bodies at the earth's surface with a definite pressure. In 1672 the celebrated Otto Guericke, in his *Experimenta Magdeburgica*, detailed an apparatus by which he could raise heavy weights. In fig. 10 we give a diagram illustrative of the arrangement. Let a be a cylinder in which a piston b works, air-tight; the piston-rod b has a rope attached to it passing over the pulleys $c\,c$, and continued to suspend a board e containing heavy weights. Suppose that by means of an air-pump the space below the piston (the piston being raised to the top of the cylinder by the weights on e) is deprived of its contained air, and a vacuum, more or less perfect, produced, the pressure of the external atmosphere would cause the piston to descend, raising the weights on e; now if a small stop-cock were opened to admit air at the lowest part of the cylinder below the piston, the weights would pull the piston up to the top of the cylinder, the pressure of the atmosphere being equal on both sides of the piston. By making a vacuum, as before, beneath the piston, it would descend; and thus, by repeating the process, the weights might be made to ascend and descend. The efficiency of a vacuum to raise heavy weights was thus established by means of this arrangement, and was no doubt pretty universally known at the period of the introduction of Savery's patent. It is clear, however, that the operation of withdrawing the air, so as to produce a vacuum by means of an air-pump, was too expensive and tedious an operation to be thought of as a working medium. Although there is no direct evidence of the fact, it is supposed that the Marquis of Worcester was acquainted with the method of forming a vacuum by condensing steam in close vessels; and, indeed, that the principle was carried out in the engine erected by him at Vauxhall. That Savery introduced the principle in his engine, we have already shown; indeed, in his patent, he claims "the method of making a speedy vacuum by condensing steam." Savery stated that he discovered the method by plunging a flask, which, with a little wine left in it, he had previously thrown in the fire, into a basin of cold water while the flask was filled with vapour. The sudden condensation of the steam in the interior of the flask created a vacuum, into which the water from the basin violently rushed. Desaguliers has thrown discredit on this statement, by saying that the experiment could not have been carried out in the way explained by Savery, inasmuch as the flask would be forced from the hand by the rushing of the water entering the flask: of this Savery makes no mention. A modern authority, however, states that this result, as indicated by Desaguliers, only happens under certain circumstances, so that the statement of Savery cannot be impeached on this ground. But another claimant has been put forward for the honour of the discovery of the principle of the formation of a vacuum

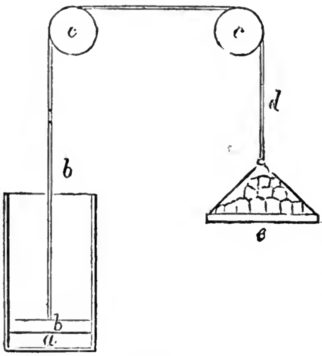

fig. 10.

by the condensation of steam. This claimant is the well-known Denis Papin. Denis Papin was born in France. Being a Protestant, he was forced to leave France on the revocation of the edict of Nantes, and coming to England, was employed by the celebrated Mr. Boyle to assist him in his experiments. In 1680 he was elected a member of the Royal Society. It was during his stay in England that he invented his celebrated "digester," in which, with the aid of high-pressure steam, he dissolved bones, &c., and to which apparatus he applied the important contrivance known as the "safety-valve:" this, under several modifications, is in use at the present time. In the form of a "riddle to stir up those that are ingenious in the same kind of learning, and make them find sometimes better things than what is propounded," he exhibited in 1685 a model of a machine for raising water; and in the solution which he himself gave of it, it appears "that the water was raised by rarefying the air in the vessel, into which it was impelled by the pressure of the atmosphere on the water in the cistern. The mode by which he rarefied the air was carefully concealed. In two of the solutions the same effect was produced by condensing it." On being appointed to the Professorship of Mathematics at Marburg, in Germany, he left England in 1687, in which country, although he ranked high as a man of science, he had gained little encouragement in the carrying out of his schemes. In Westphalia and at Auvergne he was employed to raise water by his machines; but he failed in doing so. This result was predicted by the celebrated Dr. Hooke. Having attempted a variety of methods of working machines, he, amongst others, tried the method of producing a vacuum by condensing the vapour produced by the combustion of gunpowder in a vessel. This, however, proved unsatisfactory. In 1690, in the *Acta Eruditorum* of Leipsic, he proposed a method of raising water by condensing steam in a cylinder. The following is a diagram illustrative of the arrangement proposed by Papin: let *a a*, fig. 11, be a cylinder supplied with a portion of water at *c*; *b* a tight-fitting piston, the stem or rod of which is passed through the cover of the cylinder; a lever *e* is pressed by a spring into a notch made in the piston-rod in such a way that the piston is kept suspended near the top of the cylinder, when the part in which the notch is made comes above the cover; a small pipe *f* is passed through the cover and the piston, and is capable of being kept closed at its upper extremity steam-tight. The piston being allowed to fall to the lower part of the cylinder, the stopper at the upper part of the pipe *f* is taken out, and water introduced beneath the piston to the space *c*. Fire is then applied to the cylinder *a*; the steam thus generated raises the piston. On the notched part rising above the cover, the lever *e* is pressed into it, which sustains the piston at the upper part of the cylinder. The fire is then withdrawn from the apparatus, and the cylinder being allowed to cool, the steam contained in it is condensed, and the lever *e* being withdrawn from the notch, the atmospheric pressure forces the piston to the lower part of the cylinder, carrying

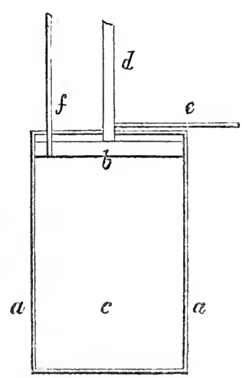

fig. 11.

with it such weights as may be attached to the rod applied, as in fig. 11. A mere glance at the mode of operation of this engine—if engine it can be called—will suffice to show how incapable it is of being made a practically working apparatus. And yet it is really marvellous how, on the verge of a great discovery, Papin was content to pursue his investigations no further, and to "abandon his pursuit at the moment he had laid the foundation of the splendid mechanism of the lever engine, and had in his grasp a brilliant reward for a life of labour." With reference to the claim put forward by the advocates of Papin and Savery as to their discovery of the principle of the formation of a vacuum by steam, it is very evident that neither could substantiate his claim, the fact that a vacuum could thus be formed being known long before their time; long before, indeed, the principle of atmospheric pressure was established, Hero, Porter, and De Caus were aware of this fact. With reference to the charge which has been put forward against Savery, that he merely carried out the ideas of Papin, it is enough and perfectly satisfactory to know, that whatever might be the extent of the information Savery derived from the labours of others, he was the first to introduce a practically useful engine—distinct in many of its features from the schemes of others, and preserving those very qualities which took it out of the category of philosophers' toys or the "riddles" of men of science, and placed it in that of beneficial agents. And perhaps no better tribute can be paid to the value of Savery's engine, than the fact that Papin was so "thoroughly convinced of the superiority" of it that he abandoned his own contrivance, and adopted Savery's.*

* The following is a diagram illustrative of what has been ascribed to Papin as a later invention; he, however, ascribes it to the ingenuity of the Elector of Hesse. under whose patronage he carried on his various experiments. Let *a* (fig. 12) be a boiler pro-

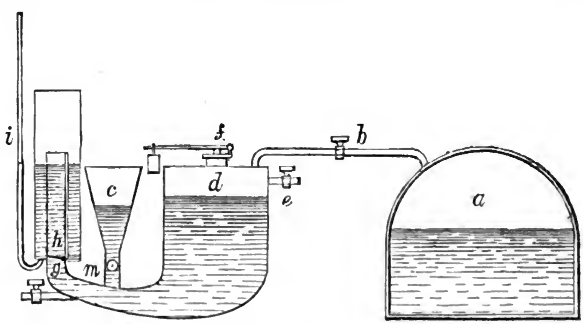

fig. 12.

vided with a safety-valve (not shown in the diagram), through which it is supplied with water; the pipe *b*, with stop-cock, connects it with the receiver *d*. In this receiver a hollow floater, or piston, is placed, containing a cylinder; this cylinder is inserted in its place in the floater through the aperture *f* in the top of the receiver, which aperture is closed with a lever valve, as in the diagram. *c* is a funnel through which water is introduced to the receiver, closed by a cock *m*; the forcing-vessel or receiver *d* is continued upwards to *g*, and is passed up near to the top of the air-vessel *h*. The water which is forced into the vessel *n* is led off to its destination through the pipe *i*. The stream from the boiler *a* is allowed to pass into the forcing-vessel *d*; pressing on the upper side of the piston, it presses it down, and the water passes into the receiver *n*. On the piston

We now approach the period of introduction of a steam-engine of a still higher range of practical value than Savery's. Before proceeding further, however, it will be necessary to point out a few of the defects of Savery's engine. In the first place, the danger of using the engine was considerable, from the high pressure at which the steam was used, and from there being no provision made for its escape on its reaching a given point. Comparing it with that now adopted in certain circumstances, the pressure was not in itself great; but the fact must be taken into consideration, that the state of the mechanical arts as then existing rendered it a matter of extreme difficulty, if not altogether an impossibility, to procure boilers and vessels so strongly and correctly made as to be considered, under the circumstances of usual working, safe. In the second place, the cost of working the engine was very great, from the large expenditure of fuel necessary to obtain the desired effect. That this expenditure was excessive may be gathered from this consideration: As the vessel each time had to be filled with cold water rushing in to supply the vacuum, a certain amount of steam on being admitted to force the water out of the vessel was condensed by coming in contact with the cold surface, and the water had to be heated for a small depth before the "steam was strong enough" to expel the water from the receiver. The cold surface of the interior of the receiver with which the steam came in contact produced condensation to such an amount as to form rather a considerable item in the cost of working the engine. When to reduce this loss the sides of the receivers were only moderately cooled, the vacuum in the interior was so much impaired, from a quantity of vapour of considerable pressure remaining, that the effective height to which the water could be raised was much lessened. This, in fact, operated at all times to such an extent as to limit the pressure of the atmospheric column to twenty or twenty-one feet. There was still another objection, and that a serious one, namely—the plan of working the engine by opening and shutting of cocks through the agency of the attendant, the efficiency of the engine being thus dependent on his carefulness and attention.

We have already explained the arrangement by which Papin proposed to use the vapour of water by making it act on the surface of a piston moving in a cylinder. This arrangement, although defective, contained, as we have noticed elsewhere, the germ of the steam-engine in its practically working condition; and this mechanism of a piston and cylinder was that which was destined, under the hands of succeeding inventors, to be an important feature in the modern steam-engine. The inventor who adopted this mechanism, and whose engine we are now about to notice, is well known in the history of the steam-engine as Thomas Newcomen, ironmonger, of Dartmouth. In conjunction with John Cawley, glazier, of the same place,—to whom, according to Desaguliers, he communicated his pro-

reaching to the bottom of the vessel *d*, or the limits of its play, the stop-cock *f* is closed to prevent the further flow of steam into *d*, and the steam remaining in *d* is allowed to pass off by opening the cock *e*. Simultaneously with the opening of the cock *e*, the cock *m* is opened, which admits the water from the receiver *c* to pass into and fill the forcing-vessel *d*, raising at the same time the piston; the water in *h* is prevented from descending by a valve placed on the pipe *g*. The cylinder which is placed in the floating piston is inserted through the valve *f* in a red-hot state; this makes the steam hotter. The air-vessel *h* tends to keep up a continuous stream through the pipe *i*. This air-vessel was not, however, considered essential, for an engine framed without it raised water into a reservoir seventy feet high.

ject,—he had been prosecuting a series of experiments on the power of steam. In the course of his labours he had written to the celebrated Dr. Hooke, a well-known *savant* and intimately acquainted with the contrivances of Papin, with reference to his project. Dr. Hooke, in a letter to Newcomen, dissuaded him from expending time and labour in endeavouring to produce motion on Papin's plan, *i. e.* by piston and cylinder; and made use of the remarkable expression, "could he (referring to Papin) make a speedy vacuum under your piston, your work is done." This expression shows that Dr. Hooke must have been ignorant of the great rapidity with which steam is condensed by contact with a cold body; or from being convinced that Papin had not been able to effect the arrangements which he claimed as his own. Nothing daunted, however, by this most discouraging opinion from one who ranked high as an authority, Newcomen and Cawley still prosecuted their experiments, which ultimately resulted in the bringing out of a machine, the component parts of which are still retained in one of the many forms of the steam-engine. In the patent granted to Newcomen and Cawley in 1705, the name of Savery was included. This arose from the fact that the latter was in possession of a patent for a "method of making a speedy vacuum by condensing steam." It does not appear, however, that Savery aided in carrying out the plan; and it is now conceded that, save receiving a portion of the profits, he had no further connexion with the scheme; to the other patentees, therefore, must the honour of the invention be paid. It is right, however, to state, that the assistance which Cawley rendered is unknown; and it appears probable that Newcomen was the principal party to whom the invention and its principal details were due.

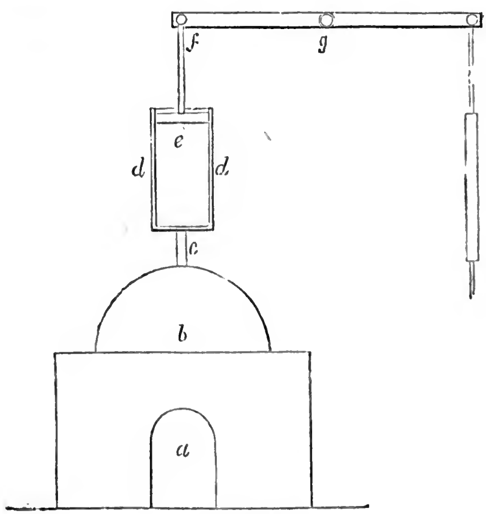

fig. 13.

The nature of the action and arrangements of the engine as first introduced by Newcomen may be gathered from the diagram in fig. 13. Let *a* be the furnace heating the boiler *b*; *c* a pipe conveying the steam to the interior of a cylinder *d*, the upper end of which is open to the air, in which a piston *e* works; this is attached to a lever *f* oscillating in the centre *g*, and having at its other extremity *h* a weight, as a pump-rod weighted, which, acting as a counterpoise, pulls the piston up to the top of the cylinder. Now supposing steam to be introduced to the interior of the cylinder, and thereafter to be condensed by throwing cold water over the exterior surface, a vacuum will be produced in the cylinder; and the atmosphere pressing on the upper side of the piston will force it downwards; and pulling down the end *f* of the great beam, will raise the end *h*, and along with it the counterpoise-weight or pump-rod there attached. The power of this engine will obviously depend on the surface of piston, the atmosphere exerting a pressure of about 14·75 lbs. on each square inch. Supposing the piston to be 50 inches in area, the weight which the engine would be able to lift would be nearly 800 lbs. This is the theoretical view of the case; the practical one widely differs. The effect obtained, as above noticed, depends on the absence of friction and the perfect formation of a vacuum. None of these desiderata, in the earlier stages of the engine, could be obtained. To reduce the friction of the piston moving in the cylinder, the piston was provided with "packing" placed round its edges, and made of hemp or leather well-lubricated. The friction, however, of the piston and working-beam was of so considerable an amount, that it detracted much from the working capabilities of the engine. The bad formation of a vacuum also reduced its working-power. When the void was imperfect, the vapour remaining in the cylinder resisted the atmospheric pressure in proportion to its temperature; this being tantamount to reducing the weight which could be lifted at the end of the beam. The fall of the cylinder was also prevented to a certain extent by air, which entered into the cylinder along with the steam from the boiler; this air not being condensed by the cold water, remained in the interior of the cylinder, and operated as an opposing power to the descent of the piston in proportion to the amount. This defect, which was termed *wind-logging*, continued to increase in power with the operation of the engine; and unless means had been afterwards adopted, the air would have so increased in volume as to stop the motion of the engine. The form of engine introduced at first by Newcomen resembled in some points that of Papin; an essential difference between them will, however, be obvious on consideration. In Papin's engine the piston was raised by the force of the steam; it required therefore, to be of a pressure considerably above that of the atmosphere. In Newcomen's engine, however, the steam was used at the ordinary pressure, or 212°, and only as a means of producing a vacuum beneath the piston, and thus aiding the atmospheric pressure by the improved mechanical means. The substitution, moreover, of the beam and connecting-rods opened the way to a great number of applications. Hence it will be observed that the name, "atmospheric engine," by which Newcomen's contrivance was known, was not so inappropriate.

We now proceed to detail the various improvements introduced from time to time, which resulted in bringing the atmospheric engine to comparative perfection. And first, as to the method of forming a vacuum in the cylinder. As in the engine already described, the cold water, to produce the vacuum, was originally thrown over the exterior of the cylinder. This plan was productive of much loss of working effect, from the circumstance that the boiler, being placed immediately beneath the cylinder, received the plashings of the cold water on its surface; this happening at every stroke of the engine, tended to condense the steam in the boiler. To obviate this, the cylinder was surrounded with an outer case, leaving a space between it and the interior cylinder. Into the space thus formed the cold water was introduced. A practical inconvenience was soon discovered to attend this plan, as the water soon became heated, and therefore comparatively useless in producing a vacuum in the interior of the cylinder. Again, it was necessary that, during the time when the cylinder was being filled with steam, the water in *the space* should be nearly of the same temperature as the steam. Means, therefore, were adopted by which this hot water was quickly withdrawn from the space as soon as the cylinder was filled with steam, and also for refilling the space as quickly with cold water, to produce the vacuum. These desiderata were effected by supplying the cold water from a cistern placed immediately above the cylinder, and by leading a pipe from the space between the cylinder and its casing to a small reservoir. The heated water thus obtained was conveyed to the boiler, compensating in some measure for the loss of power from causes already named. It is evident that if no means were taken to prevent it, the successive condensations of the steam in the interior of the cylinder would produce water, which in time would fill it. To remove this water, a pipe was inserted in the bottom of the cylinder, and conducted to a distance of at least thirty feet below it. It was necessary to take this so far down to counteract the force of the atmospheric pressure; as the pipe communicated with a vacuum, the water in the cistern, with which the eduction-pipe was connected, would be forced *into* the cylinder, unless the column of water in the tube or eduction-pipe was of sufficient length.

The air which found its way to the interior of the cylinder was ejected into the atmosphere through a pipe furnished with what was called a snifting-valve, opening upwards into a kind of cup containing water; the piston descending forced the air through this, the water surrounding it keeping it tight after the air escaped. The piston was rendered tight, and air prevented from finding its way to the interior of the cylinder, by a small quantity of water placed on its upper side, this supplied by a small pipe leading from the cistern above the cylinder. The pipe leading from the boiler to the cylinder was furnished with a cock, by which the supply of steam was regulated.

The operation of the engine, as thus constructed, is easily understood. On the steam being raised at a temperature of 212°, and the cock on the steam-pipe opened, the counterpoise—suppose this to be the weighted rod of a pump for withdrawing water from a mine—draws the piston to the top of the cylinder; the supply of steam is then shut off by turning the cock on the steam-pipe to its original position. The cold water is now admitted to the space between the cylinder and its casing, the steam under the piston being condensed; the atmospheric pressure on the upper side of the piston forces it downwards, drawing along with it the end of the beam, and raising the other, and also the water in the pump; the cold-water cock is then shut, and the steam opened. An equilibrium being thus restored on both sides of the piston, the counterpoise draws it up to the top of the cylinder; the cock of the pipe for withdrawing the hot water from the space around the cylinder is opened, and the water descends to the cistern; the cold-water cock is immediately opened, and the condensation being effected, the piston descends as before.

In the spring of 1712 Newcomen succeeded in obtaining a contract for drawing water from a mine at Wolverhampton. The account given by Desaguliers of the difficulties encountered in bringing this engine to work is very curious: "After a great many laborious attempts having been made, he at last made the engine work; but not being philosophers enough to understand the reasons, or mathematicians enough to calculate the powers and proportions of the parts, they very luckily found by accident what they sought for. They were at a loss for the pumps; but being so near Birmingham, and having the assistance of so many admirable and ingenious workmen, they soon came to the method of making the pumps, valves, clacks, and buckets, whereas they had but an imperfect notion of them before." The erection of this engine was the occasion of an improvement of great importance being accidentally discovered. The improvement consisted in a quicker means of obtaining a vacuum. As before described, the piston was kept tight by water playing on its upper surface; on the first trial of this engine, it made several strokes in quick succession. "After a search, they found a hole in the piston, which *let the cold water in to condense the steam in the inside of the cylinder.* The method of effecting the condensation was therefore changed; and effected henceforth by injecting cold water into the interior of the cylinder. The diagram in fig. 14 shows this arrangement: *a a* the cylinder, *b* the piston, *c* a pipe leading from the cold-water cistern, and provided with a cock to regulate the supply; the lower extremity of this pipe is inserted in the bottom of the cylinder, and the water is delivered in the form of a jet *d*, and, diffusing itself among the steam, the condensation is quickly effected; *e* the snifting-valve and pipe; *f* the pipe 30 feet long, for taking away the hot-water from the cylinder. This plan of obtaining a quick condensation suggested also a means of regulating the speed of the engine in cases where the weight to be lifted was variable, by throwing in a greater or less quantity of injection-water, thus producing a vacuum more or less perfect. Notwithstanding the very great improvements thus effected from time to time, the atmospheric engine at this stage of its progress was much restricted in its usefulness, and this from the unremitting attention which its operation demanded from the attendant. "When, for instance, the attendant opened the steam-cock, he was obliged to watch the descent of the piston, and at the instant when it was elevated to the proper height, it was to be again quickly shut, and at the same moment the injection-cock was to be opened. If the one did not follow the other, there resulted a great loss of vapour, or of effect; and this difficulty was further increased by the irregular production of the steam itself, from the varying intensity of the heat of the furnace.

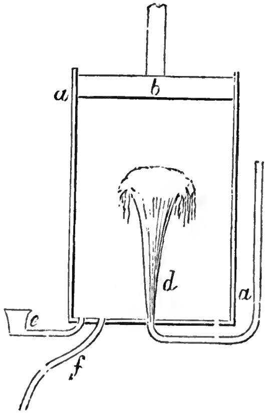

fig 14.

After the injection had condensed the steam, and the piston was at liberty to descend, if the communication between the boiler and the cylinder was not opened at the precise instant when it had reached the limit of its downward movement, the immense weight on the piston, falling into the vacuum with a great velocity, would shake the apparatus to pieces. All this precision was required too from a mercenary attendant fourteen times every minute, at the hazard of the total destruction of the apparatus." It is obvious, then, that the further and more extended practical introduction of the engine depended on some method being discovered of making its movements self-acting. According to Desaguliers the honour of the invention of the self-acting movements is due to an idle boy of the name of Humphrey Potter, an attendant on the engine. The following is the statement: "It was usual to work with a buoy in the cylinder, enclosed in a pipe, which buoy rose when the steam was strong, and opened the injection-pipe, and made a stroke, whereby they were only able, from this imperfect mechanism, to make six or eight strokes in a minute, till a boy named Humphrey Potter, who attended the engine, added what is called a scoggan, a catch that the beam or lever always opened; and then it would go fifteen or sixteen strokes in a minute." "To scog," says a writer, in explanation of the term, "is a verb found in certain vocabularies throughout the north of England, implying to sculk; and this young gentleman, impelled by a love of idleness or play common to boyhood, and having his wits about him, after some meditation, devised this contrivance, by which so important an improvement was effected, and himself allowed the means of scogging for his own diversion." Whether this is the correct account of the origin of this improvement, it is difficult to ascertain; certainly the statement of Desaguliers has never been proved to be wrong. In the year 1718 an engine was erected having self-acting movements, termed "hand-gear," the invention of Mr. Henry Beighton, an engineer of Newcastle, and which consisted of a series of tappets operated on by the beam, and by which the various cocks were opened and shut as required. The following is a description of the means employed for this purpose: The entrance to the steam-pipe was covered with a sliding-valve placed inside the boiler; this valve was worked by a lever attached to the spindle of the valve which projected through the top of the boiler, as in fig. 15, where *a* is the steam-pipe, *b* the sliding-valve, the spindle of which passes through *c*, and is worked by the bent lever *d*. To this bent lever a horizontal one *e*, fig. 16, is connected; the other extremity is formed into a fork at *f*; a spindle joins the two extremities of the fork; and two stirrups, as at *g*, connected each side of the fork with an axle rotating on the centre *h*. This axle was made to move by the pins in the beam *n n* striking the ends of the spanners *k m*, which were firmly fixed in the axle *n*. On the axle, at a position between the two prongs, a lever called a *tumbling-bob* was fixed, having a Y-end, or two projecting arms *i i*, and a weight at the other. The injection-cock was opened and shut by the mechanism shown in fig. 17. Let *a a* be the beam corresponding to *n n*, in fig. 16, having projecting-pins which strike the end of the lever *d*, terminated with a toothed quadrant taking into a second quadrant, fixed on the spindle of the injection-cock. The following is the operation of the apparatus: on the beam *n n* falling, a tappet, or projecting-pin, strikes one of the spanners *k;* this turns the axle vibrating at *n*, and causes the tumbling-bob to fall over with considerable force, one of the arms *i* striking the bar which joins the two prongs of the fork *e f*; this pulls forward the lever *e* towards the beam, and opens the steam-cock *b*,

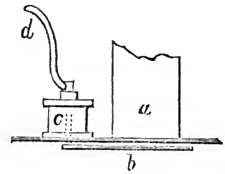

fig. 15.

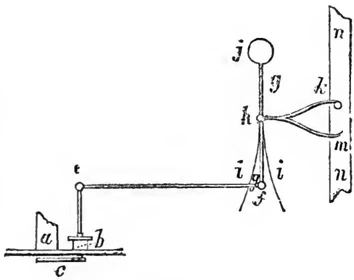

fig. 16.

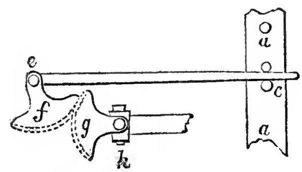

fig. 17.

fig. 16. Simultaneously with the striking of the tappet on the spanner *k*, another tappet strikes the end of the lever *d*, fig. 15, and operating on the quadrants *fg*, shuts the injection-cock *h*. The piston is now drawn upwards by the counterpoise. On arriving within a short distance of the top of the cylinder, a tappet strikes the spanner *m*, fig. 16, and causes the tumbling-bob to fall over, moving, as before, the lever *e* from the beam; one steam-valve is thus shut, and by means of the tappets, lever, and quadrants, the injection-cock *h*, fig. 17, is opened. By means of this contrivance the atmospheric engine was rendered self-acting. Thus improved, the machine remained for a considerable period *in statu quo*. Minor improvements were from time to time introduced; but it was reserved for the celebrated engineer John Smeaton to bring it to as great a state of perfection as was possibly allowed by the nature of its principle. In fig. 18 we give a diagram illustrative of the general arrangements of an atmospheric engine, after the introduction of the self-acting movements of Beighton, and anterior to the improvements of Smeaton.

In 1767, Smeaton was employed to construct an engine for the New River Company, and he availed himself of an opportunity of introducing several improvements. In calculating the proportions, on considering that the stoppage of water occurring at every stroke, and putting the piston, beam, and other appliances, from a state of rest to that of motion twice every stroke, resulted in a great loss of power, he determined to work the engine slower, putting on the piston all the load it would bear, working with larger pumps. In order still further to reduce the velocity of the column of water in the pump-barrel, he made the beam oscillate on a centre out of its true centre; the stroke of the piston being then nine feet, whilst that of the pump, which lifted thirty feet, was only six feet. This arrangement necessitated the employment of a long narrow cylinder, eighteen inches in diameter: with these arrangements he increased the load of the piston from seven pounds to ten pounds and a half on the inch. From the employment of a long cylinder Smeaton contemplated gaining other advantages, namely, "that every part of the steam being nearer the surface of the cylinder, would be more readily condensed; and, in consequence, that

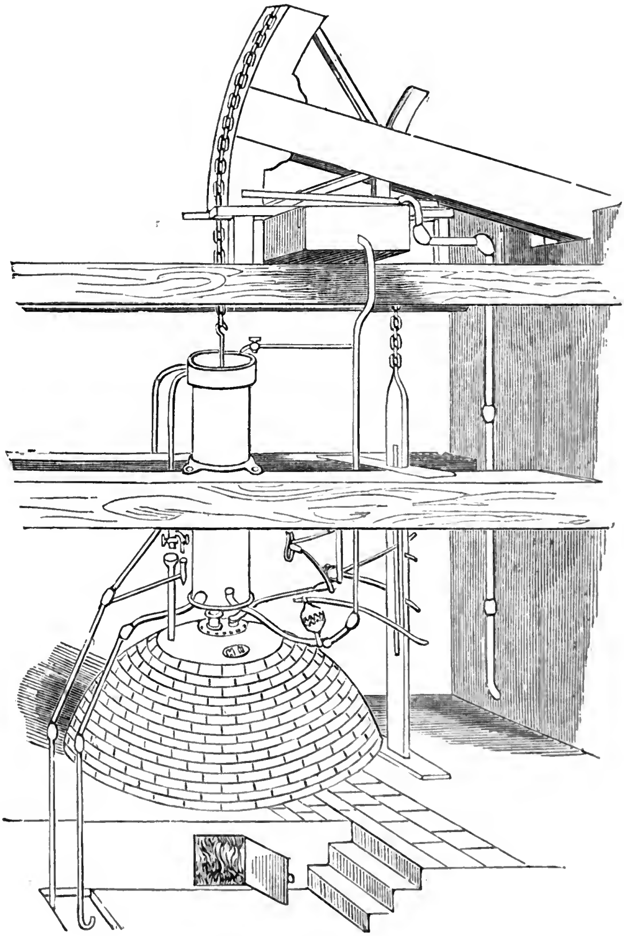

fig. 18.

a less quantity of injection-water would serve the cylinder, which would itself be more heated." Under these advantages Smeaton thought himself quite secure; "but how great," he writes, "was my surprise and mortification to find, that instead of requiring less injection-water than common, although the injection-pump was calculated to afford as much injection-water as usual, in proportion to the area of the cylinder, with a sufficient overplus to answer all imaginable wants, it was unable to support the engine with injection; and that two men were obliged to assist to raise the injection-water quicker by hand, to keep the engine in motion. At the same time the cylinder was so cold I could keep my hand upon any part of it, and bear it for a length of time in the hot well. By good fortune the engine performed the work it was appointed to do, as to the raising of water; but the coals by no means answered my calculation. The injection-pump being enlarged, the engine was in a state for doing business; and I tried many smaller experiments, but without any good effect, till I altered the fulcrum of the beam so much as reduced the load upon the piston from $10\frac{1}{2}$ lbs. to $8\frac{1}{4}$ lbs. per inch. Under this load, though it shortened the stroke at the pump-end, the engine went so much quicker, as not only to raise more water, but to consume less coals; took less injection-water, the cylinder became hot, and the injection-water came out at 180° of Fahrenheit; and the engine, in every respect, not only did its work better, but went more pleasantly. This at once convinced me that a considerable degree of condensation of the steam took place in entering the cylinder, and that I had lost more this way by the coldness of the cylinder than I had gained by the increase of load. In short, this single alteration seemed to have unfettered the engine. But in what degree this condensation took place under different circumstances of heat, and where to strike the medium, so as upon the whole to do the best, was still unknown to me. But resolving, if possible, to make myself master of the subject, I immediately began to build a small fire-engine at home, that I could easily convert into different shapes for experiments, and which engine was set to work in 1769." The result of the experiments conducted with this engine Smeaton carefully tabulated, and took as a guide to regulate his future practice. The engines of a large class which he afterwards erected fully verified by their performance the correctness of his assumptions, and evidenced the practical care with which he had, in this as in other matters, conducted his experiments. In 1772 he was employed to construct an engine at Long Benton Colliery, at Newcastle,—and in this he introduced the several improvements suggested by his experiments,—similar in construction to that introduced by Beighton; it was, however, "distinguished by juster proportions and greater nicety of detail than had yet been realised; and the innovations thus introduced were found to be highly beneficial in practice." The engine erected by Smeaton, and known as the "Chacewater Engine," was the most celebrated of his performances. We give, in fig. 19, a diagram showing the arrangements, derived from a plate in *Smeaton's Reports* (vol. ii. plate 11; published by Walton and Maberly, Paternoster Row). The diameter of cylinder was 72 inches, length of stroke 9 feet; making 9 strokes per minute with its full load of 51 fathoms of pump; capable of turning out per hour, from working barrels full $16\frac{1}{4}$ inches, 800 hogsheads of water, with a consumption of 13 bushels of coal, London measure, per hour. Calculated according to the modern formulæ, the power of this engine may be taken at 76 horses; but from Mr. Smeaton's statement, he estimated it at a higher rate. He says: "This engine, though not the largest that has been built, will be of considerably greater power than any I have seen; and, when worked at its full extent, will work with a power of 150 horses acting together; to keep which power throughout the twenty-four hours would require at least 450 horses to be maintained." Although there is nothing in connexion with the improvement of the atmospheric engine which can be said to be the invention of Smeaton, still the high praise is due to him of "giving the most perfect form and proportion to those materials supplied by his predecessors and contemporaries." "The improvements"—we quote from the *Artizan* treatise—"introduced by Smeaton chiefly resolve themselves into greater care in the construction of the

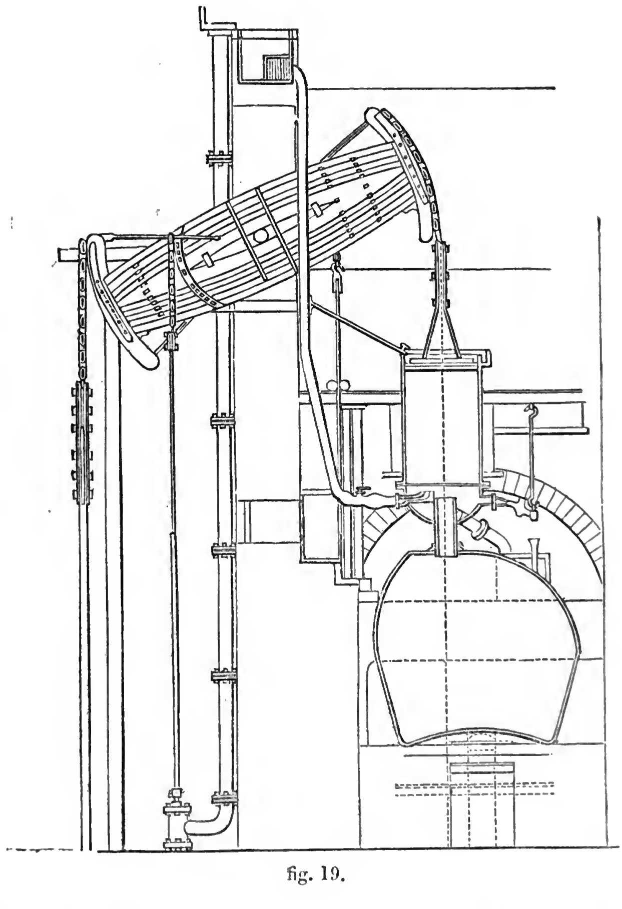

fig. 19.

engines, and a better proportion and arrangement of the boiler; and involve neither the application of any new principle, nor any great expenditure of ingenuity. Before Smeaton's time, the manufacture of the engines was in the hands of very ignorant mechanics, who did not know the difference between power and force; and their perpetual aspiration was to make the piston exert a great force, without taking into account the velocity of the movement necessary to make it operate effectively. It was very rarely the case that the engine was adequately supplied with steam; and when an engine was found incompetent to its work, in consequence of this inadequacy, it was generally provided with a larger cylinder, which only aggravated the evil. Then the cylinders were very ill-bored; and the condensation from the water lying on the top of the piston, as well as from water escaping past it, was very considerable; while, at the same time, the piston rarely travelled a sufficient distance in the cylinder; and a great deal of steam was lost every stroke by filling a useless vacuity. The boilers, besides being too small, were generally badly set, the bottom being too far from the fire; and the firing was badly conducted, the coals being piled in a heap on the middle of the grate, instead of being spread evenly over it. The injection-cistern was generally set too low, by which means the water was not adequately dispersed within the cylinder; and the valve-gearing was for the most part so constructed that the regulator did not open fully, by which means the steam was throttled, and a heavy counter-weight was necessary to suck the steam into the cylinder, which of course had afterwards to be raised at an expenditure of power." The correction of these faults was left for Mr. Smeaton to effect.

Such as we now leave it, was the degree of perfection to which the steam-engine had arrived. The principles of its action apparently precluded the attainment of a higher degree of practical usefulness; and it remained for a brighter genius and a more original mind, than was possessed by any of those who had hitherto directed their attention to the subject, to thoroughly grapple with, and to understand, its defects; and by opening up a new path of discovery, to place the steam-engine, as a social power of rare value, in the high position to which its wonder-working powers has fairly entitled it.

CHAPTER II.

THE HISTORY OF THE INTRODUCTION OF THE MODERN STEAM-ENGINE.

In the year 1736, at the little town of Greenock on the banks of the Clyde, James Watt was born. Of a slender form, sickly appearance, retiring and bashful in his manners, and bearing with him no evidence of an intellectual capacity superior to his fellows, this youth, unaided by family wealth or station, or even by the adventitious aids of an early liberal education, was destined, during a long and active life, to be the means of introducing a power which aided this country materially during a time of difficulty and danger, and to leave behind him a name world-wide in its reputation.

When about sixteen years of age, he became acquainted with an obscure mechanic in Glasgow, who, "by turns a cutler and whitesmith, a repairer of fiddles and a tuner of 'spinnets,' was a useful man at almost every thing;" adding to this list of accomplishments "a knowledge of the construction of mathematical instruments and of 'spectacle-glasses,' he was dignified by the title of 'optician.'" To this individual Watt in his sixteenth year was apprenticed, chiefly, as is probable, more from the fact that it offered an easy calling suitable for his delicate health, than from any inducement it held out as that by which he could afterwards make a fair livelihood. After a short apprenticeship of less than two years, James Watt removed to London, where he succeeded in obtaining employment under a regular mathematical-instrument maker. Here he obtained that knowledge of business habits and processes which had been withheld from him in his earlier engagement. His stay in London was very limited; and probably from a severe cold which he caught while following his avocations, and the effects of which he felt for many years afterwards, he returned to his native town after an absence of little more than a year. He next endeavoured to raise a business of his own, and began to practise both in Greenock and Glasgow. In the latter place he met with an obstacle which threatened to put a sudden stop to his progress; this arose from the fact that he was not a "freeman," or "burgess," of the town. One spot, however, existed, within the boundaries of which all such absurd laws and regulations were inoperative and harmless for evil;—this was the "College of Glasgow." By the kind offices of some of the dignitaries, Watt was appointed mathematical-instrument maker to the university; and a room was allotted him within its precincts, in which he could carry on his avocations without molestation. Thus was the apparently untoward circumstance amply compensated for. And it is by no means idle to conjecture what would have been the results on the future progress of the steam-engine had that absurd law not been in existence which drove Watt out of what might be looked upon as the open path of commerce, to take refuge in the place, of all others, the best fitted for, and offering the most eligible opportunities of, carrying on the series of experiments which by a fortuitous chain of circumstances were shortly presented to his notice; and by the successful prosecution of which he was destined to make himself so famous.

In the year 1759, in this situation, Watt had his attention directed to the subject of the steam-engine through the representation of Mr. Robinson, afterwards Professor of Natural Philosophy in the University of Edinburgh, and author of the well-known work entitled *Elements of Mechanical Philosophy.* The scheme proposed had reference to the moving of wheel-carriages by the aid of steam; but in consequence of Mr. Robinson leaving college, it was abandoned. Two years afterwards, however, Watt again returned to the subject, and instituted some experiments with a Papin's digester; and formed a sort of steam-engine "by fixing upon it a syringe one-third of an inch in diameter, and furnished," says Mr. Watt, whose own account we now quote, "also with a cock to admit the steam from the digester or shut it off at pleasure, as well as to open a communication from the inside of the syringe to the open air, by which the steam contained in the syringe might escape. When the communication between the cylinder and digester was opened, the steam entered the syringe; and by its action upon the piston, raised a considerable weight (15 lbs.), with which it was loaded. When this was raised as high as was thought proper, the communication with the digester was shut off, and that with the atmosphere opened; the steam then made its escape, and the weight descended. The operations were repeated; and though in this experiment the cock was turned by hand, it was easy to see how it could be done by the machine itself, and make it work with perfect regularity. But I soon relinquished the idea of constructing an engine upon this principle, from being sensible it would be liable to some of the objections against Savery's engine, namely, from the danger of bursting the boiler, and the difficulty of making the joints tight; and also that a great part of the power of the steam would be lost, because no vacuum was formed to assist the descent of the piston."

Two years after relinquishing his experiment, as above stated, his attention was again directed to the subject, by a model of a steam-engine on Newcomen's plan, belonging to the Natural Philosophy class, being placed in his hands to be repaired (1763-4). At first directing his attention to the dry matter-of-fact details of the task he had intrusted to him, his active mind received a new impulse from the result of one or two trials of the engine, and he directed the full energy of his intellect to master the principle of the machine, and to ascertain the cause of its defects as an economical prime-mover. In conducting the experiments, two things attracted his attention; the first was the great loss of steam from the condensation caused by the cold surface of the cylinder; secondly, the great quantity of heat contained in a small quantity of water when converted into steam. If a quantity of water is heated in a close boiler some degrees above the boiling-point, and the steam suffered to escape suddenly, the temperature of the boiling-water remaining in the boiler will be reduced to the ordinary boiling-point. The steam, however, which escaped, although carrying off all the excess of heat, would, if condensed, form but a small quantity of water. The saving of this heat was therefore a matter of the highest importance. The loss of steam occasioned by the alternate heating and cooling of the cylinder was sufficient to fill the cylinder three or four times, and to work the engine. "By means of a glass tube inserted into the spout of a tea-kettle, he allowed the steam to flow into a glass of cold-water until it was boiling hot. The water was then found to have gained nearly a sixth part by the steam which had been condensed to heat it, and he drew the conclusion that a measure of water converted into steam can raise about six measures of water to its own heat, or eighteen hundred measures of steam can heat six measures of water." "Hence he saw that six times the difference of temperature, or fully 100 degrees of heat, had been employed in giving elasticity to steam, and which must all be subtracted before a complete vacuum could be obtained under the piston of a steam-engine." "Being struck," says Mr. Watt, "with this remarkable fact, and not understanding the reason of it, I mentioned it to my friend Dr. Black, who then explained to me his doctrine of latent heat, which he had taught some time before this period (summer of 1764); but having been occupied with the pursuits of business, if I had heard of it I had not attended to it, when I thus stumbled upon one of the material facts by which that beautiful theory is supported." In making his experiments, Watt found that the boiler of the model, although large enough according to the standard then in use, did not supply steam fast enough for the wants of the engine, which had a cylinder two inches diameter and six inches stroke. The vacuum too was very imperfect, yet required a large quantity of injection-water to effect it. These defects he attributed to the fact that a small cylinder consumed a greater quantity of steam than a larger one, in consequence of the condensation caused by the increased surface in proportion to its capacity. This defect he sought to remedy by substituting a cylinder made of materials which would conduct heat more slowly than brass, of which the model cylinder was made. For this purpose he constructed one of wood soaked in linseed-oil, and baked dry. This, however, was a failure, for in addition to its want of durability, an essential feature in practice, it was found to condense the steam as much as before. The principal loss sustained was, therefore, by the alternate heating and cooling of the cylinder; and the conviction was forced upon him that the grand secret lay in being able to effect the condensation of the steam without cooling the cylinder. To the attainment of this Watt directed his whole energies, and in the year 1765 the felicitous idea struck him, "that if a communication were opened between a cylinder containing steam, and another vessel were exhausted of air and other fluids, the steam, as an expansible fluid, would immediately rush into the empty vessel, and continue to do so until it had established an equilibrium; and if that vessel were kept very cool by an injection or otherwise, more steam would continue to enter until the whole was condensed." This brilliant idea was soon put to the test of experiment and found correct; and thus was solved the great problem which had for so many years perplexed and baffled his predecessors. It is said, that as soon as this happy thought had been realised, all the train of details necessary to carry it into efficient practice followed in rapid succession; and that not for a moment had he any hesitation in conceiving the rapid and immediate perfecting of the whole machine. In carrying out the idea into practice, the first difficulty that presented itself to the mind of Watt was, doubtless, a means of relieving the condenser from the accumulated water which would result from the successive condensation effected in it. This might, of course, be drawn away by the simple force of gravity, by using a pipe thirty feet long, as in Newcomen's engine. This plan, however, would not be effectual for removing the uncondensed steam, or the air that might find its way into the condenser. Some other plan was therefore desiderated. Watt proposed and adopted a pump which would draw off the contents of the condenser, this pump being worked by the engine itself. This constituted another step towards the perfecting of the mechanism: others rapidly followed. The next improvement was surrounding the cylinder with a casing, by which the heat would be retained. This of itself, however, would not effect the desired end: he therefore, to prevent the action of the cold atmosphere on the upper surface of the piston and on the interior surface of the cylinder, which would necessarily be exposed on its descent, closed the top of the cylinder with a close-fitting cover, in the centre of which the piston-rod worked through an aperture rendered tight by what is termed a "stuffing-box." The necessity of adopting the next expedient suggested to him was thus made obvious; and in place of the power of the atmosphere he employed the "*elasticity of the steam from the boiler to impel the piston down the cylinder.*" By this arrangement the method adopted of keeping the piston tight, by having water on its upper surface, was precluded from use; and instead, Watt adopted a hemp-packed piston lubricated with tallow. Thus, by successive improvements, the atmospheric engine was changed into a "steam-engine."

Before *illustrating* the improvements introduced by Watt, we propose to trace further the points connected with its history. Although the claim of Watt to the originality of the idea of separate condensation is now generally, if not universally, acknowledged, still it is but right to notice that of another party to this high honour. The claim is put forward by Mr. Hornblower, a rival and contemporary of Watt, in Gregory's *Mechanics* (vol. ii. first edition, p. 362), in the following statement: "About the time that Mr. Watt was engaged in bringing forward the improvement of the engine, it occurred to Mr. Gainsborough, the pastor of a dissenting congregation at Henley-upon-Thames, and brother to the painter of that name, that it would be a great improvement to condense the steam in a vessel distinct from the cylinder where the vacuum was formed; and he undertook a set of experiments to apply the principle he had established; which he did by placing a small vessel by the side of the cylinder, which was to receive just so much steam from the boiler as would discharge the air and condensing water, in the same manner as was the practice from the cylinder itself in the Newcomenian method, that is, by the snifting-valve and sinking-pipe. In this manner he used no more steam than was just necessary for that particular purpose, which, at the instant of discharging, was entirely uncommunicated with the main cylinder, so that the cylinder was kept constantly as hot as the steam could make it. Whether he closed the cylinder, as Mr. Watt does, is uncertain; but his model succeeded so well as to induce some of the Cornish adventurers to send their engineers to examine it; and their report was so favourable as to induce an intention of adopting it. This, however, was soon after Mr. Watt had his act of parliament passed for the extension of his term; and he had about the same time made proposals to the Cornish gentlemen to send his engine into that county. This necessarily brought on a competition, in which Mr. Watt succeeded; but it was asserted by Mr. Gainsborough, that the mode of condensing out of the cylinder was communicated to Mr. Watt by the officious folly of an acquaintance, who was fully informed of what Mr. Gainsborough had in hand. This circumstance, as here related, receives some confirmation by a declaration of Mr. Gainsborough, the painter, to Mr. More, late Secretary to the Society for the Encouragement of the Arts, who gave the writer of this article the information; and it is well known that Mr. Gainsborough opposed the petition to parliament through the interest of General Conway." Much doubt is, however, thrown upon the accuracy of this statement, from the fact, that Mr. More, the gentleman alluded to, in a trial, Bolton *v.* Bull, distinctly stated on oath, that he "never saw the principle laid down in Mr. Watt's specification either applied to the steam-engine previous to his taking it up, or ever read of any such thing whatever." It is not now an easy matter to reconcile this contradiction with the statement of Mr. Hornblower. Having given a brief statement regarding the claim made to the honour of the discovery of separate condensation, we now proceed to note the various steps in the history of the introduction of Watt's steam-engine.

Having satisfied himself as to the correctness of his principle, Watt proceeded to test it still further by the aid of a model on a large scale. The cylinder of this model was 9 inches diameter, and the piston-rod was attached to a balanced beam. An accident, however, occurred, which, along with his want of means, as well as of time to prosecute his experiments, brought his labours to a close. Having taken up the practice of a land-surveyor and engineer, and his time being pretty fully occupied, the invention lay dormant on his hands for three or four years. His silence on the matter doubtless proceeded from a variety of causes, the principal of which was, likely, the fact, that as a fair trial could only be given to his engine on a large scale, the risk of bringing it out would be too great, the apparatus required being exceedingly costly. From Watt's practice as an engineer, he became acquainted, however, with the celebrated Dr. Roebuck, an enterprising English gentleman resident in Scotland. An able practical chemist, he had succeeded in discovering a method of making sulphuric acid at a comparatively low cost; and being possessed of business habits and qualities of the first order, he succeeded in establishing at Prestonpans, near Edinburgh, a manufactory, in which the process was carried out on a large scale. The profits accruing from this establishment were such, that he gave up the practice of his profession, and confined his attention to carrying out commercial projects on a large scale. He founded the celebrated iron-works at Carron, which, as a project, were highly successful. Urged by his success in this undertaking, he leased the estate of Kinneil, a few miles from Carron, and which contained extensive beds of coal. While carrying on his operations there with the same energy which characterised his other proceedings, he became acquainted with Watt, who, no doubt, struck by his ability and business habits, looked upon him as one in every respect calculated to aid the undertaking of bringing the steam-engine into practice, and accordingly confided to him the secret of his discovery. Dr. Roebuck consented to bear the expense of conducting trials on a large scale; and Watt forthwith proceeded to construct a large engine under his inspection. For a period of eight months, alterations and improvements succeeded each other, until at last the engine was brought to a state of comparative perfection—so far, at least, as could be attained, from the imperfect style of workmanship then available. The engine was tried at a coal-mine on Dr. Roebuck's estate; and such was the satisfactory nature of its operations, both as regarded the great saving of fuel and the water used for condensation, that Dr. Roebuck was satisfied as to its powers and capabilities, and closed with Watt, supplying the necessary funds to take out a patent, and to establish a manufactory for the production of the engines; the terms of partnership being, that the money for the above purposes was to be found by Roebuck, he obtaining two-thirds of the profits. On these terms Watt proceeded with his patent, which was taken out in 1769, and of which the following is the specification. It was not accompanied with drawings or sketches of any kind.

"My method of lessening the consumption of steam, and consequently fuel in fire-engines, consists of the following principles:

"First: That vessel in which the powers of steam are to be employed to work the engine, which is called the cylinder in common fire-engines, and which I call the steam-vessel, must, during the whole time the engine is at work, be kept as hot as the steam that enters it: first, by enclosing it in a case of wood, or any other materials that transmit heat slowly; secondly, by surrounding it with steam or other heated bodies; and thirdly, by suffering neither water nor any other substance colder than the steam, to enter or touch it during that time.

"Secondly: In engines that are to be worked wholly or partially by condensation of steam, the steam is to be condensed in vessels distinct from the steam-vessels or cylinders, although occasionally communicating with them: these vessels I call condensers; and whilst the engines are working, these condensers ought at least to be kept as cold as the air in the neighbourhood of the engines, by application of water or other cold bodies.

"Thirdly, whatever air or other elastic vapour is not condensed by the cold of the condenser, and may impede the working of the engine, is to be drawn out of the steam-vessels or condensers by means of pumps, wrought by the engines themselves, or otherwise.

"Fourthly, I intend, in many cases, to employ the expansive force of steam to press on the pistons, or whatever may be used instead of them, in the same manner as the pressure of the atmosphere is now employed in common fire-engines. In cases where cold water cannot be had in plenty, the engines may be wrought by this force of steam only, by discharging the steam into the open air after it has done its office.

"Lastly, instead of using water to render the piston or other parts of the engines air and steam-tight, I employ oils, wax, resinous bodies, fat of animals, quicksilver and other metals in their fluid state.

"And the said James Watt, by a memorandum added to the said specification, declared, that he did not intend that any thing in the fourth article should be understood to extend to any engine where the water to be raised enters the steam-vessel itself, or any vessel having an open communication with it."

After Watt had obtained his patent, he proceeded to perfect the details of his engine. From the bad workmanship which he had to contend with, his difficulties were of a serious kind; that which harassed him most being the difficulty of keeping the piston tight without incurring a heavy loss by friction. But another obstacle was about to be thrown in the path of progress, and which at one time bade fair to utterly ruin Watt's prospects of receiving a pecuniary reward for his great labours: this was the bankruptcy of Dr. Roebuck. The coal-fields of Kinneil, instead of throwing a golden shower of profits into his lap, were the means of bringing him to ruin. The quality of the coal was far beneath his expectations; and the difficulties of getting even an inferior produce daily increasing, he was necessitated, from the drain on his capital, to part with, from time to time, his share in other lucrative concerns with which he was connected: and thus, by degrees, the very perseverance which distinguished him in better times, tended, by its prompting him to preserve in this instance the wreck of his once great fortune, to sink him still further into difficulties, until at last irretrievable ruin overtook him; and he was obliged to enter into a negotiation to give up his connexion with Watt, from which he might have reaped a harvest greater than he had gathered from all his previous projects, lucrative as they were, put together. But this apparently untoward circumstance was the means of ultimately placing Watt in the eminent position which he afterwards occupied; so true, as we often find it, is the saying, that "man's extremity is God's opportunity."

The party with whom Roebuck negotiated for a transfer of his rights in the patent of Watt, was the celebrated Matthew Bolton, of Soho, near Birmingham; a man whose name will always be handed down to posterity in conjunction with his more celebrated compeer. The transfer was effected, and a partnership formed between Bolton and Watt. In character the very opposite in many respects of Watt, Bolton was possessed of rare business talents, an extensive acquaintance with business forms, and having that indomitable spirit of "perseverance which insures success" in an eminent degree; these, united with a degree of courage in prosecuting his engagements in the face of difficulties, rendered him a fitting coadjutor for the retiring and unambitious Watt. "To a man like Watt," says an able writer, "so unfitted, from feeling and habit, to stand alone, nothing could have been more auspicious than his gaining the protection of two such men in succession (as Roebuck and Bolton). Obstacles were seen by either only to be surmounted; and they both possessed, in an eminent degree, the master-art of infusing into all around them a portion of their own matchless energy. Projectors themselves, they were considerate of his feelings, and knew how much the flow of thought in irresolute or hesitating genius is quickened by the kindness and condescension of a patron. Assisted by their experience, and animated by their generous approbation of what he had already achieved, he was roused and carried onward to impart greater perfection to his mechanism."

At the period of the transfer of Roebuck's rights in the patent to Bolton, Watt was engaged in surveying in the north of Scotland. Shortly after the death of his wife happening, he was induced to accept of the invitation of his partner, and to take up his abode at Soho. This now celebrated locality, at the time of Bolton's purchase of it, is described as a "barren heath, on one black summit of which stood a naked hut, the habitation of a warrener." A little iron mill was subsequently erected, and round the hill there rippled a small stream. Bolton, with the quick perception which distinguished him as a man of business, saw at once the superior advantages which it held out as the site of a manufactory for the fabrication of those articles for which Birmingham has been so long famed. By collecting the water, he obtained sufficient quantity to move the water-wheel, which, in its turn, gave motion to an almost endless variety of manufacturing machines and tools.

Watt was now in a position for prosecuting his labours with vigour, and surrounded by those mechanical appliances, without which the attainment of perfection in the working details was hopeless. An engine was accordingly erected; and many Cornish adventurers, greatly interested in the success of the engine, on invitation, examined its operation. In their report they gave a favourable opinion as to the saving of fuel effected by it. Some years of the term for which the patent was valid had, however, expired; and fearful that its whole period would pass over before pecuniary results accrued, so as to afford a profit, or to reimburse the large expenses which had been gone to in perfecting the engine, Watt, at the suggestion of Bolton and his other friends, applied to parliament for an extension of his patent. This, after some opposition, was granted for the term of twenty-five years, dating from the time of the grant, namely 1775. This extension was no doubt deserved, no less a sum than 50,000*l.* having been expended in the manufacture of the engines by the firm before any return was realised. Having thus secured for a lengthened period the profits which might accrue from the sale of the engines, Watt was now in a position to introduce his machine with every advantage to the public. In this he was materially assisted by the admirable commercial arrangements of Bolton, who, after the grant of extension, became a partner with Watt in the manufacture of the machines; thus sharing the profits on this head, as well as those derived from a monopoly of the principle. "Had Watt," says Playfair, "searched all Europe, he could not have found another man so calculated to introduce the invention to the public in a manner worthy of its importance."

The most public and open inspection of the engines at work was invited, and every means taken to afford just opportunities of ascertaining their value. A congress of mechanics and scientific men was convened at Soho, and an elaborate series of trials made and comparisons instituted between its working capabilities and one on the principles of Newcomen of the best construction, in order to show the superior working capabilities of the new engine: these were manifest to all. But still further to place the merits of the machine on a basis which would satisfy all as to the character of its claims, the patentees issued the following: "All that we ask from those who choose to have our engines, is *the value of one-third part* of the coals which are *saved* by using our improved machines, instead of the old. With our engine, it will not, in fact, cost you but a trifle more than half the money you now pay to do the same work, even with one-third part included; besides an immense saving of room, water, and expense of repairs. The machine itself which we supply is rated at that price which would be charged by any *neutral manufacturer* of a similar article. And to save all misunderstanding, to engines of certain sizes certain prices are affixed." To aid in the introduction of the new machines, Bolton and Watt took old atmospheric engines off the hands of those who wished to lay down the improved form, and this frequently at a rate above their value.

Again, in estimating the power of their engines, or calculating the work which each could perform, Bolton and Watt, instead of placing the estimate of a horse's work at a low figure, and thus in the same proportion increasing the power of their engine, they actually increased the power of a horse's work to one-third. Smeaton had valued the work done by a strong horse as equal to lifting a weight of 22,000 pounds one foot high in a day; Bolton and Watt estimated at 33,000. But more than this, they stated that their engines were "calculated so, that they will raise 44,000 pounds one foot high with a bushel of coals; and when we say our engines have the force of five, ten, or more horses, we mean and guarantee that they will lift 44,000 pounds for each horse-power." On these terms, an engine which, according to Smeaton's estimate, was equal to twenty horses, was, according to Bolton and Watt, only equal to ten; thus giving the purchasers of the new engine an advantage of 100 per cent in value for no increase of cost.

Thus placed before the public on terms so highly liberal, the invention made rapid progress in public favour; and some idea of the profits accruing may be derived from the fact, that at Chacewater mine, Cornwall, the saving of fuel effected was equal to 6000*l.* annually; 2000*l.* of revenue from this one source being drawn by the firm.

The manufacture of the engines increased with such rapidity, that the original establishment at Soho was found too limited in its dimensions for the great quantity of work now flowing into the factory. Another was therefore constructed in the near neighbourhood, in which the operations could be carried on with a high degree of concentration, so essential to the turning out of work rapidly and efficiently. "We are," writes Bolton to the celebrated Smeaton, "systematising the business of engine-working; we are training workmen, and making tools and machines, to form the different parts with more accuracy and at a cheaper rate than can possibly be done by the ordinary methods of working. Our workshops will be of sufficient extent to execute all the engines which are likely to be soon wanted in this country; and it will not be worth the expense for any other engineer to erect similar works, for that will be like building a mill to grind a bushel of corn." The expenditure thus occasioned to the firm was not thrown away: a body of expert workmen was soon organised.

Having thus brought up our historical notes in connexion with Watt's engines to the contemplated point, we are prepared to proceed to the illustration of the successive steps of his invention, and of those beautiful contrivances which emanated from his mind.

The diagram in fig. 20 will illustrate the arrangements of parts of the early engines introduced by Watt for pumping the water from mines. Let *a* be the cylinder, in which the piston *b* works a rod passing through a steam-tight stuffing-box *c*; the cylinder is surrounded by an external casing *dd*, into the space formed by which the steam enters from the boiler through the pipe *e*. By opening the valve *e*, the steam is introduced to the pipe beneath the cylinder, and introduced into its interior through the aperture *f*. By opening the valve *g*, the steam is allowed to pass down to the interior of the condenser *h*. In this diagram the piston-rod is supposed to be attached to the end of the great beam which works the mine-pump, and the valves to be worked by mechanism, which we shall figure afterwards.

Before starting the engine, the air was extracted from the various parts. This was effected by opening the valves, and allowing the steam to flow into all the vessels and pipes; the air is thus forced down the pipe to the condenser *h*, and through the valve which connects this with the air-pump *j*.

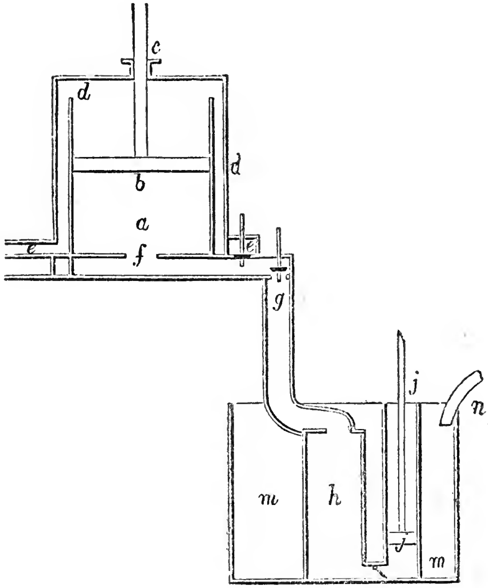

fig. 20.

The valve *e* is then shut, thus preventing more steam from entering the cylinder *a* through the aperture *f*; at the same time the steam in the condenser *h* is condensed by the cold water which surrounds it, and supplied to the cistern *m m*, in which it stands, by the spout *n*, supplied by a common force-pump worked by the great beam. The vacuum being thus formed beneath the piston *b*, the pressure of the steam, which has free access to the upper side of the piston, forces it downwards to the bottom of the cylinder. By the action of the beam, the air-pump piston is pulled upwards, and the water withdrawn from the condenser *h*. By the valve mechanism, the valve *g* is shut, and the valve *e* opened; steam is thus introduced beneath the piston, and an equilibrium being established between both sides, the counterpoise at the end of the great beam draws up the piston to the top of the cylinder; the air-pump is thus depressed, and the portion of condensed water lying in the lower part of the barrel passes through the clack or valve in the piston; the mechanism of the valve then shuts the valve *e*, and opens *g*; this taking place on the piston *a* reaching the top of the cylinder, the steam below the piston rushes through the valve *g* to the condenser, and a vacuum being formed as before, the piston is forced by the pressure of the steam on its upper side towards the bottom of the cylinder. The opening and shutting of the valves *e* and *g* was effected by simple mechanism, as follows.

Let *a*, fig. 21, be the spindle of the valve admitting steam to the cylinder, and *b* that of the valve admitting the steam to the condenser; these are connected by a joint to levers moving on the centres *c c*; *h h* is the plug-frame, having studs or projecting pins *o n*; these strike the handles or levers which are fixed on the rod *i i*, and to which the levers *r p* are fixed, actuating the levers *d e*, and lifting or depressing the valves *a b*; *s* is the counterbalance weight which acts the tumbling bob in Beighton's valve gearing already noticed. The condenser, in its original form as introduced by Watt, consisted of a series of thin copper pipes communicating with each other, and placed in a cistern filled with cold water: in some instances flat copper pipes were used; the object, in both cases, being to present as great a surface as possible to the action of the cold water, and to effect a rapid condensation. Notwithstanding many drawbacks attendant upon this plan, it was considered an economical one, inasmuch as a comparatively small power was required to work the pump for withdrawing the air and condensed water. To receive a quick condensation by this method, it was indispensable to have a large amount of surface exposed to the cold water; this necessitated condensers of such size, that Watt was at last obliged to return to a plan which he had adopted while in Scotland during his trials under Roebuck, of condensing the steam by introducing a jet of cold water into the condenser. The clumsy outer casing was, after repeated trials, found to be possessed of inconveniences; Watt therefore discarded it, and adopted a plan of intercasing composed of thin sheet-iron, the space being only one inch and a half between it and the cylinder; this space was supplied with steam by a pipe leading from the main steam-pipe. This arrangement involved a radical change in the method of distributing the steam to the cylinder. The details of the new construction may be gathered from the diagram in fig 22.

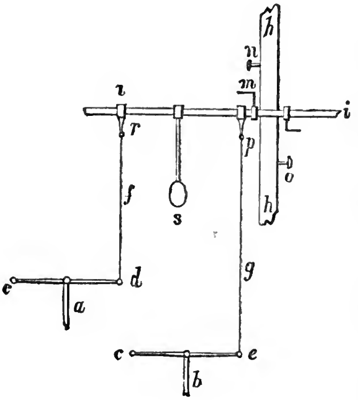

fig. 21.

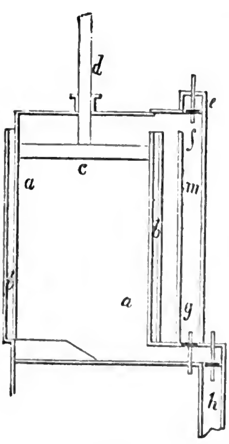

fig. 22.

Let *a a* be the cylinder, *b b* the outer casing, *c* the piston, *d* the piston-rod, *e* the steam-pipe leading from the boiler, *f* the "steam-valve," *g* the "equilibrium-valve," and *h* the "eduction-valve" in the pipe leading the steam to the equilibrium-valve. Supposing the piston at the top of the cylinder, the equilibrium-valve is closed, and the steam-valve *f* and eduction-valve *h* opened; the steam from below the piston rushes through *h* to the condenser, and a vacuum is formed; the steam pressing on the upper side of the piston, it is forced downwards. On reaching the bottom, the steam-valve *f* and eduction-valve *h* are closed, and the equilibrium-valve *g* opened; this allows the steam to gain access to the under side of the piston, as well as to its upper side; an equilibrium of pressure is therefore formed, and the counterpoise pulls the piston to the top, the steam above it flowing through the equilibrium-valve. In this form of engine there is alternately steam and a vacuum on the under side of the piston, the steam being always above the piston.

About the year 1780, Watt introduced another modification, having for its object the attainment of a more perfect condensation: this he proposed to effect by having a perpetual vacuum below the piston, while there was alternate vacuum and steam-pressure above it; thus, on the piston having accomplished its loaded stroke, that is, from top to bottom, the vacuum being made, the whole of the time in which the piston was ascending might be occupied in freeing the cylinder from the air and steam. This idea was carried out by aid of the following arrangements.

In fig. 23, *aa* is the cylinder, *b* the piston, *c* the "steam-valve," *d* the steam-pipe, *e* the "eduction-valve," *ff* the eduction pipe leading to the condenser, *g* the steam-port leading to the upper side of the piston. On the piston reaching the bottom of its stroke, the steam-valve *c* was shut, and the eduction-valve *e* was opened; the steam from the upper side of the piston rushed through *g* and *e*, and down the eduction-pipe *f* to the condenser; the vacuum was thus made on both sides of the piston, the counterpoise pulling the piston to the top; the eduction-valve remaining open during its ascent, a longer time was thus given to the formation of the vacuum above the piston. The advantages expected to flow from this ingenious arrangement did not, however, exist: it was found that in practice the condensation was so quickly performed, in fact almost instantaneously, that the longer time produced no better vacuum; and the cylinder approximating so much to the coolness of the condenser, a considerable quantity more of steam was required. Leakage to some extent also resulted from the arrangement. This arrangement of engine was therefore abandoned.

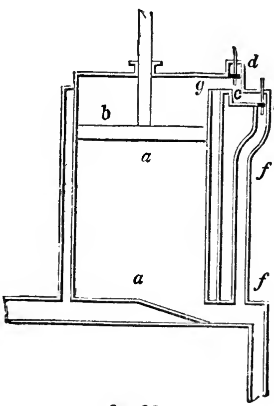

fig. 23.

We now come to notice an important improvement in the working of steam-engines, which the fertile genius of Watt added to the list of his brilliant inventions: this improvement was that of working the steam expansively. The patent for the expansive steam-engine was taken out in 1782; but the attention of Watt had been directed to the principle many years before; in 1769 he wrote to Dr. Small, as to a "method of still doubling the effect of steam, and that tolerably easy." Many matters, however, diverted his attention from this important point; and it was not until the above date that he took steps to introduce an engine in which the principle was carried out. The due understanding of its *rationale* is so important to the student of the steam-engine, that we propose entering into its consideration at some length.

Where steam is admitted to press on the top of a cylinder, during the whole of its descent the piston will move downwards with an accelerating velocity, which, if not checked, will be of such amount as materially to damage the mechanism. An able authority supposes that the value of the expansive principle was made known through the result of some trials which were instituted for the purpose of moderating the velocity of the piston, and consequently the shock as the piston reached the bottom of the cylinder. In Newcomen's engine he supposes this to have been effected by shutting the injection-cock earlier; and in Watt's condensing-engine, by shutting "the steam-valve at such a period of the stroke as would prevent the catch-pins from striking." This shutting off the steam-communication from the boiler, at a certain part of the stroke of the piston, allowing the steam to expand as the piston descends, constitutes the principle of the method of working expansively. By the action of the well-known law of pneumatics (see volume on *Natural Philosophy* in this series), the pressure of the steam on the piston decreases as the space increases into which the steam has liberty to expand itself; thus if the steam is cut off at one-fourth of its stroke, the pressure will, at the end of the stroke, exert only a force of one-fourth of its original pressure. By thus decreasing the power, a simple method of equalising the tendency to an accelerated motion was attainable. In addition, however, to this advantage, a still greater one resulted from the adoption of the principle in the economisation of steam, and the consequent saving of fuel. If steam of the temperature of 212° "flows into a cylinder six feet long, until the piston has moved eighteen inches downwards, when this quantity has expanded into double its former volume, and in doing so has pressed the piston to the middle of the cylinder, it will exert a pressure of not more than 7 pounds on each square-inch area of the piston. When the piston has been depressed another eighteen inches, the vapour will have expanded into three times its original bulk, and will then urge the piston downwards with a force of not more than $4\frac{1}{2}$ pounds on each square inch; and when it has reached the bottom of the cylinder, and expanded into four times its original bulk, it will not exert a greater energy than about $3\frac{2}{3}$ pounds on each square inch. If now we calculate the varying power of the steam from the commencement to the termination of its stroke, beginning with a force of 14 pounds, and ending with $3\frac{2}{3}$ pounds, it will have exerted an average pressure of nearly $8\frac{1}{2}$ pounds on each square inch of the piston. But if the vapour had been permitted to flow freely into the cylinder as fast as the piston descended, it would have pressed it with a force of 14 pounds during the entire stroke of the piston. We thus see that one foot and a half of steam, acting expansively, has pressed $8\frac{1}{4}$ pounds through six feet; while six feet of steam, operating with its energy uniform and unimpaired, has only carried 14 pounds through six feet; thus showing that more than one-half of the whole steam has been saved by making it act expansively.

"Although the saving of steam is very considerable by making it work expansively, the power of the engine is reduced; thus, where the steam is cut off at one-fourth of the stroke, while the efficacy of the steam is increased four times,—that is, one-fourth the quantity of steam will complete the stroke,—the power is diminished nearly one-half. In engines worked expansively, therefore, the size of cylinder must be increased in proportion to the extent to which the expansive principle is carried. But although the engine is made larger to do the same quantity of work, this work will be done with a less consumption of fuel: this is obvious from the consideration, that at whatever point the steam is cut off, so much steam is saved; and that the steam, although it exerts a gradually decreasing force on the piston, still exerts a power of some extent, which power, whatever may be its amount, is gained without any expenditure of steam. To carry out the system of expansive working most conveniently, it is best to use steam of a pressure considerably higher than that of the atmosphere: unless this pressure is considerable, expansion cannot be carried out to any great extent with advantage; for if steam of a low pressure were used, the ultimate tension would be reduced to a point so nearly approaching that of the vapour in the condenser, that the difference would not suffice to overcome the friction of the piston, and a loss of power would be occasioned by carrying expansion to such an extent. It is clear that in the case of engines which carry expansion very far, a very perfect vacuum in the condenser is more important than it is in other cases." The advantage of applying steam expansively will be seen by an inspection of the following table: if the steam is cut off at one-half of its stroke, the performance of the engine will be multiplied 1·7 times; at

$\frac{1}{3}$	2·1	$\frac{1}{6}$	2·8
$\frac{1}{4}$	2·4	$\frac{1}{7}$	3·
$\frac{1}{5}$	2·6	$\frac{1}{8}$	3·2

Watt effected the cutting off of the steam at any desired point by merely altering the position of the tappets or projecting pins in the plug-frame, by which the valves were actuated upon at the proper time. As the motion of the piston was necessarily variable when the expansion principle was adopted, Watt contrived several ingenious mechanical combinations, by which the effect of the engine on the work it had to perform was uniform; he, however, did not apply these to any great extent, as he employed steam a little greater in pressure than that of the atmosphere, and cutting off only at one-third or one-fourth, according as circumstances dictated.

The reader desirous of becoming acquainted with these further evidences of Watt's inventive talent, will find several plans figured, by which this uniformity was obtained, in Stuart's *Descriptive and Historical Anecdotes of Steam-Engines.* We proceed to the consideration of more interesting and important matters in connection with the inventions of Watt.

Under the new arrangements it was a matter of importance to ascertain the state of the vacuum in the condenser and cylinder; for on the perfection of this obviously depended the efficiency of the engine. In order to ascertain this, Watt applied a mercurial barometer, having a connection with the inside of the pipe leading to the condenser; and another barometer was placed in connection with the boiler. The rise and fall of the mercury in the barometer attached to the condenser indicated the degree of exhaustion which had been made in it; and by the same operation in the barometer attached to the boiler, he had a measure of the pressure of steam acting in the piston: from the data thus obtained, he was able to calculate with considerable precision the amount of power given out by the engine. He afterwards, for this purpose, introduced a highly-ingenious invention which he termed the *indicator;* a diagram of which we now append, in order to show the nature of its operation. A small cylinder *b*, fig. 24, truly bored, is fixed on the cylinder-cover, having connection with its interior: a small piston *c* works in the cylinder *b*, the spindle or rod is continued upwards, its head terminated by a pointer, which is placed along a scale *d;* round the lower part of the spindle of the piston a spiral spring is coiled, one end of which is fixed to the piston, the other to a small bracket. The upper side of the piston is open to the air, the lower is open to the cylinder. The zero point of the scale is so adjusted, that the pointer will point to it when the cylinder is filled with air; and the pressure on both sides of the piston of the indicator is equal. On a vacuum being made in the steam-cylinder, the piston of the indicator is forced downwards; and the spring being thus put in a state of tension, the pointer will indicate the different points in the scale, corresponding to the degree of vacuum in the cylinder. When the cylinder becomes filled with steam, the piston of the indicator rises, and it falls again on the vacuum being made. Thus the power of the engine at any period of its stroke is faithfully transferred to the piston of the indicator, and by this means the power of the engine is estimated. In a future chapter we shall describe the modern indicator, and the means by which it is made to record on paper the working capabilities of the engine to which it is attached.

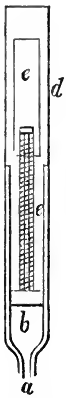

fig. 24.

We give a diagram, in fig. 25, illustrative of the arrangements of Watt's single-acting pumping-engine, as adopted at this period. At the present time the principle of this engine is still the same: the modifications in the details, arising from greater perfection in workmanship, although tending to give an appearance of greater elegance to its form, have not been extended to alteration of its principle of action. To such a high state of perfection did Watt bring it, that an eminent authority states that a pumping-engine "made after Watt's primitive type, would, with an equally effectual boiler, and an equal means of clothing and expansion, do about the same amount of duty as the best of the modern construction." We have already detailed the method of action of this engine, so that we deem a further explanation unnecessary; a literal reference to its parts, and a few words as to the method of "working the engine," may, however, be useful. The cylinder is indicated by the letters *a a*, *b* the piston, *d* the piston-rod, attached to the end of the working beam *e e* by a chain passing round the quadrant (see p. 84, fig. 164, treatise on *Mechanics and Mechanism*, in this series, companion volume to the present); *f f* the plug-frame for working the valves by the tappets and levers as shown; *g* the equilibrium-pipe; *h* the condenser; *i* the air-pump; *j* the cold-water cistern; *k* the hot-water cistern. In commencing to work the engine, the first operation is expelling the air from the interior of the cylinder *a a:* this is effected by relieving the catches of the steam, equilibrium, and eduction valves; these being actuated by weights attached to them, are opened, and steam is thus admitted to all the internal parts, as cylinder and equilibrium-pipe. The first effect of this is to condense the steam by coming in contact with the cold surfaces of the engine; after the cylinder *a a* becomes hot, the steam finally issues through the "snifting-valve" placed at the foot either of the

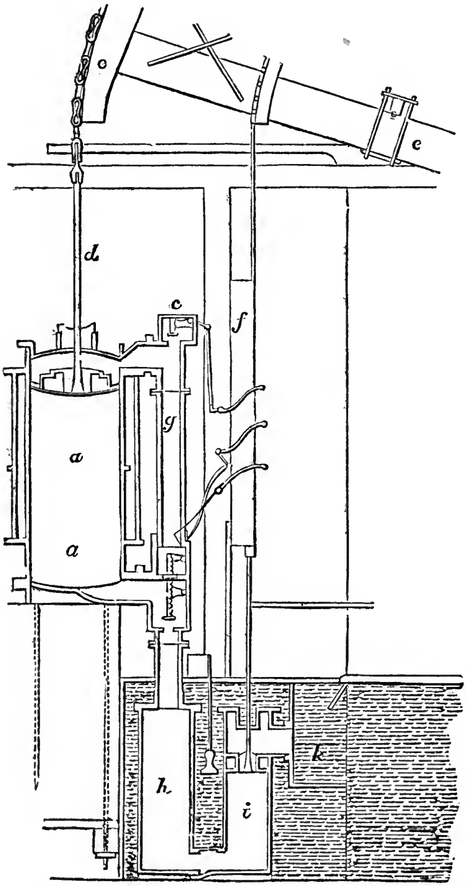

fig. 25.

condenser or of the air-pump. The valves are then to be shut, and a vacuum is thus formed in the engine. The first stroke of the engine is then made by opening the steam and eduction valves, and opening the injection-cock, so as to admit a jet of water to the condenser; the piston is then forced down into the vacuum by the steam above the piston. The plug-tree *ff* (fig. 25), in descending, strikes its tappets on the spanner or levers of the eduction and steam valves, shutting them, and opening the equilibrium-valve; the steam above the piston rushes throught his to the under side of the piston; and an equilibrium being thus established on both sides of the piston, it is drawn up to the top of the cylinder by the action of the counterpoise at the pump end of the beam.

The single-acting engine as here described, although admirably adapted for the purposes for which it was introduced, namely, withdrawing water from coal and other mines, was obviously unfitted for extension to other purposes in which a continuous rotatory motion was desired. By a slight modification of the valves of his engine, Watt was enabled to overcome the difficulty; and in the "double-acting engine," for which we are indebted to his genius, the piston is both raised and depressed by the action of the steam, a vacuum being alternately made above and below the piston. In 1781 he took out a patent for this modification, but his attention had been drawn to it many years before; in fact, while prosecuting his petition for a prolongation of his original patent in 1774, he had exhibited a drawing of the plan to the House of Commons. In this drawing he explained how, after the piston had been pressed by the steam to the bottom of the cylinder, by shutting off the connexion beween the upper part and the boiler, and opening a communication between it and the under side of the cylinder, the steam by this means could be made to *raise* as well as *depress* the piston into a vacuous space, *which might be made above and below it alternately.* For the introduction of this form of engine, by which the dead-weight of the counterpoise was got rid of, and the efficacy of the engine as a general motive power so vastly increased, and the range of its powers so much extended, we are probably indebted to the rivalry which existed between the firm of Bolton and Watt and other engine-makers, and to the machinations which many of them condescended to employ for the purpose of obtaining a share of the public patronage. Holding such an extensive monopoly, a monopoly not only of legal power, but also, it may be said, of mechanical genius, and of a vast experience such as no others could lay claim to, it need not be wondered at that the firm encountered a vast amount of obloquy and reproach from various interested sources, and that angry feelings and bitter animosity on the part of their rival brethren in the trade existed to a large extent. Some notion of the state of matters thus existing may be derived from the statement of a late engineer (whose mind and talents should, we think, have prompted more generous feelings), who declared that, "when men of *better* judgment had constructed engines as good, or *better* than their own, they have (*i.e.* Bolton and Watt) just candour enough to admit the fact, and pride and avarice enough to claim them as their invention;" and who even went the length of trying much "to make it clear that Mr. Watt had no right to any patent whatever!" But this state of matters, however much to be deplored, was not the only thing Bolton and Watt had to contend against: their own feelings of rectitude and just principle, which undoubtedly characterised them in all their dealings, bore them up against all the attacks of slander and detraction; but an extensive and powerful combination to wrest from them the pecuniary advantages of their invention touched them in another way, and called forth another and more public reprisal. As already mentioned, the profits derived by Bolton and Watt from their engines was exactly in proportion to the saving which they effected to the proprietors who had them erected. Nothing in commerce could be fairer than this; yet to the discredit of a large number of them, they, forgetting the *two-thirds* which by the use of the engines were put into their pockets, they grudged the third which the patentees asked for the great benefits thus conferred. By a species of sophistry, which we see often acted upon by men who, in other matters, fulfil to the letter the moral law of the rights of property, they thought it no wrong to apply to their own use freely, and without consulting the rightful owners, the property which *mental* labour had created. They covertly, if not openly, therefore, supported a horde of "pirates," who endeavoured to wrest the invention of Watt from his grasp. Bolton and Watt for a length of time took no steps to stop this flood of wrong; but at last it reached to such a height, that a due regard to their own social rights, as well as to the claims of public morality, rendered it imperative upon them to take some public and decided steps to put, at once and for ever, a stop to these proceedings. An engine having been erected on Watt's plan at a mine at Cornwall, an action was begun against Mr. Bull, by whom several of the Cornish miners were represented. The principal plea put in, in defence, was the vagueness and want of precision in the specification, and through this the invalidity of the patent. The judges were divided on this point, and no judgment was given. Advantage, however, having been taken of this, and reckoning on it as a legal defect sustained by the patentees, the attempts to evade the patent rights again became numerous; and further steps, to put a stop to this, were again taken by the patentees. The trial before the Court of King's Bench this time resulted in their favour. The immediate effect of this "Cornish conspiracy," as it has been termed, was doubtless the introduction of the double-acting engine; for Watt, foreseeing the extent to which it could be applied in a vast range of manufacturing operations, was no doubt anxious to occupy this field also, and not to depend altogether on that of Cornish pumping-engines. It was in connection with the double-acting engine that Watt introduced those beautiful and philosophical inventions which we are now about to notice.

In the application of the steam-engine to the production of a *continuous* motion, the first step to be taken was the changing of the reciprocating motion of the piston-rod into a continuous rotatory one. If the reader will turn to pp. 47-49 of the companion treatise to the present volume, *Mechanics and Mechanism*, in this series, he will there find a description of the method of effecting this purpose by means of what is called a "crank." Although the works of philosophy and mechanics published at periods long anterior to the time of Watt and his contemporaries contained illustrations of this contrivance, and although, moreover, evidence of its use could be seen in almost every street in the knife-grinder's wheel (see p. 48, fig 72, *Mechanics and Mechanism*), or in many houses in the country in the "housewife's spinning-wheel," the animated rivalry which existed between several mechanics who claimed the honour of its discovery, as an important appliance of the steam-engine, is very remarkable; the great importance which was thus attached to its exclusive possession may be viewed, therefore, "as one of the many curious illustrations afforded, in the progress of this machine, of the great value of even an apparently trifling improvement." We may here trace the history of its application to the steam-engine.

In the year 1779, a Mr. Matthew Wasbrough, of Bristol, patented a contrivance by which the balanced beam of the atmospheric engine could produce a rotatory motion. This was effected by the employment of one or more pulleys, wheels, or segments of wheels, to which were fastened ratchets or checks. In another case he shifted a wheel and its axis from one set of teeth to another. A third method was, employing racks with teeth, which tumbled or moved on their own axis or centre; and these racks he fastened to the working beam or great lever, or they were connected with it by means of chains. "For other purposes, instead of a working beam, he substituted a wheel or pulley, working by racks or chains from the steam piston; and to regulate the motion, he in some cases added a fly." Wasbrough fitted up one of his machines at Birmingham for a Mr. John Pickard. This party was instrumental, however, in introducing a much simpler method of producing rotatory motion; this was by substituting the crank. For this he took out a patent in 1780; and associated with him, in carrying its application into practice, the inventor of the previously mentioned mechanism, Wasbrough. They succeeded in introducing the method of working into several mills.

From Mr. Watt's own statement there appears every reason to conclude, that the idea of using the crank had been borrowed from his factory at Soho. The following is the statement alluded to:

"I had very early turned my mind to the producing continued motions round an axis; and it will be seen, by reference to my first specification in 1769, that I there described a steam-wheel, moved by the force of steam acting in a circular channel against a valve on one side, and against a column of mercury, or some other fluid metal, on the other side. This was executed upon a scale of about six feet diameter at Soho, and worked repeatedly; but was given up, as several practical objections were found to operate against it. Similar objections lay against other rotative engines which had been contrived by myself and others, as well as to the engines producing rotatory motions by means of ratchet-wheels. Having made my reciprocating engines very regular in their movements, I considered how to produce rotative motions from them in the best manner; and amongst various schemes which were subjected to trial, or which passed through my mind, none appeared so likely to answer the purpose as the application of the crank in the manner of the common turning-lathe (an invention of great merit, of which the humble inventor, and even its era, are unknown). But as the rotative motion is produced in that machine by the impulse given to the crank in the descent of the foot only, and behoves to be continued in its ascent by the momentum of the wheel, which acts as a fly, and being unwilling to load my engine with a fly heavy enough to continue the motion during the ascent of the piston (and even were a counterweight employed, to act during that ascent of a fly, heavy enough to equalise the motion), I proposed to employ two engines acting upon two cranks fixed on the same axis, at an angle of one hundred and twenty degrees to one another; and a weight placed upon the circumference of the fly at the same angle to each of the cranks, by which means the motion might be rendered nearly equal, and a very light fly only would be requisite. This had occurred to me very early; but my attention being fully employed in making and erecting engines for raising water, it remained *in petto* until about the year 1778 or 1779, when Mr. Wasbrough erected one of his ratchet-wheel engines at Birmingham, the frequent breakages and irregularities of which recalled the subject to my mind, and I proceeded to make a model of my method, which answered my expectations; but having neglected to take out a patent, the invention was communicated, by a workman employed to make the model, to some of the people about Mr. Wasbrough's engine, and a patent was taken out by them for the application of the crank to steam-engines. This fact the said workman confessed; and the engineer who directed the works acknowledged it, but said, nevertheless, the same idea had occurred to him prior to his hearing of mine, and that he had even made a model of it before that time; which might be a fact, as the application of a single crank was sufficiently obvious. In these circumstances I thought it better to endeavour to accomplish the same end by other means than to enter into litigation; and if successful, by demolishing the patent, to lay the matter open to every body. Accordingly, in 1781, I invented and took out a patent for several methods of producing rotative motions from reciprocating ones, amongst which was the method of the sun-and-planet wheels.

"This contrivance was applied to many engines, and possesses the great advantage of giving a double velocity to the fly; but is, perhaps, more subject to wear, and to be broken under great strains, than the crank, which is now more commonly used, although it requires a fly-wheel of four times the weight, if fixed upon the first axis. My application of the double engine to these rotative machines rendered unnecessary the counter-weight, and produced a more regular motion; so that, in most of our great manufactories, these engines now supply the place of water, wind, and horse-mills; and, instead of carrying the work to the power, the prime agent is placed wherever it is most convenient to the manufacturer.

"I do not exactly recollect the date of the invention of the double engine; but a drawing of it is still in my possession, which was produced in the House of Commons when I was soliciting the act of parliament for the prolongation of my patent in 1774 and 1775. Having encountered much difficulty in teaching others the construction and use of the single engine, and in overcoming prejudices, I proceeded no further in it at that time; nor until, finding myself beset with a host of plagiaries and pirates in 1782, I thought it proper to insert it and some other things in the patent above mentioned."

The mechanism of the "sun-and-planet" wheels above alluded to, for the purpose of obtaining continuous rotatory motion from the reciprocating movements of the piston-rod, the reader will find explained in pp. 70-77, fig. 142, *Mechanics and Mechanism.* The method employed in the single-acting engine for connecting the piston-rod with the end of the working beam was obviously (see p. 84, fig. 164, *Mechanics and Mechanism*) incapable of being applied to the double-acting engine; where the piston was *pushed* up by the pressure of the steam, not *pulled* up by the counterpoise, as in the single-acting engine. The mechanism which Watt at first employed will be understood from an inspection of the diagram in fig. 26. Let *a* be the piston-rod, furnished with a rack at its upper end, working into teeth of a segment fixed on the rod of the working beam; as the piston-rod moved up and down, the teeth actuated those of the segment, and made the beam *c* reciprocate. In working expansively, a small fly-wheel, shown by the dotted lines *d*, was applied to the mechanism; on the centre of this was fixed a small toothed wheel, which was worked by the rack, of

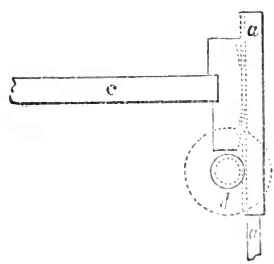

fig. 26.

the piston; the fly moved alternately from side to side as the piston ascended and descended. This contrivance was found possessed of many disadvantages on being carried into practice, especially in large engines, not the least of which was the great noise and jar occasioned by the teeth of the rack and segment engaging as the direction of motion of the piston-rod was changed. Some more elegant contrivance was therefore desiderated, and Watt's genius and mechanical ability no more failed him here than at other and more trying times; and the result of his cogitations was the production of that most beautiful and philosophical mechanism known as the "parallel motion." The principle of this contrivance the reader will find in p. 84, fig. 165, *Mechanics and Mechanism;* and an exemplification of its arrangement as carried out in practice in the diagram, fig. 63, p. 44 of the same work. The diagram here given, fig. 27, illustrates the arrangement of the parallel motion as first applied to the double-acting engine. Let *a a* be the working beam, *f* is the piston-rod, *g* the air-pump rod, *b c d* the links. Other exemplifications of this motion will be found in the diagrams in succeeding chapters of this volume.

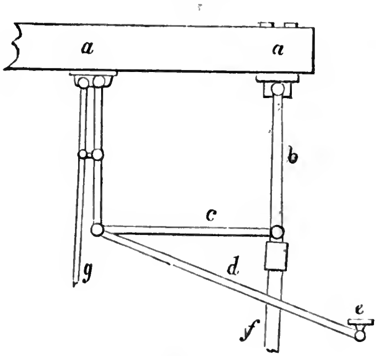

fig. 27.

In order to render the double-acting engine as perfect in its arrangements as possible, and independent of the attention of careless workmen, Watt introduced a method by which the engine itself regulated its own motion. This he effected by adopting what is now known as the "governor," a description of which will be found in pp. 87-89, *Mechanics and Mechanism*, and illustrations showing its application to the opening and closing of the valve by which the steam is admitted to the engine. In the single-acting engines the throttle-valve was opened and shut by hand, a

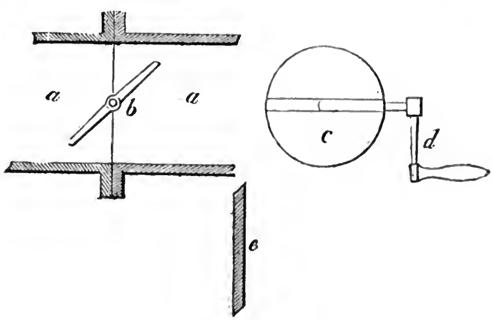

fig. 28.

sufficient uniformity of motion being thus obtained. A view of the valve is given in fig. 28: *aa* parts of the steam-pipe, joined together by a "flange-joint;" at the point of junction a thin disc or valve *b* is placed; the axis of this passes through a stuffing-box in the pipe, and is moved by a handle *d*. When the valve is parallel with the line of pipe, the steam-way is fully open; when brought up with its edges pressing on the interior of the pipe, the steam-way is closed; intermediate positions admit the steam in greater or less proportions. The manner in which the edges of the valve are "chamfered" off to go closely up to the pipe is shown at *e*. The "governor" was not the sole invention of Watt; in the application of it, however, to the steam-engine, it received the impress of his mechanical genius, and was, as it left his hands, in elegance and justness of proportion, and in original adaptation to his peculiar purposes, a very different affair than when used for regulating the sluice of water-mills, for which purpose, under the name of "lift-tenter," it was largely used. It is right, however, to state that, according to Stuart, a Mr. Clarke of Manchester suggested the adaptation of the "lift-tenter" to the regulation of the motion of the steam-engine.

The valves attached to the cylinder had to undergo some modification in their application to double-acting engines. The nature of these will be learned from an inspection of the diagram in fig. 29. The spindle of the valve *b* is continued upwards, and formed into a small rack; this works into the teeth of a quadrant *e*, which is moved by the spanner or lever *d*, worked by the plug-frame of the engine; the spindle or tail of the valve *c* works in a small aperture in a bracket below; additional steadiness was obtained by making the rack or slide in a projecting bracket.

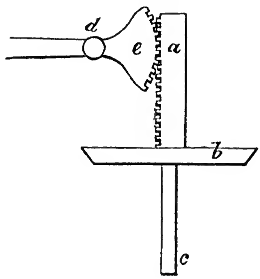

fig. 29.

In fig. 30 we give a diagram illustrative of the arrangements of the double-acting engine as it left his hands: *a* the cylinder, *b* the piston-rod, *d* the parallel motion, *mm* the beam, *o* the connecting-rod, *p* the sun-and-planet wheel giving motion to the fly-wheel, *e* the air-pump rod and plug-frame for moving the valves *f*, *g* the air-pump, *h* the condenser, *n* the hot-water pump for taking the hot water from the air-pump to the cistern, from which it is pumped by the pump *s*, and delivered to the boiler. Supposing the piston at the top of the cylinder, the action of the engine is as follows: as steam is being admitted by the upper valve to the upper side of the piston, it descends; and at a certain part of its stroke, the lappets in the plug-frame shut the steam-valve, and as the piston descends, the steam expands; on nearly reaching the bottom of its stroke, the upper exhaustion-valve is opened, and a communication made between the upper side of the piston and the condenser; the steam above the piston now rushes to the condenser, and a vacuum is formed. The lower steam-port is now opened, and the steam presses the piston upwards into the vacuum formed above the piston; at the proper period the lower steam-port is closed, and the lower exhaustion-valve opened; the steam now rushes from beneath the piston to the condenser, and a vacuum is formed beneath the piston. The movements thus proceed as long as required.

We have next to notice the arrangements which Watt introduced for the purpose of making the boiler supply its own wants; thus adding to the

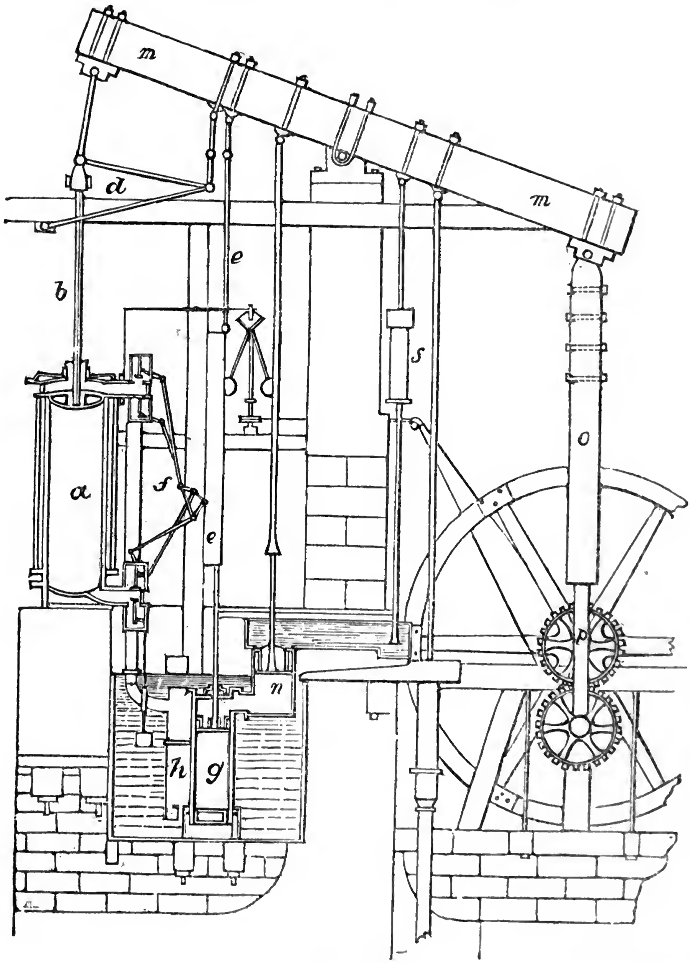

fig. 30.

means by which the steam-engine, in almost every respect, was made automatic. In fig. 31 we give a diagram illustrative of the general arrangements of the boiler. Previous to Watt's improved arrangements, the boilers of steam-engines were generally rude and clumsy affairs, ill adapted for raising steam either quickly or economically. This was owing, no doubt, partly to the low state of the mechanical arts, which precluded any attempt at nice adjustment of parts; and partly to no one studying the subject in all its bearings, in order to arrive at a knowledge of the just proportions necessary to attain the greatest amount of steam at the least expenditure of fuel. The shape, too, was chiefly dependent on caprice or preconceived notions, being confined principally to globular and hemispherical shapes, with flat or concave bottoms. The waste of fuel from these boilers at length attracted the attention of practical men, with a view to remedy their defects. Boilers of an oblong form were therefore introduced; and the best of this kind, known as the "wagon" from its shape, owed its introduction to Watt. He also applied numerous valuable appendages, as already alluded to, and which we now propose to describe by the aid of the diagram here attached.

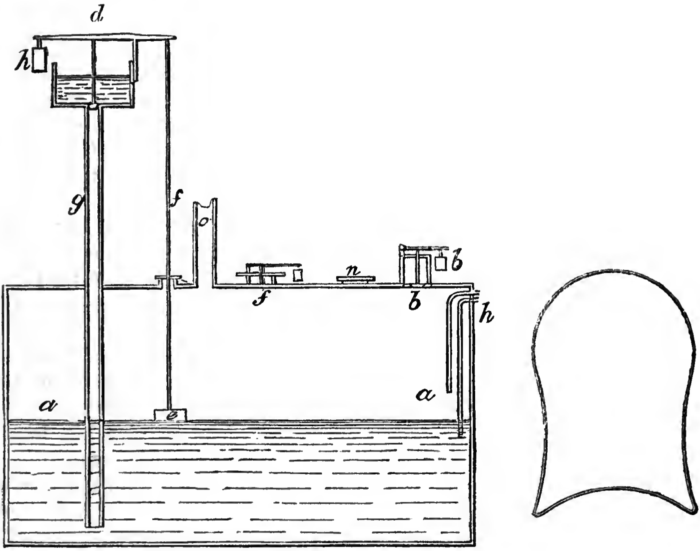

fig. 31.

And first, as to the important point of supply of water. A vertical pipe *g* was connected with the boiler, and reached to within a few inches of the bottom. This pipe varied in height according to the pressure of the steam employed in the boiler, allowing some 34 inches for each pound of pressure above that of the atmosphere. The top of this pipe was terminated by a small cistern, which was supplied with hot water from the hot-water cistern; this cistern was furnished with a valve opening upwards; the spindle was continued and connected by a jointed lever to the lever *d;* this lever vibrated on the centre attached to the side of the cistern; one end of this lever was weighted with a counterpoise, and the other had a rod attached to it, which descended into the interior of the boiler, passing through a stuffing-box, and having attached at its lower end a stone float *e*. The action of this apparatus was as follows. On the water getting too low, the float sunk, pulling with it the end of the lever, raising the counterpoise weight and the valve *d;* this allowed the water to descend the pipe to the boiler. On the level of the water thus rising, the float also rose, and actuating the lever, the valve was let into its seat, thus stopping the flow of water through the pipe. The safety-valve *b b*, instead of being open as in the old engines, was confined in a box, through the cover of which the spindle of the valve worked in a stuffing-box, and the steam which escaped was led by a pipe to the chimney-flue. Another safety-valve was also attached, as at *f*, and was termed "the internal safety-valve:" its office was to admit air to the interior of the boiler, when by any means a vacuum was formed in it by the condensation of the steam: to effect this, the valve opened inwards. The gauge-cocks *h h* were used to ascertain the state of the water in the boiler. When one was opened, water was forced through it alone, steam through the other: when this happened, the proportion of water in the boiler was accurately adjusted; if, on the other hand, steam rushed through that cock which should have emitted water, the water was deficient, and *vice versa*. Access was had to the interior of the boiler, for the purpose of cleaning it out, &c., through the "man-hole door" *n*: this was covered by a plate, and properly secured. The steam for the engine was conveyed by the pipe *o*. In a future chapter, while describing modern appliances of the steam-engine, we shall describe other arrangements and contrivances which the genius of Watt applied to the perfection of the steam-engine.

We have now brought the history of the steam-engine up to the period when Watt ceased making his improvements on it. Such was the perfection of his contrivances and the nicety of his details, that he left little to be done towards its improvement by other hands. On this point a recent writer, an engineer of note, has the following: "However far we may proceed in the path of steam-improvement, we shall find unequivocal traces of his having been there before; and the conceptions which start up in our minds, and which at first sight we believe to be original and important, we shall find, on inquiry, to have previously suggested themselves to his imagination. The fact appears to be, that the track of knowledge chosen by him has been so thoroughly explored, that he has left nothing for his successors to discover; and we do not at present see how any material improvement can now take place in steam-engines, except by the introduction of new powers of nature which the progress of discovery may reveal. The machine may perhaps be thrown into still more commodious forms, and greater niceties of workmanship may be lavished upon its construction; but every thing is to be got, by Watt's principle of action, that mere fire and water can give; and the next step of improvement must be the employment of cheaper agencies. And though the present steam-engine may pass away, as it no doubt will, and cease to have any existence except in the page of history, Watt's glory will suffer no obscuration, but in the lapse of years must rise to a wider and brighter effulgence. However excellent or extraordinary the new mechanism may be, it will, we believe we may predict, rather be compounded of the ideas of a multitude of minds than be the product of a single master-spirit; and ages must elapse before another such example of intellectual strength as Watt presented can be given to the world."

To this generous tribute paid to the memory and the genius of Watt, we must add another, emanating from the most practical and celebrated of our modern engineers, himself a bright example of what genius aided by perseverance can accomplish—William Fairbairn of Manchester. "The innumerable attempts that have been made to improve the principle of the condensing steam-engine since the days of its celebrated inventor Watt, have nearly all proved failures, and have added little, if any thing, to the claims next to perfection of that great man's ideas. It would be idle to speculate upon the various forms and constructions, from that time to the present, which have been brought forward in aid of the original discovery of condensation in a separate vessel. All that has been done is neither more nor less than a confirmation of the sound views and enlarged conceptions of the talented author of a machine which has effected more revolution and greater changes in the social system than probably all the victories and all the conquests that have been achieved since the first dawn of science upon civilised life. It would be useless to trace the history of the successful and the unsuccessful attempts at improvement which, for the last half-century, have presented themselves for public approval; suffice it to observe, that no improvement has been made upon the simple principle of the steam-engine as left by Watt, and but few upon its mechanism. In the construction of the parallel motion, the application of the crank, the governor, and the sun-and-planet motions, all of which have risen spontaneously from the mind of Watt, there is no improvement. The principles upon which all of them are founded have been repeatedly verified beyond the possibility of doubt; and their mechanism is at once so exceedingly simple and so ingeniously contrived, as to limit every attempt at improvement in these parts of the steam-engine. What appears to be the most extraordinary part of Mr. Watt's engine is, its perfect simplicity, and the little he has left to be accomplished by his successors."

We now hasten to conclude our notice of Watt. After the expiry of the period which parliament had granted him to monopolise the profits of the steam-engine, Watt retired from the firm; and leaving the management of the business to his son and the son of Bolton, retired from "that establishment which his genius had matured, and to which it had given a celebrity as wide as the boundaries of civilisation, to the enjoyment of the fortune which he had accumulated from the meritorious and well-directed exertions of a life distinguished for its activity and usefulness. The patent expired in 1800; and in the house which he occupied while at Soho, he resided till his death, which event occurred on the 23d of August, 1819. He had suffered some inconvenience through the summer, but was not seriously indisposed till within a few weeks of his death. He then became perfectly aware of the event which was approaching; and, with his usual tranquillity and benevolence of nature, seemed only anxious to point out to the friends around him the many sources of consolation which were afforded by the circumstances under which it was about to take place. He expressed his sincere gratitude to Providence for the length of days with which he had been blessed, and his exemption from most of the infirmities of age; as well as for the calm and cheerful evening of life that he had been permitted to enjoy, after the honourable labours of the day had been concluded. And thus, full of years and honour, in all calmness and tranquillity, he yielded up his soul without a pang or a struggle, and passed from the bosom of his family to that of his God." We conclude this portion of our treatise by giving the celebrated *éloge* pronounced on Watt as an inventor by M. Arago, the well-known French philosopher; also his character as a man by Lord Jeffrey.

"Gentlemen,—This creator of six or eight millions of workmen—of workmen indefatigable and industrious, among whom the arm of authority is never called upon to interpose for the suppression of revolt; this man, who, by his brilliant inventions, conferred upon England the means of sustaining itself during a political convulsion where its very existence as a nation was endangered; this modern Archimedes, this benefactor of the whole human race, whose memory future generations will eternally bless,—what was done to heap honour upon this man? The peerage is in England the first of dignities, the highest of national rewards. You will naturally suppose that Mr. Watt was at least elevated to the highest rank in the peerage. Such a thing was never even thought of. . . . Futurity will behold Watt appear before the grand jury of the inhabitants of the two hemispheres: they will see him penetrating, with the aid of his mighty machine, into the bowels of the earth, in the short period of a few weeks, to depths where, before his time, it would have required a century of painful labour to arrive; and there opening up spacious galleries and mines, clearing them in a few minutes of the immense volumes of water that encumber them, and snatching from virgin earth the boundless mineral wealth deposited there by bountiful nature. Uniting delicacy with power, he will be seen twisting with equal success the immense folds of the gigantic cable, by which the ship of the line embraces in safety her anchor in the midst of the tumultuous tossing waves; and the microscopic filaments of the delicate muslins and the aërial lace which float on the zephyrs of fashion. A few oscillations of the same machine will bring into culture extensive swamps; and fertile countries will be rescued from the periodic and deadly miasmata raised up by the burning heats of a summer sun. . . . Population, well fed, well clothed, well warmed, increasing with rapidity, is fast covering with elegant mansions the surface of countries formerly the deserts of the world, and which eternal barrenness appeared to condemn to the dominion of beasts of prey. In a few years, what are now but hamlets will become important cities; in a few years, towns such as Birmingham—where already one reckons three hundred streets—will take rank as the largest, most beautiful, and wealthiest cities of a powerful kingdom. Transferred to our ships, the steam-engine will replace a hundred-fold the power of triple and quadruple ranks of rowers, from whom our forefathers exacted a labour reckoned among the severest punishments of the most atrocious criminals. The steam-engine, in conclusion, drawing in its train thousands of travellers, will traverse the railway with far greater velocity than the best race-horse loaded only with his pigmy jockey.

"There, gentlemen, is a rapid sketch of the legacy of benefits conferred on the world by that machine which the ingenuity of Watt carried to such admirable perfection. We are accustomed to quote the 'Augustan age,' the time of Louis the Fourteenth. Noble spirits have already arisen, who have thought it just to speak of the age of Voltaire, of Rousseau, of Montesquieu. For my part, I pronounce without hesitation, that when to the immense services which the steam-engine has already achieved, there shall be added all the marvels it promises for the future, a grateful world will also cite the ages of Papin and of Watt."

The following is Lord Jeffrey's admirable sketch of the character of Watt. From this will be seen that the greatness of Watt as an engineer proceeded from the fact, that he was not merely an engineer, but did not disdain to take what would be called by a mere mechanic discursive flights into the regions of general science, gathering therefrom that strength of mind and that energy of imagination which enabled him to go so far beyond the beaten path of the mere mechanical improver. "Independently," says Lord Jeffrey, "of his great attainments in mechanics, Mr. Watt was an extraordinary, and in some respects a wonderful man. Perhaps no individual in his age possessed so much and so varied information, had read so much, or remembered what he read so accurately and well. He had infinite quickness of apprehension, a prodigious memory, and a certain rectifying and methodising power of understanding, which extracted something precious out of all that was presented to it. His stores of miscellaneous knowledge were immense, and yet less astonishing than the command he had at all times over them. It seemed as if every subject that was casually started in conversation with him, had been that which he had been last occupied in studying and exhausting; such was the copiousness, the precision, and the admirable clearness of the information which he poured out upon it, without effort or hesitation. Nor was this promptitude and compass of knowledge confined in any degree to the studies connected with his ordinary pursuits. That he should have been minutely and extensively skilled in chemistry and the arts, and in most branches of physical science, might, perhaps, have been conjectured; but it could not have been inferred from his usual occupations, and probably is not generally known, that he was curiously learned in many branches of antiquity, metaphysics, medicine, etymology, and perfectly at home in all the details of architecture, music, and law. He was well acquainted too with most of the modern languages, and familiar with their most recent literature. Nor was it at all extraordinary to hear the great mechanician and engineer detailing and expounding for hours together the metaphysical theories of the German logicians, or criticising the measures or the matter of German poetry.

"It is needless to say that, with those vast resources, his conversation was at all times rich and instructive in no ordinary degree; but was, if possible, still more pleasing than wise, and had all the charms of familiarity with all the substantial treasures of knowledge. No man could be more social in his spirit, less assuming or fastidious in his manner, or more kind and indulgent towards all who approached him. He rather liked to talk, at least in his latter years; but though he took a considerable share in the conversation, he rarely suggested the topics on which it was to turn, but readily and quietly took up whatever was presented by those around him, and astonished the idle and barren propounders of an ordinary theme by the treasures which he drew from the mine they had unconsciously opened. He generally seemed, indeed, to have no choice or predilection for one subject of discourse rather than another, but allowed his mind, like a great encyclopædia, to be opened at any letter his associates might choose to turn up, and only endeavoured to select from his inexhaustible stores what might be best adapted to the taste of his present hearers. As to their capacity, he gave himself no trouble; and, indeed, such was his singular talent for making all things plain, clear, and intelligible, that scarcely any one could be aware of such a deficiency in his presence. His talk too, though overflowing with information, had no resemblance to lecturing or solemn discoursing; but, on the contrary, was full of colloquial spirit and pleasantry. He had a certain quiet and grave manner, which ran through most of his conversation; and a vein of temperate jocularity, which gave infinite zest and effect to the condensed and inexhaustible information which formed its main staple and characteristic. There was a little air of affected testiness too, and a tone of pretended rebuke and contradiction with which he used to address his younger friends, that was always felt by them as an endearing mark of his kindness and familiarity, and prized accordingly beyond all the solemn compliments that ever proceeded from the lips of authority. His voice was deep and powerful, though he commonly spoke in a low and somewhat monotonous tone, which harmonised admirably with the weight and brevity of his observations, and set off to the greatest advantage the pleasant anecdote, which he delivered with the same grave brow, and the same calm smile playing soberly on his lips. There was nothing of effort indeed, or impatience, any more than of pride or levity, in his demeanour; and there was a finer expression of reposing strength and mild self-possession in his manner, than we ever recollect to have met with in any other person. He had in his character the utmost abhorrence for all sorts of forwardness, parade, and pretension; and, indeed, never failed to put all such impostures out of countenance, by the manly plainness and honest intrepidity of his language and deportment.

"In his temper and dispositions he was not only kind and affectionate, but generous and considerate of the feelings of all around him; and gave the most liberal assistance and encouragement to all young persons who showed any indications of talent, or applied to him for patronage or advice. His health, which was delicate from his youth upwards, seemed to become firmer as he advanced in years; and he preserved up almost to the last moment of his existence, not only the full command of his extraordinary intellect, but all the alacrity of spirit and the social gaiety which had illumined his happiest days. His friends in this part of the country never saw him more full of intellectual vigour and colloquial animation,—never more delightful or more instructive,—than in his last visit to Scotland in autumn 1817. Indeed, it was after that he applied himself, with all the ardour of early life, to the invention of a machine for mechanically copying all sorts of sculpture and statuary; and distributed among his friends some of his earliest performances, as the productions of 'a young artist just entering on his eighty-third year!'"

The discoveries of Watt, and the ingenious arrangements which he introduced, gave a great impulse to the inventive talent of others. The pecuniary advantages attendant upon the successful introduction of a steam-engine were too obvious not to act powerfully as an inducement for practical mechanics, as well as scientific men, to turn their attention to the subject. We propose, under the present division of our work, to describe a few of the more important of these inventions. The first we notice is that of Hornblower, the first who introduced into practice the "double-cylinder engines," modifications of which principle are now so largely adopted. The patent was taken out in 1781; but in 1779 Dr. Falck described a method by which he proposed to double the effect of steam by the use of two cylinders, taking advantage of its expansion. He employed two cylinders, the steam-communication from the boiler being common to both: in rushing into one cylinder, it was prevented from doing so into the other; and after depressing the piston of the first cylinder, it was admitted into the other, on the piston of which it operated in like manner.

Mr. Jonathan Hornblower, previous to the introduction of Watt's steam-engine to the Cornish districts, had been generally employed in the construction of engines on the old principle for the Cornish adventurers; it was therefore a matter of great importance to him, to be able to retain his business there. He therefore made strenuous efforts to oppose the introduction of Watt's engine to a field which he looked upon as exclusively his own; and with this view, he took out a patent for his double-cylinder expansive engine in 1781, which is said to have been invented so early as 1776. A description of this engine was given by Hornblower in the *Encyclopædia Britannica*, which pretty clearly explains its principle. The following diagram and explanation is derived from this.

In fig. 32, A B are two cylinders, of which A is the larger; the piston-rods are connected with the beam, as in Watt's single-acting engine; a square pipe G supplied the steam to the cylinder B; the eduction-pipe lead-

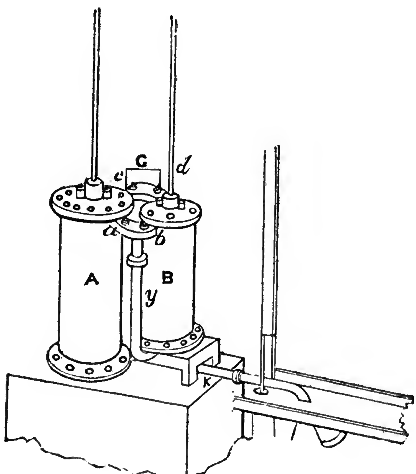

fig. 32.

ing to the condenser is shown at K, which was formed of a conical shape; this was connected with rod-pumps for extracting the air and water; water was admitted to the condenser by a valve placed at the bottom, and a pipe was connected with it leading upwards, and furnished with a blow or snifting valve. The square pipe G branched off to both cylinders, and was furnished with two cocks *c d;* on the other side of the cylinders another square pipe is also placed, having in like manner two cocks *a b;* the vertical pipe *y* establishes a communication between the upper and lower parts of the cylinder B by opening the cock *b*. All these valves or cocks are actuated by the plug-frame attached to the great beam, in somewhat the same way as in Watt's engine; a pipe similar to *y* is placed on the other side of the cylinders, communicating with the valve *d*. "When the cocks *c* and *a* are open, and the cocks *b* and *d* are shut, the steam from the boiler has free admission into the upper part of the small cylinder B, and the steam from the lower part of B has free admission into the upper part of the great cylinder A; but the upper part of such cylinder has no communication with its lower part. . . . . Suppose all the cocks open, and no condensation going on (in the condenser), the steam must drive out all the air, and at last follow it through the snifting-valve. Now shut the cocks *b* and *d*, and open the escape-valve of the condenser, the condensation will immediately commence, and draw off the steam from the lower part of the great cylinder. There is now no pressure on the under side of the piston of the great cylinder A, and it immediately descends. The communication *y* between the lower part of the cylinder B and the upper part of the great cylinder A being open, the steam will go from the lower part of B into the space left by the descent of the piston A. It must therefore expand, and its elasticity must diminish, and will no longer balance the pressure of the steam coming from the boiler and pressing above the piston of B. This piston, therefore, if not withheld by the beam, would descend till it came in equilibrio, from having steam of equal density above and below it. But it cannot descend so fast, for the cylinder A is larger than B, and the arch of the beams, at which the piston is suspended, is no longer than the arm which supports the piston of B; therefore, when the piston of B has descended as far as the beam will permit it, the steam between the two pistons occupies a larger space than it will when both pistons were at the top of their cylinders, and its density diminishes as its bulk increases. The steam beneath the small piston is therefore not a balance for the steam on the upper side of the same; and the piston B will act to depress the beam with all the difference of these pressures. The slightest view of the subject must show, that as the piston descends, the steam that is between them will grow continually rarer and less elastic, and that both pistons will draw the beam downwards. Suppose, now, that each one had reached the bottom of its cylinder, shut the cock *a* and the eduction-valve at the bottom of A, and open the cocks *b* and *d*. The communication being now established between the upper and lower part of each cylinder, their pistons will be pressed equally on the upper and lower surfaces; in this situation, therefore, nothing hinders the counterweight from raising the pistons to the top. Suppose them arrived at the top; the cylinder B is at this time filled with steam of the ordinary density, and the cylinder A with an equal absolute quantity of steam, but expanded into a larger space. Shut the cocks *b* and *d*, and open the cock *a* and the eduction-valve at the bottom of A; the condensation will again operate, and cause the pistons to descend; and then the operation may be repeated as long as the steam is supplied; and one measure-full of the cylinder B of ordinary steam is expended during each stroke." A glance at this invention will show the close similarity existing between it and the arrangements of Watt's engines: "the condenser and air-pump, the cylinder-covers with their stuffing-boxes, and indeed every thing good about the engine, is evidently borrowed from Mr. Watt, with the single exception of the two cylinders; and by them nothing was accomplished that had not been already attained by Mr. Watt quite as effectually with a single cylinder only." Although Hornblower claimed for his engine a superiority in an economical point of view, giving it a power equal to sixteen with the same quantity of coal which in Watt's only gave ten, still his practice did not bear out this assumption: Professor Robinson, by a series of elaborate calculations, made it evident that the same effect was produced in this as in Watt's expansion engine; which were borne out by the practice of Hornblower himself. From having adopted the principle of the separate condenser, this engine was an infringement of Watt's patent; proceedings were therefore taken, some years after the introduction of Hornblower's patent, against several parties who had used it. At the expiration of Hornblower's patent, he applied to parliament for a renewal of his privileges, without, however, being successful.

In fig. 33 we give a drawing of a very ingenious form of steam-engine, known as Dr. Cartwright's, in which there are several points worthy of notice. In fig. 33, *a a* is the cylinder, *b b* the piston; the piston-rod is continued downwards to work the piston of a small pump, which withdraws the water of condensation from the condenser *d*, forcing it up the pipe *e* to the hot-water well *g g*; a float-ball is placed within this cistern, which acts upon the lever closing and opening the valve on the top of the well to admit the atmosphere; this cistern, acting as an air-vessel, sends the water in a

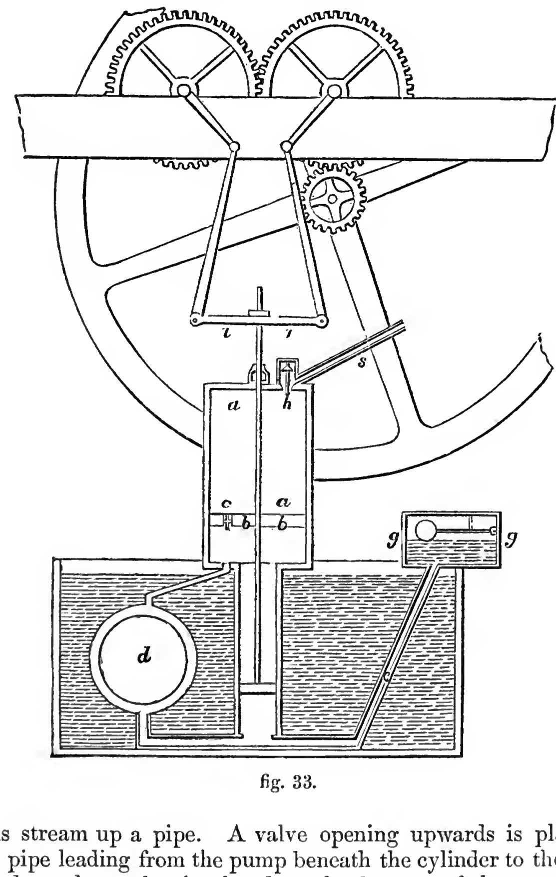

fig. 33.

continuous stream up a pipe. A valve opening upwards is placed at the top of the pipe leading from the pump beneath the cylinder to the hot-water cistern, and another valve is placed at the bottom of the pump, opening upwards; a pipe communicates with the interior of the cylinder at bottom, and is led to the condenser *d*, into the space formed by the two concentric circular vessels, the outsides of which are kept cold by being immersed in the cold water contained in the cistern. Steam is admitted to the upper side of the piston by the pipe *s* through the valve *h*; the spindle of this valve is continued for a short distance on both sides, the upper end passing through a stuffing-box in the valve-case; a valve *c* is placed in the piston, opening upwards; the piston-rod passes through a stuffing-box in the cylinder-cover; and by a cross-head, levers, and wheels, the reciprocating motion of the piston-rod is changed to the circular motion of the fly-wheel. For a description of this movement see *Mechanics and Mechanism*, p. 80, fig. 153.

The following is a description of the movement of this engine. On the piston being placed at the top of the cylinder, the piston strikes the tail or lower end of the spindle of the valve *h*, raising it out of its seat; this allows the steam to pass to the cylinder, pressing down the piston; the valve *c* in the piston is at the same time closed by its upper end striking against the cylinder-cover; on the piston reaching the bottom of the cylinder, the valve *h* is pressed into its seat by the cross-head *i i* striking its spindle, and the valve in the piston is opened by its lower end striking against the cylinder-bottom; the steam above the piston rushes through this valve, and pressing into the space between the vessels forming the condenser, the condensation is effected, and a vacuum formed above the piston; the momentum which the fly-wheel has derived from the downward stroke of the piston carries the piston upwards through the vacuum; the valve *h* is then opened, and *c* closed as before, and another down-stroke is made. Simultaneously with the descent of the piston in the cylinder, the piston of the pump is forced down; this closes the valve at bottom, and forces the water contained in the barrel of the pump beneath the piston up the pipe *e*, opening the valve and passing into the cistern; on the great piston rising, the pump-piston also rises, raising at the same time the valve, and drawing up the condensed water from the condenser. Several engines of this description were erected, and worked satisfactorily. In this engine, the whole of the parts of the piston were metallic. In a future chapter we propose to describe the construction of this form of piston. In this form of engine, the air which was pumped out of the condenser along with the condensed water was passed to the hot-water cistern; on its accumulating to a great degree, it depressed the surface of the water, the float sunk along with it, and the valve in the top of the box being opened, a portion of the air escaped.

In 1804 Arthur Woolfe, of Cambourne in Cornwall, obtained a patent for an improved steam-engine, in which advantage was taken of the expansive properties of steam. He employed steam of considerable pressure to work the piston of a small cylinder; and on its escaping from this, it was applied to the piston of a cylinder much larger in size, and which communicated with a condenser. The properties of steam on which this engine was founded, and the truth of which Woolfe thought he had established, were as follow :

Previous to his experiments being instituted, a fact had been asserted relative to the expansive property of steam, that with the expansive force of four pounds to the inch, steam was capable of expanding into a space four times its volume, and yet be equal thereafter to the pressure of the atmosphere. His experiments led him to infer, that steam of five pounds to the inch would expand into five times its volume; and that with steam of 6, 10, 20 lbs. to the inch, would expand into 6, 10, 20 times its bulk, and still have a pressure equal to the atmosphere, without any additional supply of heat. On this supposed discovery of the expansive property of steam, he proportioned his cylinders: if he adopted steam of six pounds to the inch, his large cylinder was six times the volume of the small one. Experience, however, soon showed the fallacy of this opinion; indeed, Woolfe himself was the first to become aware of it, and in his after-practice he adopted different proportions. The principle, however, of his engine is still in vogue with many of our engineers of high standing, and is being carried out in numerous instances, and with great success; it being beyond a doubt, that, by judicious arrangements, it is calculated to become an economical method of working.

We have now to notice the principle of "*the high-pressure steam-engine*," and a few historical points connected with it. The distinction between low-pressure and condensing engines, and high-pressure and non-condensing engines, is simple enough, and easily remembered. In the former, the steam, after working the engine, is passed into the condenser, and a vacuum being formed on one side of the piston, it is sucked down as it were, and by this means a considerable degree of power is obtained; in the latter, the steam, after working the piston, is passed at once to the atmosphere. An eminent authority thus distinguishes between the two, and draws a comparison between them: "All locomotive engines are of the high-pressure variety; and generally all engines are made on the high-pressure plan where the carriage of condensing water would be inconvenient, as the first cost of the machine becomes a point of more importance than an increased consumption of fuel. High-pressure engines are, *cæteris paribus*, necessarily more expensive in fuel than low-pressure engines, as they occasion the loss of the power derivable from a vacuum; and as the quantity of heat in the same *weight* of steam is nearly the same at all pressures, there is no counteracting source of economy to compensate for this deduction. The use of high-pressure engines in circumstances in which the low-pressure engine is applicable, is not to be commended; and the high-pressure engine is rarely employed for other purposes than locomotion on railways, except in the case of very small engines required for some temporary or trivial purposes. . . . . Where high-pressure steam is employed, it is expedient to make the pressure considerable, as the deduction to be made for the pressure of the atmosphere is less in proportion with a high than with a moderate pressure. Some locomotive engines are worked as high as 90 lbs. to the square inch." Notwithstanding the objections urged against the use of high-pressure engines, they are adopted in great numbers, and for an almost infinite variety of purposes in connexion with our arts and manufactures. Although with steam of high-pressure considerable danger exists in the liability to explosion of the boilers, still, from the general simplicity of detail, and the consequent cheapness in construction, and their extreme portability, we need not wonder at the extensive demand which is made for them.

The merit of the introduction of the first high-pressure steam-engine belongs to Leupold, a native of Plunitz, near Zwickau. He described it in his celebrated work entitled *Theatrum Machinarum Hydraulicārum*, published in 1727. With a modesty which formed not the least striking characteristic of this amiable man, he attributed the invention to Papin, because this individual furnished the idea of using the expansive force of steam to raise water, and from his having taken the four-way cock which Papin used in his air-engine. The engine as constructed by Leupold is remarkable for the simplicity of its details; a diagram showing the method of its operation is given in fig. 34: where *aa* is part of the boiler, on which a four-way cock *b* is placed; *c* and *d* are two pipes communicating with the bottom of the two cylinders, in which the pistons *e* and *f* work; these are placed alternately,—that is, when the piston *f* is at the top, *e* is at the bottom; they are both loaded with lead, to act as counterpoises, and bring down the ends of the beams *g* and *h* to which they are attached; the other ends of these beams have pump-rods attached. Supposing the piston *f* at the top of the cylinder, the four-way cock is turned one quarter round; this opens a communication between the cylinder in which *f* works

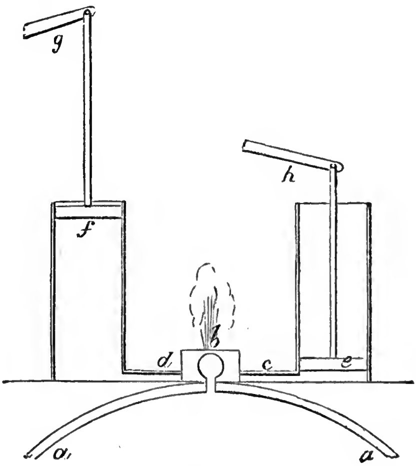

fig. 34.

and the open air, and between the boiler and the cylinder in which *e* works; the steam in *f* passing into the air, the pressure on the piston is relieved, and it descends; the steam, however, acting on the piston of the cylinder *e*, presses it to the top: there have been thus two strokes of the pump-rods, one up by the cylinder piston *f*, the other down by *e*. On *f* reaching the bottom of its cylinder, and *e* the top, the four-way cock is turned back again a fourth; the communication between the interior of cylinder *e* and the atmosphere is thus opened, and between the boiler and cylinder *f*; a down stroke of *e* is thus made, and an up one of *f*; and so on alternately.

By an inspection of the specification of Watt's steam-engine, already given, it will be seen that he contemplated the use of high-pressure steam; he, however, had a decided objection to its use, and consequently did not further prosecute his ideas. In 1802, Messrs. Trevethick and Vivian, of Cambourne in Cornwall, took out a patent for a high-pressure engine, which was used to propel a carriage or wagon: the arrangements of this engine are particularly ingenious, and some of the details modified, form features in many of the modern high-pressure engines. In fig. 35, the boiler *a a* is of a circular form, to resist the high pressure of the steam; to prevent the loss of heat by radiation, it is enclosed in a case filled with clay; the lower part of the case forms the fire-place, and the flame and heated air circulates round the boiler at its upper part, finally issuing into the chimney; *c* the cylinder, the lower part of which is within the boiler; *d* the piston; *g* the piston-rod, passing through a stuffing-box in the cylinder-cover, and having a connecting-rod *h* attached to the crank *i*; by this arrangement the fly-wheel revolves. The piston-rod works between guides, as shown in the diagram. A worm or snail wheel *j* in its revolution acts on the small wheel *k*, which is fastened on the end of the lever *l*, furnished with a counterpoise *n*; steam is admitted to the cylinder by the

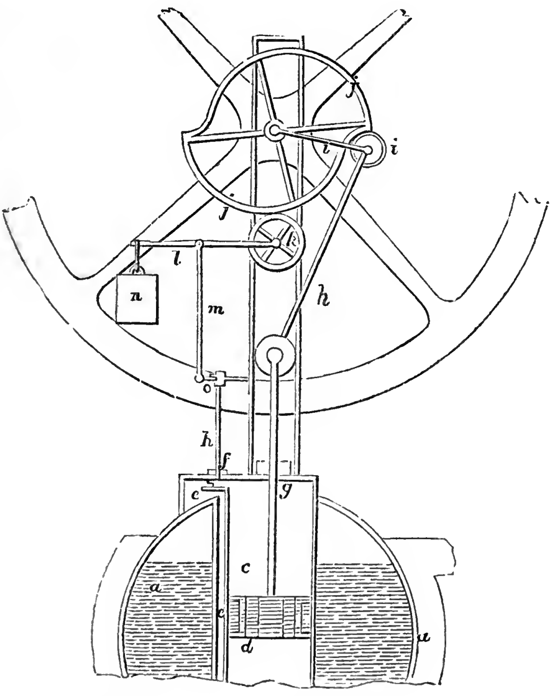

fig. 35.

passage *e* through the valve *f*; by moving this cock or valve a quarter-turn, the steam is admitted either to the upper or under-side of the cylinder. By the falling of the wheel *k*, by the action of the cam or snail-wheel *j*, the lever is depressed and the weight *n* rises; this acts on a lever *m*, and by making its lower end move outwards, pulls the horizontal lever *o* through a part of its radius; and through the medium of the lever or spindle *h* the valve is moved round one quarter. A click or ratchet is placed on the top of the spindle *h*, which, coiling up during the time that the lever *o* is moving outwards, does not move the cock *f*; but when the extremity of the worm-wheel *j* touches the wheel *k*, which will happen when the piston is near the top of its stroke, the wheel *k* goes into the cavity of the cam-

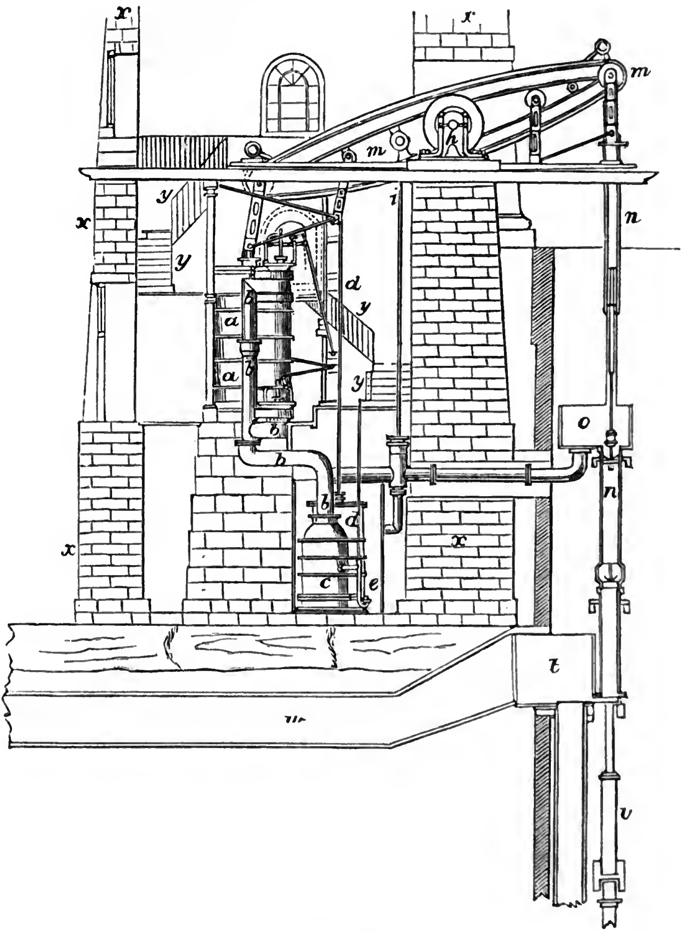

fig. 36.

wheel *j*; and the extremity of *m* returning, the lever *o* turns the cock *f* a quarter round; this admits the steam to the upper-side of the piston, and allows that beneath it to pass into the atmosphere.

We now proceed, as a conclusion to the present division of our work, to present examples of steam-engines in use at the present time; reserving for another division descriptions of the various details of modern engine-work; as boilers, safety-valves, feed-apparatus, cylinder-valves, valve gear-pistons—packed and metallic, &c. &c.

In fig. 36 we give a drawing of a large pumping engine erected at Walbottle Colliery, Northumberland, by the celebrated engineering firm of Messrs. Hawthorn of Newcastle. The principal feature in the arrangement is the economy and simplicity of working the forcing or plunger

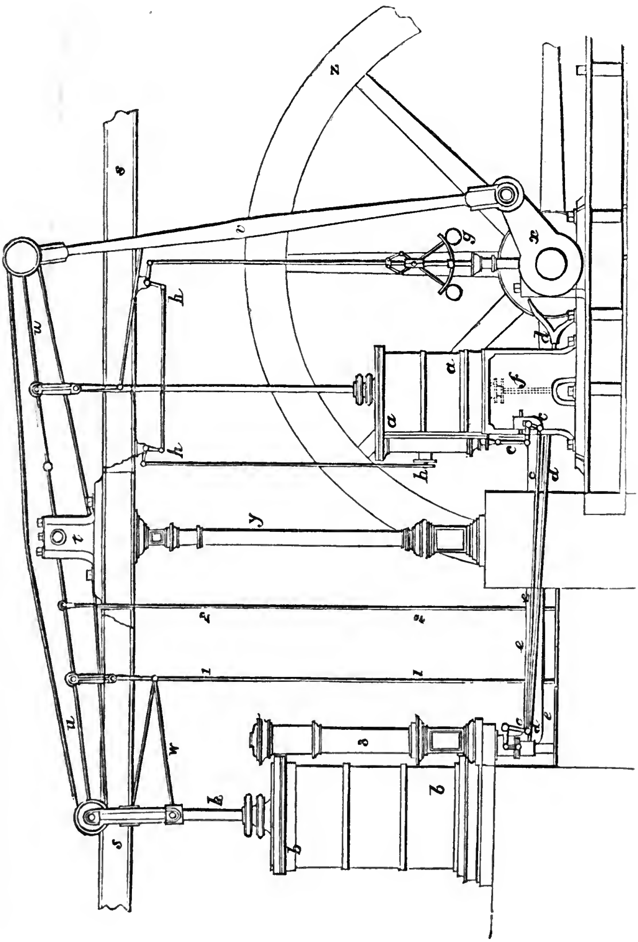

fig. 37.

pump with two lifting-pumps direct from the beam; the engine, being a double-acting condensing one on the expansive principle, there is therefore no counterpoise on the left of the beam, the engine being equally loaded at the in-door and out-door stroke. The dimensions of the engine are as follows: the cylinder *a a* is 77 inches in diameter, stroke 10 feet; the stroke of the beam *m m* $17\frac{1}{2}$ feet and 14 feet—$31\frac{1}{2}$ total: length of stroke of pumps *n n* 8 feet, diameter of the plunger or ram $28\frac{3}{4}$ inches; diameter of lifting-pumps $16\frac{7}{8}$ inches. The pumps deliver from 1100 to 1500 gallons of water per minute, according as the strokes are 5 or 7 per minute; *b b* the valves and steam-pipe leading to condenser *c*; *e* the injection-pipe and handle; *d d* the air-pump and lever; *n* the centre plummet-block, on

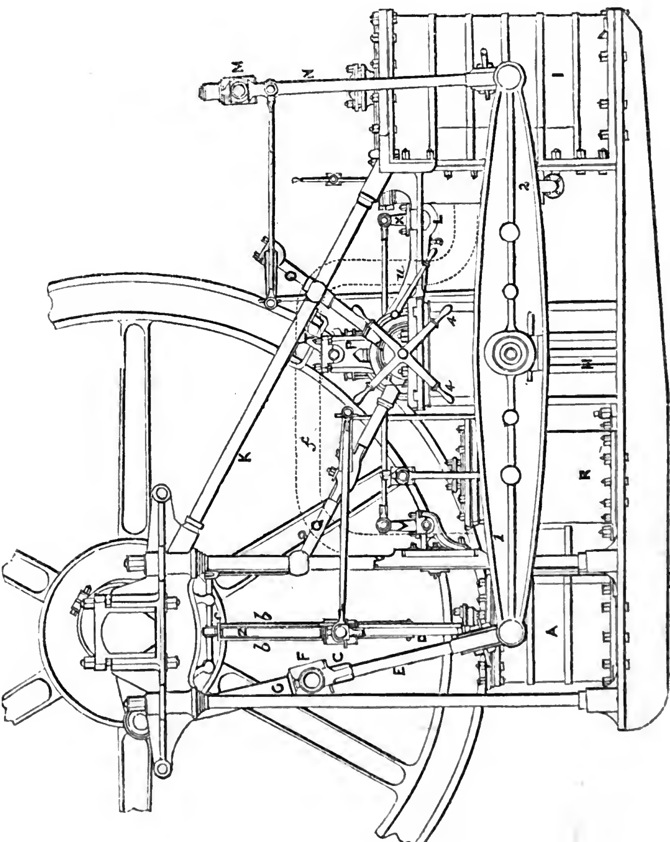

fig. 38.

which the great beam *m m* vibrates; *y y* the stairs for gaining access to the upper-story of the building *x x*. The water is led off to a neighbouring valley by the drift *t w*.

In fig. 37 we give an elevation of a double-acting condensing engine, to which M'Naught's patent has been applied; without the small cylinder *a a* the arrangement of a double-acting condensing engine, as applied to manufacturing purposes, will be easily understood from an inspection of the figure; *s s*, the spring beam, on which the plummet-block *t* is fixed; *u u*, the working beam (or *walking* beam, as it is termed by working engineers); *v*, the connecting-rod for turning the crank and fly-wheel 2 2; *y* the central pillar, *b b* the cylinder, *k* the piston-rod, *w* the parallel motion; 1 1 the air-pump rod, 2 2 the hot-water pump; the valves in valve-casing, *z*, are worked by the eccentric-rod and levers, *d d e*. Where the power of the engine originally fitted-up becomes too small for the increased work to be done, it is increased by the very judicious arrangement as patented by Mr. M'Naught of Glasgow and Manchester, and the principle of which is also shown in the diagram in fig. 37. The steam is admitted at high-pressure to a small cylinder *a a*, fitted on the side of the beam next to the connecting-rod, and the parallel motion of which is attached to the spring beam, in the same way as in the large or original cylinder *b b;* after working the piston of the high-pressure cylinder *a a*, the steam passes by the pipe *e* to the low-pressure cylinder *b b*, from which it finally passes to the condenser. The valves of the high-pressure cylinder are worked by levers *c c*, which are attached to the lever which works the valves of the large cylinder; by this arrangement the valve-gear of both the cylinders is connected; and when that of the low-pressure cylinder is disconnected, by throwing the main eccentric out of gear, both sets of valves are disengaged, and can be worked with the same handle or lever simultaneously. The cold-water pump is proposed to be worked, either by a continuation of the piston-rod of the high-pressure cylinder below the cylinder, as at *f*, or by a cross-head to the piston-rod of *a a*, furnished with side-rods attached to the ends of a cross-bar beneath the cylinder. To

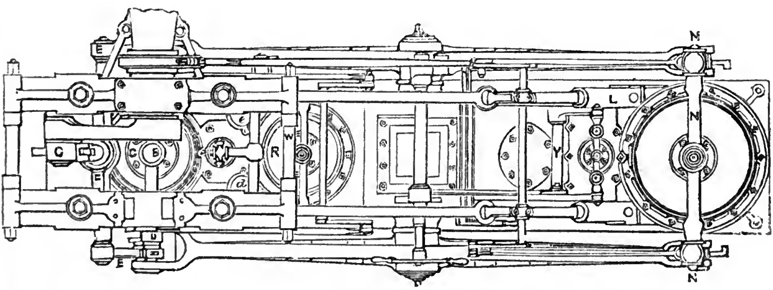

fig. 39.

this bar a pump or pumps may be attached. The steam acts upon the top of one piston and the bottom of another alternately; by this means much of the strain and shock is taken off the central journal of the beam *w w*; and by consequence, from the entablature-pillar and the walls. By this arrangement of double-cylinder engines much fuel is saved, extending in some instances to 40 per cent; increased steadiness of movement is also insured. The arrangement is also adapted to marine-engines, a class of engine which possesses many advantages, making it highly eligible for manufacturing purposes. The diagram in fig. 38 illustrates a form of marine-engine adapted for a factory, to which M'Naught's principle is applied. As this example presents many mechanical movements of interest to the student, we shall append a rather full description of its details. Fig. 38 is the side elevation, and fig. 39 the plan. The high-pressure cylinder A is 22 inches diameter, and 4 feet stroke; it is placed between the four wrought-iron columns supporting the crank-shaft. The system of connections for the crank is on the plan invented by Mr. David Napier.

The *low-pressure* cylinder I, which is worked by the exhaust steam from the cylinder A, is bolted to the sole-plate at the opposite end of the side-levers 1, 2. It is 33 inches diameter and 4 feet stroke. The crank-shaft bearing is stayed by two wrought-iron stays K, cottered into eyes cast on the inner ends of the crank-framing, and attached to the upper

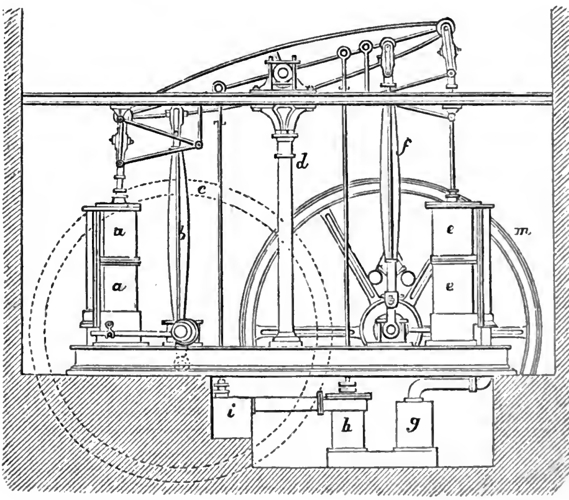

fig. 40.

inner-edge of the cylinder by two eyes cast on the ends of frames L, attached at their extremities to the hot-well and the cylinder. The body of each of the pistons consists of a single hollow casting with four radiating strengthening feathers. The packing is composed of two cast-iron rings, each with two cuts, and actuated by a series of H springs placed between the body of the piston and the interior surface of the rings. The cross-head M is attached to the top of the piston-rod by a central eye in the usual manner, and is adjustable by a nut bearing on the upper-surface of the eye; from the ends of this cross-head the wrought-iron side-rods N N, pass down to the joint-studs in the double eyes of the side-levers, where they are attached in the usual manner (see *Mechanics and Mechanism*). The parallelism of the piston-rod is maintained by the arrangement of radius bars, detailed in the division of this work *Marine Engines*. The parallel motion-shaft of the low-pressure cylinder, I, is carried by a pair of short pillars O O, passing through round eyes forged in the diagonal stays K, and resting at their lower extremities upon the upper-sides of the semicircular portions of the valve rocking-shaft pedestals P. The parallel motion-shaft of the small cylinder is carried by bearings forged on the upper-sides of the diagonal stays Q, which are fitted with round eyes at one end

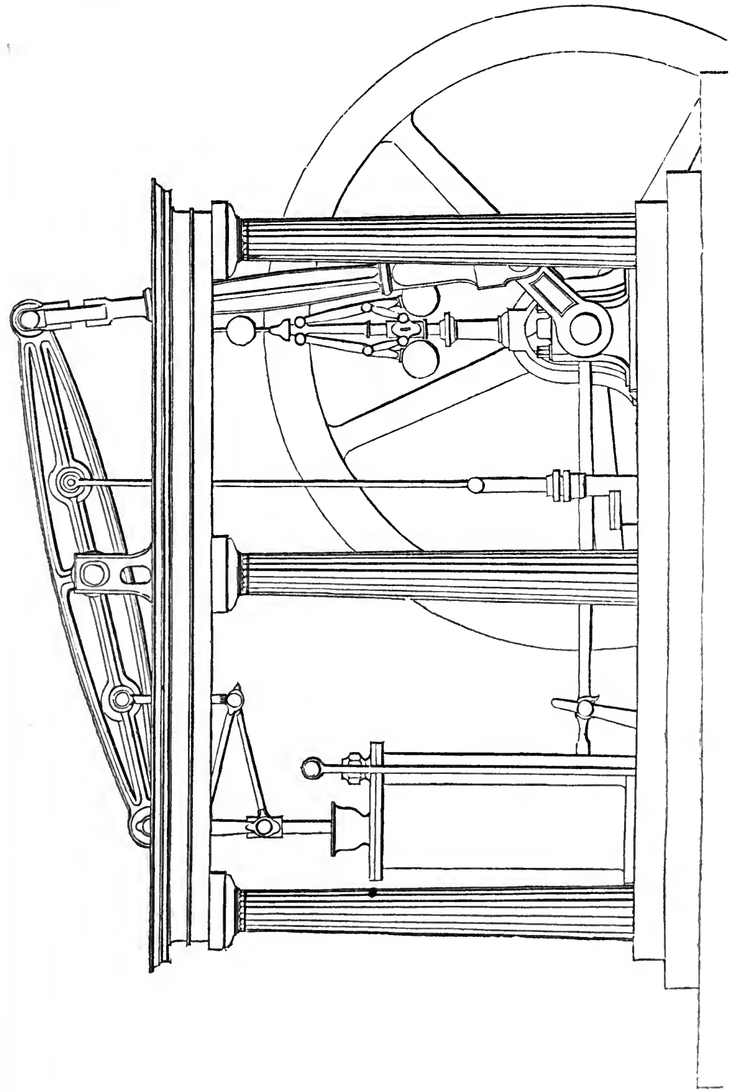

fig. 41.

for passing upon the wrought-iron pillars of the crank-framing, where they are supported by collars; the contrary ends are bolted to the pedestals P, upon which eyes are cast for the purpose. The air-pump R is worked by short side-rods attached to studs on the inner-sides of the side-levers, the cross-head being guided by light wrought-iron guide-rods bolted to the cover of the pump, and passing through eyes purposely formed in the cross-

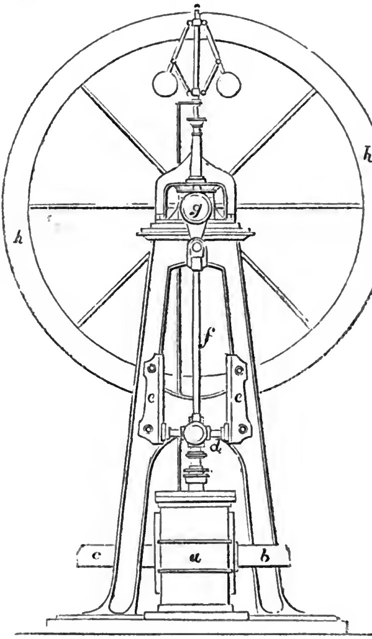

fig. 42.

head; their upper-ends being fixed in the short diagonal stays Q. The condenser is of a rectangular section, and, together with the steam-passage leading from the low-pressure cylinder, is cast in one piece with the sole-plate. An air-vessel is fitted on its top, and on each side is bolted a pedestal P for the rocking-shaft of the valve-motion. The valves are of the usual single-cup species, similar to those used in locomotive engines; they are kept up to the valve-face by slight bent springs attached to the interior of the steam-chests. They are worked by an eccentric on the crank-shaft, the rod of which is fitted with a plain gab and guard at the extremity, for the pin of the rocking-lever T; the detaching apparatus for throwing it out of gear being worked by a hand lever on the end of a transverse shaft passing across the engine. The rocking-lever T is double ended, the eye at the lower end being jointed by a connecting link to a second lever V, placed on the rocking-shaft W, carrying a lever for working the valve of the high-pressure cylinder. The main rocking-shaft passes across the engine from front to back, and carries a short-toothed segment, placed just within the front pedestal. Near the end of this segment is placed a stud-pin, from which a lever-rod passes to the lever X, fast on the rocking-shaft Y; working on bearings in the frames L, and carrying a lever at each end for giving motion to the cross-head of the low-pressure valve-spindle, which is guided by vertical rods, in the same manner as the air-pump bucket. By this arrangement the weight of one

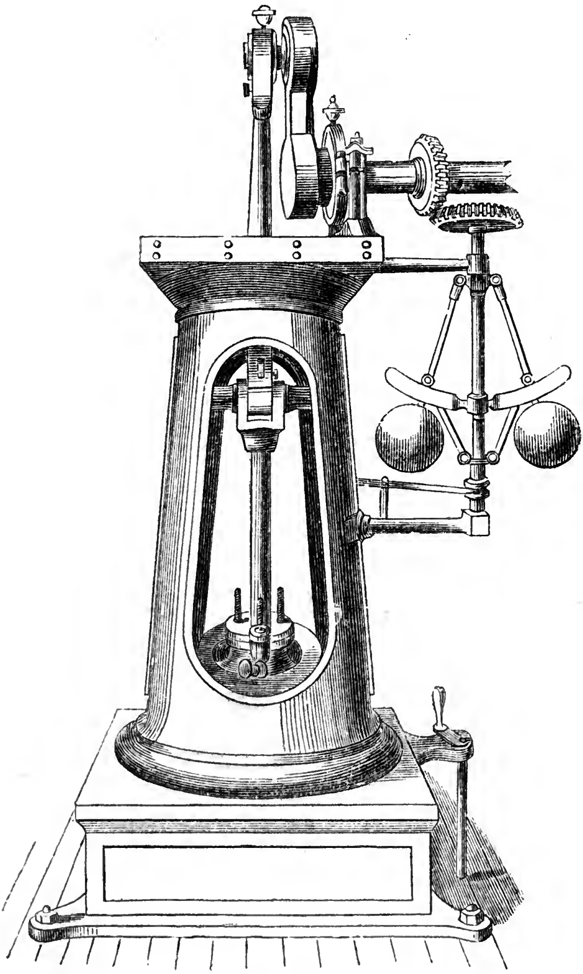

fig. 43.

valve balances the other. The governor is situated behind the high-pressure cylinder, its spindle z being supported in a footstep on the engine-house floor, and steadied at its upper-end by two wrought-iron stays attached to the crank-shaft framing. The sliding-ring worked by the governor levers is jointed to two light links *b b*, passing up to a lever on the shafts *c;* whence, by a series of levers and connecting links, the motion is communicated to the throttle-valve, which is placed in the steam-pipe in front of the valve-chest of the cylinder A. The steam-pipe from the boiler, which is not shown in the drawings, conducts the steam by the thorough-

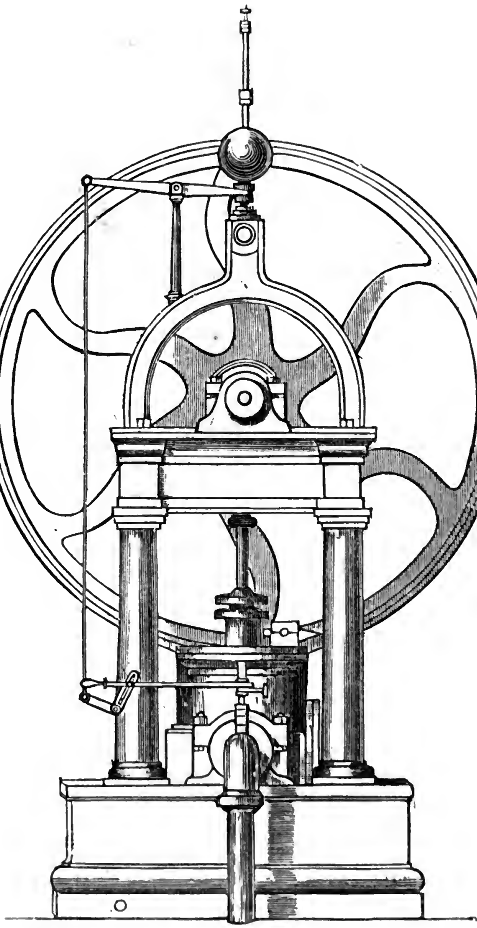

fig. 44.

fare *d*, seen in the ground-plan; a corresponding passage, *c*, conveys the exhaust steam by the dotted copper pipe *f*, to the front of the valve-chest of the low-pressure cylinder.

The hand-gear for the valves consists of a quadruple lever, fast on a short spindle carried in bearings on the top of the condenser; on the inner end of this spindle is a small pinion, working into the toothed segment, previously mentioned as being fixed on the main valve rocking-shaft. By this means, when the eccentric-rod is thrown out of gear with the rocking-lever by handle w, the valves may be worked with great care by the quadruple-lever 4, 4. The engine is bolted down to a foundation of masonry by twelve bolts,—four at the high-pressure cylinder, four at the main centre, and four at the low-pressure cylinder. Two cast-iron beams of the double *z* section, 8 inches wide and 6 deep, are laid along the bottom

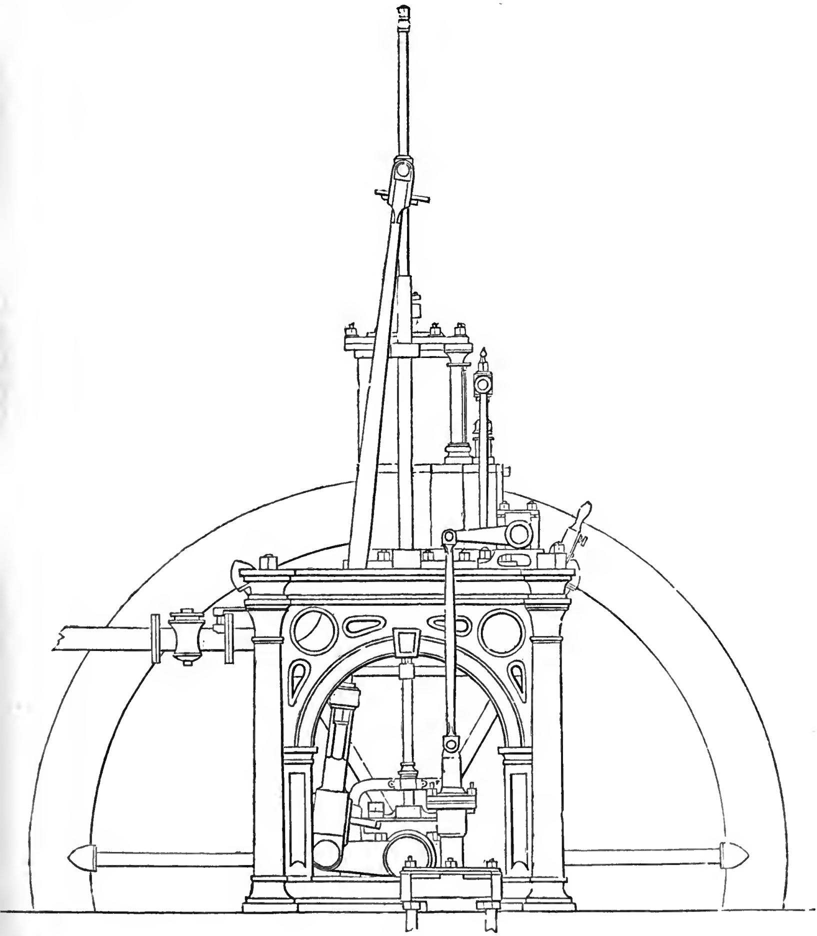

fig. 45.

of the masonry in a longitudinal direction, and through these the holding-down bolts pass; thus binding the whole foundation together, and giving the sole-plates a firm hold. Two transverse beams of similar section are laid in the masonry, above the longitudinal ones, their ends being laid in the bottom of the two side-walls of the engine-house. By adopting this

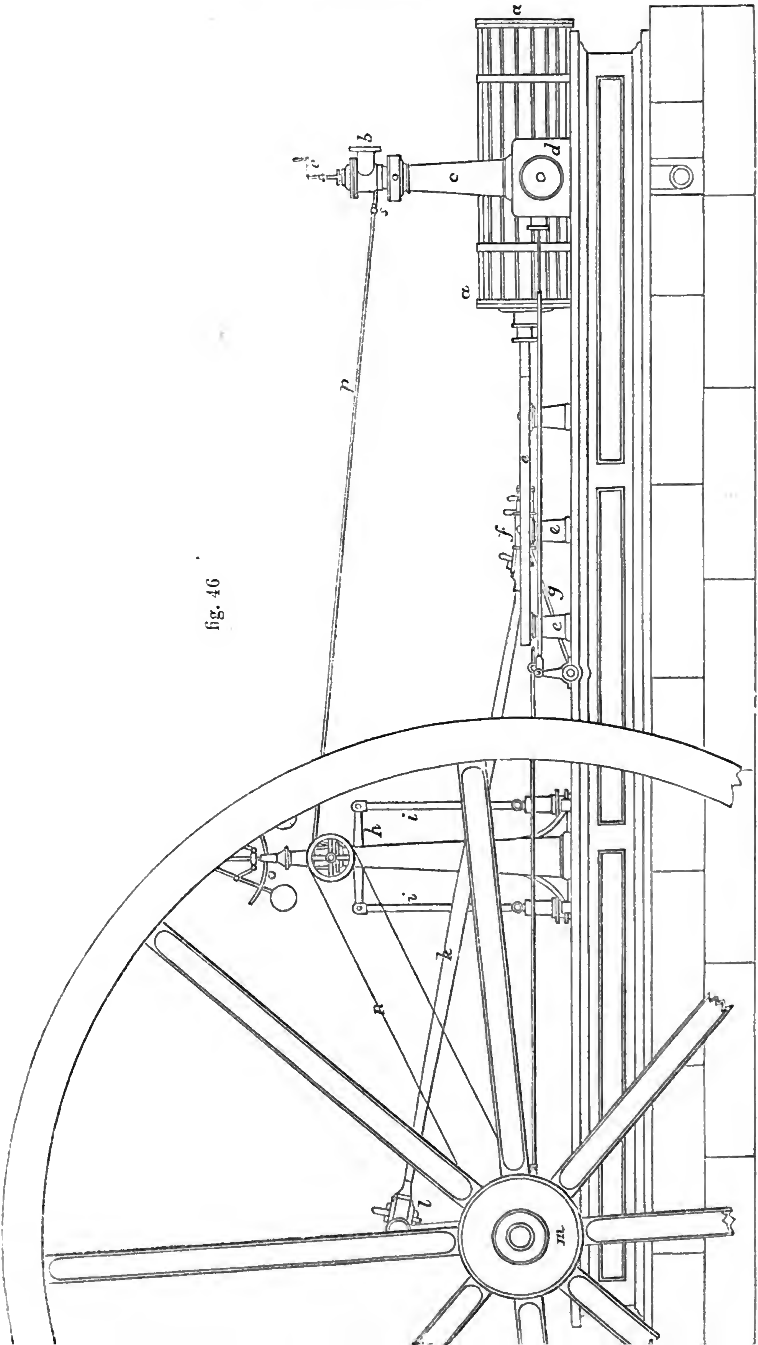

fig. 46

plan a considerable saving in the depth of masonry is effected, and a most substantial base is formed. The action of the engine is precisely similar to the ordinary Woolfe double-cylinder engine; but the relative position of the two cylinders, effects to a very great extent the economy and regu-

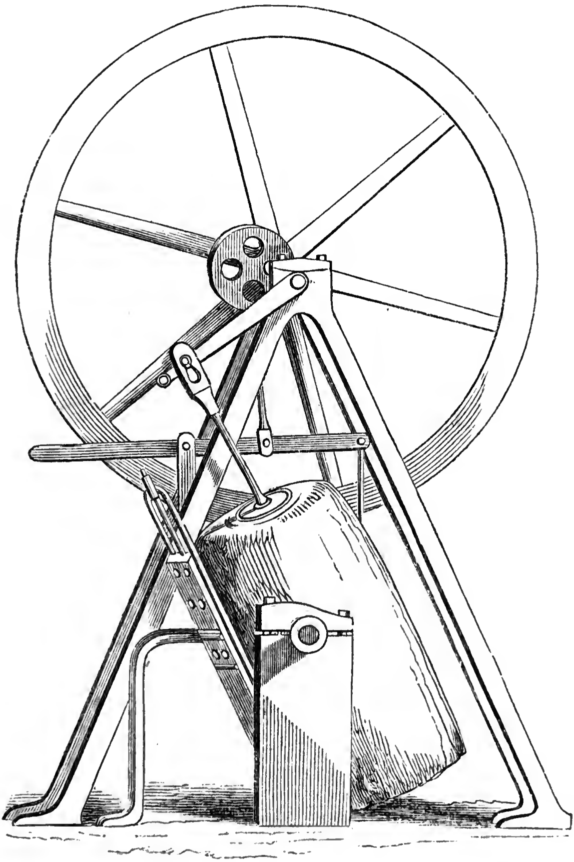

fig. 47.

larity of the expansive action of the steam, which may be here carried out to the utmost extent. The high-pressure steam, acting at one end of the side-levers, is always balanced by that of the low-pressure and the vacuum in the larger cylinder; so that the combined power of the two is conveyed to the crank-pin as if from a direct-acting cylinder. The example we have given is estimated at 60-horse power; but with the full pressure of 35 lbs. it can be worked up to 120. It was manufactured by Messrs. J. and G.

Thompson, of the Clyde Bank Foundry, for the flax-mills at Prinlaws; for the drawings and description we are indebted to the courtesy of the editors of the *Practical Mechanic's Journal*, Messrs. Johnstone.

In fig. 40 we give an illustration of another form of double-cylinder expansive engine, lately introduced by Messrs. Varley: *aa* is the high-pressure cylinder; a connecting-rod *b*, placed between the cylinder and the central pillar *d*, gives motion to the fly-wheel *c*; the eccentric on the shaft moves the valves of the small cylinder; the steam, after working the

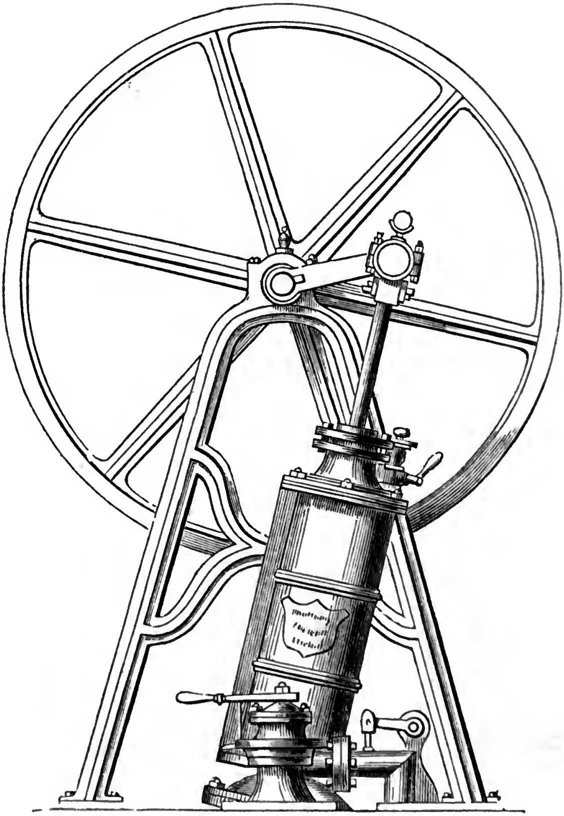

fig. 48.

small cylinder, passes to the low-pressure arc *ee*; a connecting-rod *f* moves the fly-wheel *m*; *g* is the condenser, *z* the air-pump, *i* the hot-water cistern. This engine possesses considerable novelty of arrangement, and is said to offer advantages in working economically. The balance of the moving parts is likely to insure steadiness of movement.

In fig. 41 we give a side elevation of a high-pressure steam-engine of neat design.

In fig. 42 we give an elevation of a high-pressure engine of the kind known as "crank-over-head:" *a* is the cylinder, *c* the supply-pipe from the boiler, *b* the exhaust; the piston-rod is furnished with a cross-head *d*, which slides in the parallel slides *ee; f* the connecting-rod joined to the crank *g*, *hh* the fly-wheel; motion is communicated to the governor spindle from the fly-wheel shaft; the governor acts on a throttle-valve on the pipe *c*; the valves are worked by an eccentric placed in the fly-wheel shaft.

In fig. 43 we give an elevation of Fairbairn's high-pressure crank over-head engine. This is a first-class engine of its kind, the principal peculiarity being that the working parts are placed within a circular casing of great elegance of design.

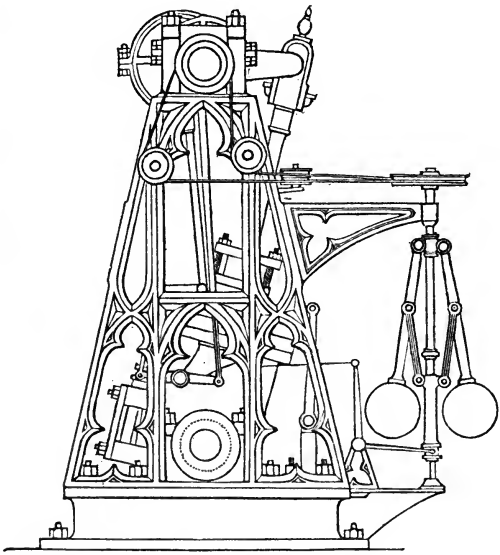

fig. 49.

In fig. 44, which is an elevation of Crosskill's fixed high-pressure steam-engine, we give another example of the crank over-head variety.

In fig. 45 we present an elevation of the form of high-pressure engine known as the "table engine;" in this form the fly-wheel shaft is beneath the table or platform on which the cylinder stands; the shaft is provided with two cranks, side-rods being connected with them, and attached at the upper-ends to the ends of a cross-head fixed on the piston-rod end; the ends of the cross-head move in parallel guides. (See *Mechanics and Mechanism.*)

In fig. 46 we give a side elevation of a horizontal engine, in which the cylinder *a* is placed horizontally; *b c c* the steam-pipe, *d* the valve casing, *e e* the piston-guide, *f* the piston-rod connected with the connecting-rod *k;* the crank is at *l*, fly-wheel at *m;* the governor *o* is moved by the cord *n*, with a small pair of bevil-wheels, *p* the rod for communicating with the throttle-valve at *s;* the pumps *ii* are worked by the oscillating lever *n*, the stud of the lever is lengthened, and a lever is connected with it, which extends downwards, and is moved backwards and forwards by the rod *g*, which is connected to it at its lower end, the rod *g* being connected with the piston-rod stud.

We now present examples of a form of engine in which the parts are much simplified; this variety is termed the "oscillating engine." The cylinder vibrates on an axis either at top or bottom; at top if vibrating in a

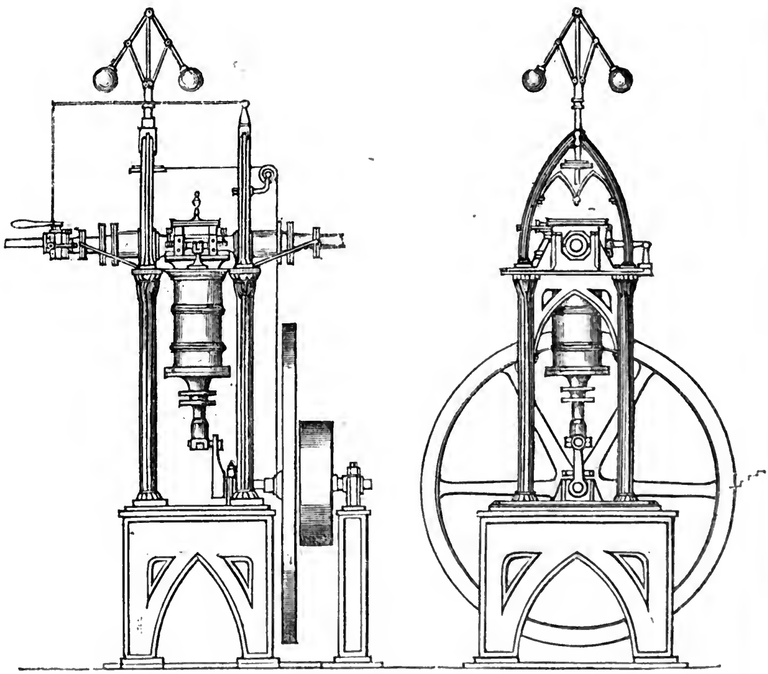

fig. 50.

vertical plane, but at bottom if horizontally; by this arrangement the rectilinear motion of the piston is made to accommodate itself to the circular motion of the crank, the piston-rod stuffing-box moving through the arc of a circle; this enables the piston-rod to be connected at once with the crank, without the intervention of a connecting-rod; thus securing the advantages of direct action. The valves are worked in the ordinary way by eccentrics and levers; but in some examples the action of the cylinder itself is made to open and shut them; thus simplifying the arrangements to a great degree. It is interesting to note that Watt constructed a model of this form of engine. This is shown in fig. 47.

The cylinder in this model, which was exhibited in the Great Exhibition, is cased with wood.

In fig. 48 we give an elevation of an oscillating engine by Evans exhibited in the Crystal Palace; and in fig. 49 another example also exhibited in the same place; it is of very elegant design, in the Gothic style, and is manufactured by Pope and Sons of Greenwich.

In fig. 50 we give two views of a modification of the oscillating engine,

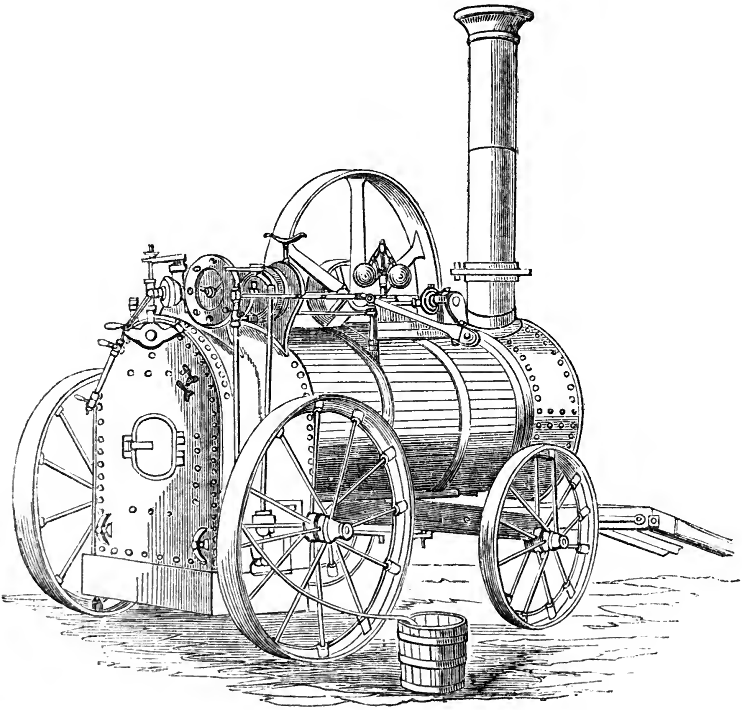

fig. 51.

introduced by Mr. Joyce of Greenwich, and termed the "pendulous engine." The principle introduced by Woolfe is carried out in this form of engine; the cylinders are bedded side by side, and inverted; and suspended between the framing, the trunnion-pipes or steam-ways being placed at the ends, or what in the ordinary engine would be termed the bottoms of the cylinders. By this arrangement, a direct motion is given to the crank, without the introduction of the usual assemblage of appliances on the beam-engine. The cylinders vibrate from side to side, the movement of the cylinders working the slides by means of a bar; in the cuts, fig. 50, a front and side elevation is given.

Portable steam-engines are now much used for a variety of purposes, and in agricultural operations. In fig. 51 we give a view of Clayton and Shuttleworth's agricultural portable engine; and in fig. 52 Messrs. Barrett and Exhall's engine for the same purposes. In fig. 54 we give an elevation of Gough's portable engine, for pumping water from quarries and excavations; and in fig. 53 another adaptation for drawing up earth from railway cuttings, &c. &c.

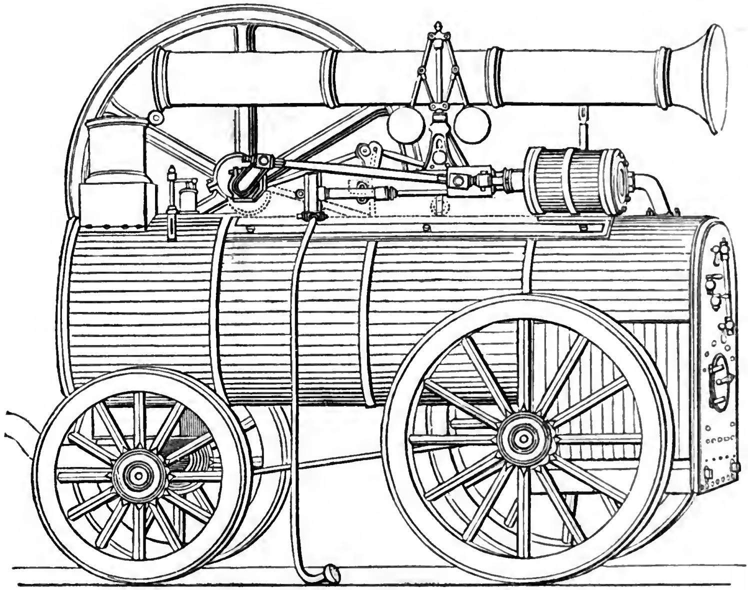

fig 52.

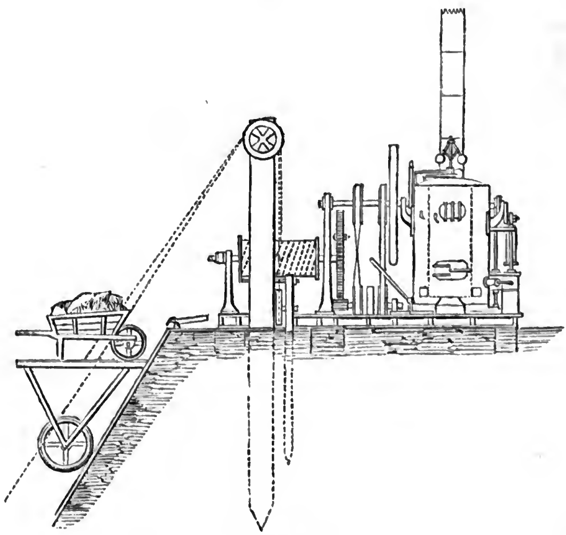

fig. 53.

In fig. 157, p. 81, *Mechanics and Mechanism*, we give the side elevation of a steam-pumping engine, applicable as a portable steam-engine for agricultural purposes by disconnecting the pump; we now give the front elevation, in fig. 55; *a* cylinder; *b* crank axle and horizontal slide; *d* the plunger; *ef* air-vessels; *g* inlet; *h* outlet.

In fig. 56 we give an illustration of the steam-engine for working a fan

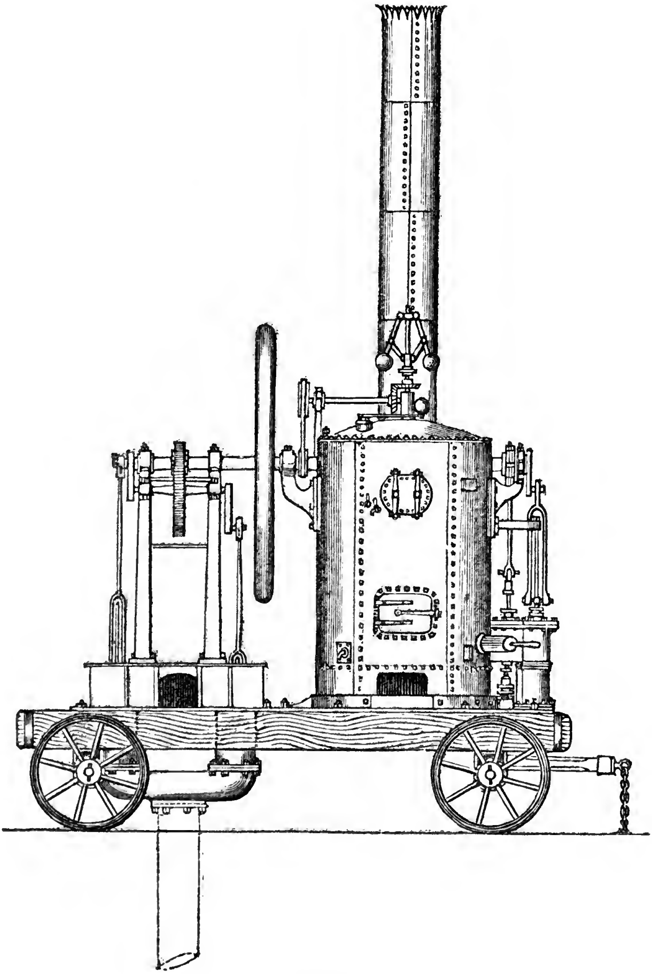

fig. 54.

for withdrawing air from mines; and in fig. 57, Usher's steam-plough. In p. 113, fig. 206, *Mechanics and Mechanism*, we give an elevation of Nasmyth's steam-hammer.

In another chapter we propose to describe the rotatory engine, and

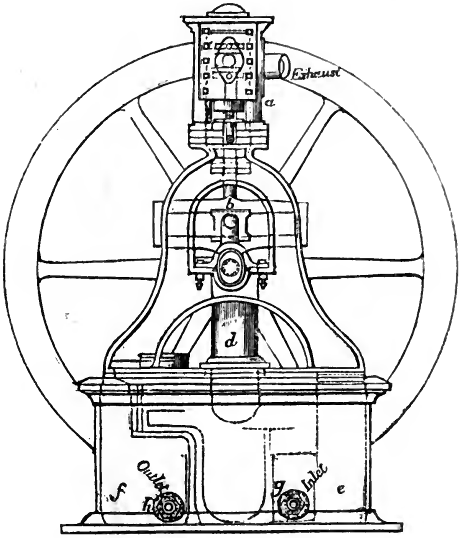
Exhaust
a
b
d
Outlet
h
f
g
Inlet
e

fig. 55.

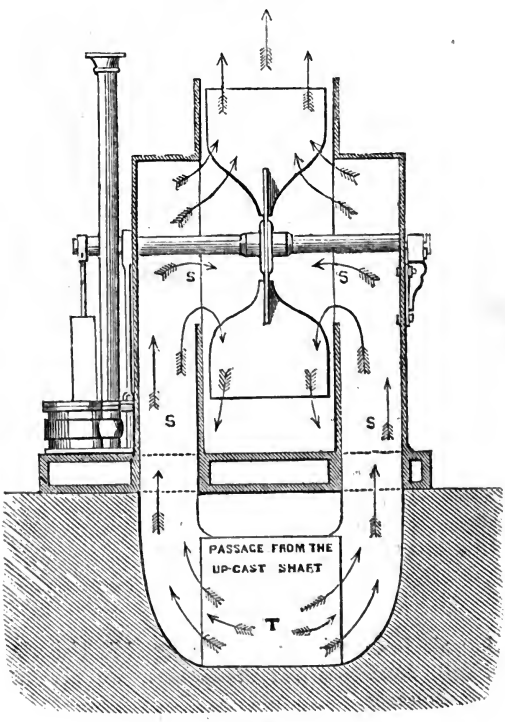
S
S
S
S
PASSAGE FROM THE
UP-CAST SHAFT
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fig 56.

other varieties, as the disc-engine, the arrangements of which present peculiarities different from those which we have already described. In the mean time we hasten to describe the various details of the cylinder engines.

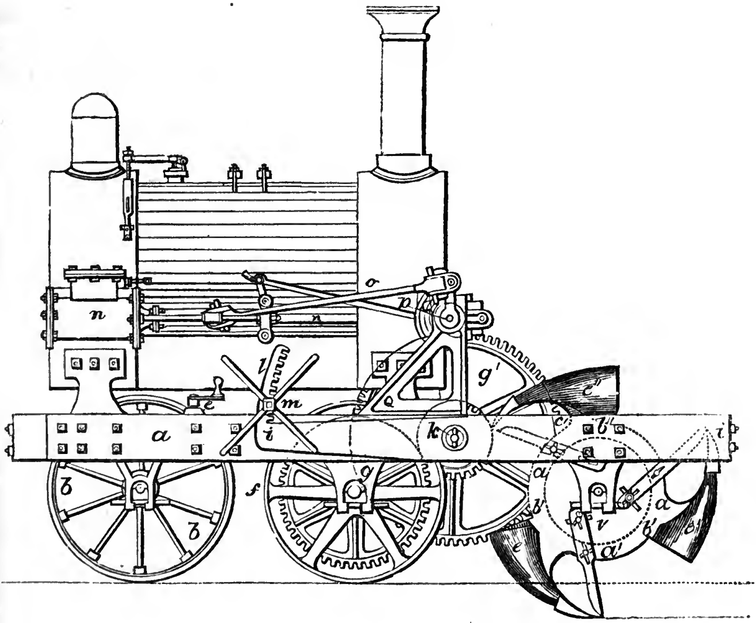


fig. 57.

CHAPTER III.

DETAILS OF BOILERS AND ENGINES.

Before describing the appliances of boilers as now adopted in modern practice, we propose giving a few sketches, illustrative of the varieties of boilers which have been introduced from time to time.

In the sketch given in fig. 19 of Smeaton's Chacewater engine, the form of boiler will be seen. Smeaton paid great attention to the construction of boilers; and a favourite form of his is known as the "hay-stack," or

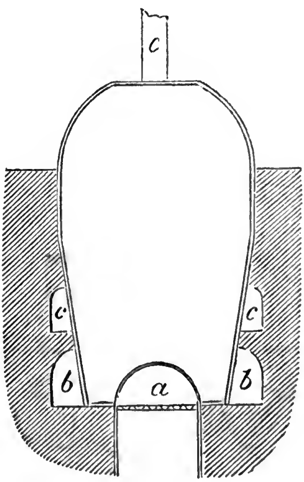


fig. 58.

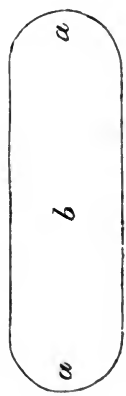


fig. 59.

"hay-cock" boiler. A diagram, showing its form, is given in fig. 58; *a* is the fire-place, *cc* the upper flues, *bb* the lower ditto; the steam was taken from the upper-part *d* through the pipe *e*. This boiler was formed of plates of cast-iron, joined together with flanges and bolts. The cylindrical boiler, as in fig. 59, is constructed with two circular or semi-spherical ends, as at *aa:* the ends of this form of boiler are in America generally made flat. In some instances an internal circular flue, as *a*, fig. 60, is provided in this form of boiler; the flue extends from end to end, and the heated air and smoke, after passing from the fire-place, goes through this flue in its passage to the chimney. This form of cylindrical boiler, called the "Trevethick," from its introduction being attributed to that engineer, is generally used for high-pressure engines. When properly constructed it is very strong, and capable of resisting a very high degree of pressure.

We have already figured the form of boiler known as the "waggon" adopted by Watt. A boiler very generally used for condensing engines,

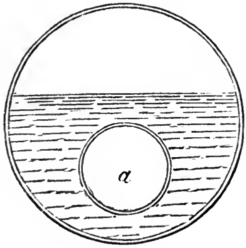


fig. 60.

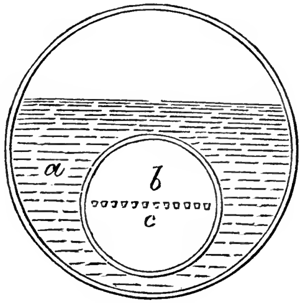


fig. 61.

and known as the "Cornish," consists of a cylindrical boiler, having a large internal circular flue, in which the fire-place is situated. The introduction of this form of boiler "has effected great improvements in the economy of fuel as well as the strength of the boiler." This form is shown in the sectional diagram in fig. 61, where *aa* is the boiler, *b* the internal flue, *c* the fire-bars. In order to obtain a larger fire-place in the Cornish boiler, one-half of the end in some instances has been cut away: this was first done by the Butterley Iron Company, and the boilers in which this arrangement is adopted are known as the "Butterley;" they are much used in Lancashire. The form is shown in the diagram fig. 62.

The form of boiler which is considered by competent authorities as a very effective and economical kind, is that known as the double-flued

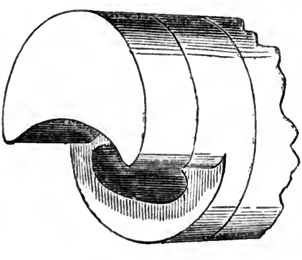


fig. 62.

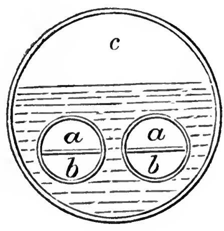


fig. 63.

and double-furnaced boiler, a sectional diagram of which is given in fig. 63; *a a* the flues, *b b* the furnaces, *c c* the boiler. This is now in general use, and is fast superseding all other constructions. "It consists," says Mr. Fairbairn of Manchester, "of the cylindrical form, varying from five to seven feet in diameter, with two flues, which extend the whole length of the boiler; they are perfectly cylindrical, and of sufficient magnitude to admit a furnace in each. This boiler is the simplest, and probably the most effective, that has yet been constructed. It presents a large flue-surface as the recipient of heat; and the double flues, when riveted to the flat ends, add greatly to the security and strength of these parts. It moreover admits of the new process of alternate firing, so highly conducive to perfect combustion, and the prevention of the nuisance of smoke."

The boiler known as the "French," as having first been introduced into practice in France, and which is much used in Lancashire, is figured in fig. 64: *a* is the cylindrical boiler; *c c*, two tubes, stretch longitudinally

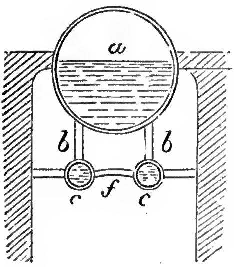


fig. 64.

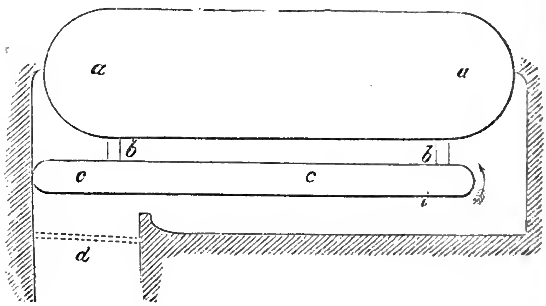


fig. 65.

below the boiler, and receive their supply of water by the vertical tubes *b b*, a brick arch *f* is thrown over, between the tubes *c c*; by this arrangement the flame and heated air from the furnace at *d*, fig. 65, pass along the under-side of arch *f* and tubes *c c;* returning to the chimney along the space between the bottom of tubular boiler *a a* and upper-side of arch *f*. This form of boiler is highly efficient; and the principle of making the flame and heated air impinge upon the outside of tubes containing water, instead of passing through the inside of tubes surrounded with water, is considered by some to be possessed of such superior advantages, as to be likely soon to supersede all other arrangements. This principle is carried

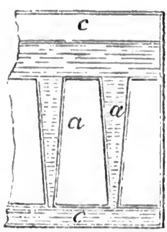


fig. 66.

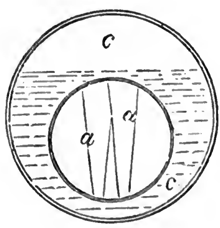


fig. 67.

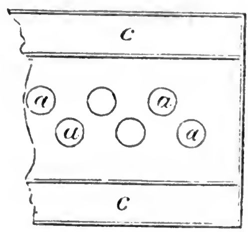


fig. 68.

out in a very effective manner by Messrs. Galloway in their patent boilers, which are taking a high place in the engineering world. Fig. 67 is a sectional diagram across the boiler; fig. 66 part longitudinal section, and fig. 68 part plan. The peculiarity consists in arranging a series of vertical conical tubes, *aa*, within the central flue, in a zig-zag form, connecting the upper and lower part of the boiler *cc*. The boiler is of the double-furnace kind, firing each furnace alternately.

The great efficiency of the locomotive boiler, in which the heated air passes through the inside of tubes which are surrounded externally with water, has directed the attention of engineers to the construction of boilers for stationary engines on this principle. Fig. 69 is a longitudinal section

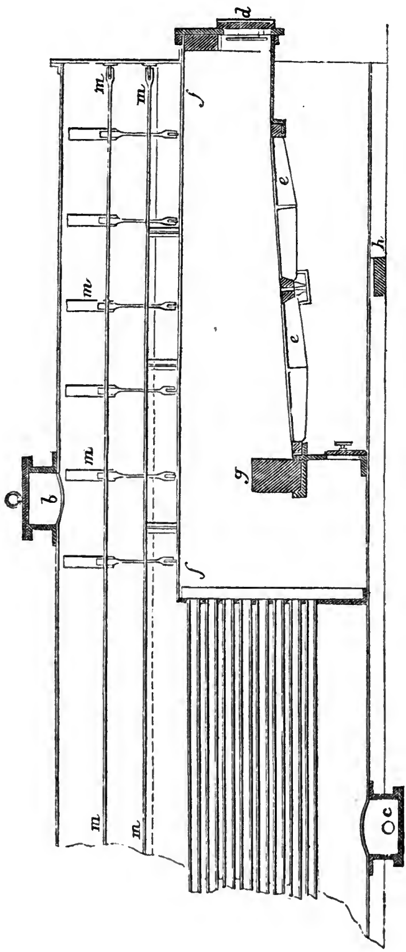


fig. 69.

of Messrs. Gordon's multitubular boiler, and fig. 70 a transverse section. This form of boiler requires no brick-setting; but after being attached to the engine and to the chimney-flue, can be set at work. They have double furnaces, which are fired alternately: *d* is the fire-door, *ff* the combustion-

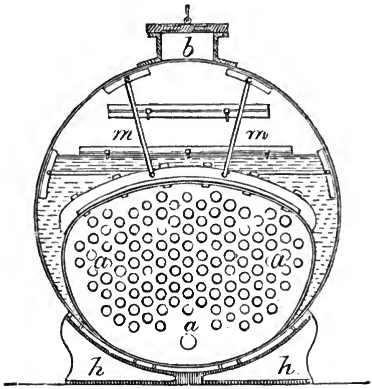


fig. 70.

chamber, *ee* the fire-bars, *g* the fire-bridge, *aa* the tubes, *c* the pipe from which to withdraw the sediment, *b* the man-hole door, *m m* the stays to strengthen the boiler, *h h* the standard for supporting the boiler.

The forms of boilers we have here given are such as are generally adopted for land or stationary engines; those for marine being arranged somewhat differently. It is impossible, under this division, to notice even a tithe of the arrangements introduced; we must content ourselves, therefore, with a few general notes.

The form of boiler originally introduced into steam-boats was merely

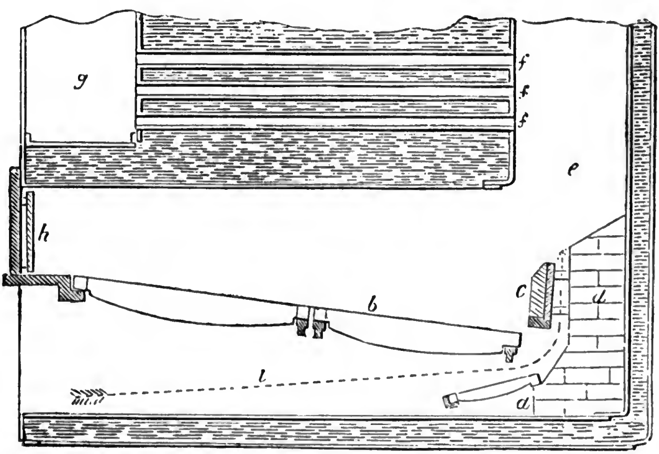


fig. 71.

a land-boiler, with large internal flues, like the Cornish boiler; the difference being, that in the latter the boiler was encased in brick-work, while in the former the external casing was of iron, leaving a space between, in which water was placed. The plan of the locomotive tubular boiler was next introduced, and with marked success. The next improvement was turning the tubes over the furnaces, as in fig. 71 : *h* the fire-door, *b* the fire-bars, *ff* the tubes passing through the boiler to the funnel-flue *g*. A form of boiler has been introduced, both for land and marine engines, which promises good results; it is known as the "vertical tubular," and is represented in the diagram, fig. 72, where *a* is the furnace door, *b* the lines representing the tubes; the heated air passes up through these, giving out the heat to the water with which they are surrounded. The tubes pass out at the top of the casing. As the water-level is below the top of the tubes, as at *b*, the steam is rendered thoroughly dry, or "anhydrous," as it is termed, and the inconveniences of priming are obviated.

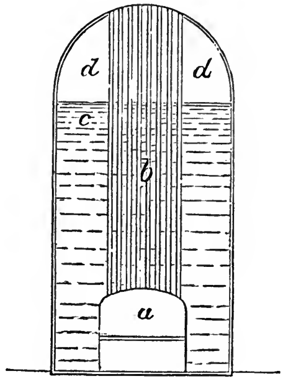


fig. 72.

The principle of boiler as patented by the Earl of Dundonald is considered good; it has been adopted with marked success in the line of Ocean American steamers of Collins. The diagram in fig. 73 shows the arrangement. The "boilers are provided with two rows of fire-places, and two tiers of tubes, one above the other, for the purpose of increasing the grate and boiler surface." The improved form of this boiler, as secured by the last patent

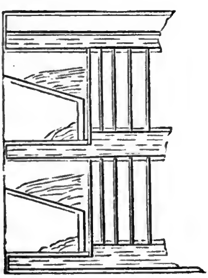


fig. 73.

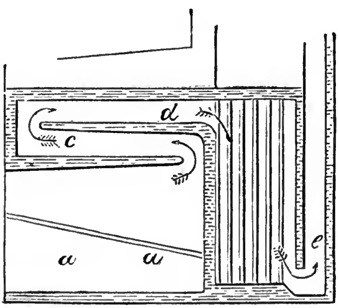


fig. 74.

of the Earl of Dundonald, is given in fig. 74 : *a a* the fire-bars (there are four furnaces abreast), the heated air passes over the inverted bridge named the "economical heat trap;" along *c* and *d*, and down among the tubes, and finally up the chimney-flue *e*; by this arrangement, "the heated products of combustion are retained in contact with the most efficient part of the heating surface of the boiler, until the complete absorption of all the useful caloric is effected." The natural tendency of heated air is to ascend; and only to descend when deprived of its caloric or principle of levity. In the ordinary boiler, the heated air has a free and uninterrupted ascent to the funnel; but in the patent boiler it is conveyed through the flues to the summit of the tube-chamber, and there constrained to maintain that elevated position by its levity, until the water has effectually absorbed all the useful caloric held in combination, and the products of combustion, deprived of their superabundant principle of levity, descend to the interior aperture leading to the funnel, where they escape into the atmosphere at a low temperature. It will be noticed, that in this form of boiler the French principle of filling the tubes with water, making the flame pass outside, is carried out.

Having now illustrated the forms of boiler introduced both for land and marine engines, to the extent we deem necessary for the purposes of our work, we now proceed to illustrate the appliances of modern boilers.

In condensing, or low-pressure engines, the water is supplied to the boiler through a stand-pipe; this is of altitude to contain a column of water sufficient to counterbalance the pressure of steam in the boiler. A small cistern is placed on the top of this stand-pipe, which is supplied with water from the hot-well by the power of the engine; a small valve is placed at the bottom of this cistern, which is opened by a lever; this lever is acted upon by the float in the inside of the boiler, the wire or rod connected with it passing through the top of the boiler, and fastened to the end of the lever: the arrangement has already been figured in Chapter II. In some instances, the wire or rod of the float passing through the boiler has stuck in its stuffing-box, and thus rendered the apparatus inoperative. A plan to obviate this has been recently introduced; this consists of a pipe, same height as the stand-pipe, containing a column of water; the rod of the float passing through this is moved without friction, and cannot stick. This apparatus of stand-pipe and float acts as a safety-valve in some measure, as before mentioned. The height of column of water in the stand-pipe is calculated so as to counterbalance the pressure of steam in the boiler; but should the pressure of steam increase beyond a certain point, the water will be forced out of the pipe through the valve in the cistern, and thus give timely warning. The stand-pipe has another apparatus connected with it, by which the degree of combustion in the furnace is regulated. At the throat of the chimney a valve, consisting of a flat plate sliding in a frame, is placed; when this is forced fully into its frame the aperture of the chimney is closed, thus preventing the smoke, &c. from the furnace gaining access to the chimney: by this means the intensity of combustion is lessened, and the fire finally goes out. In proportion, therefore, to the degree of opening of the mouth of the funnel, so will be the intensity of combustion in the grate. The sliding-valve has connected with it a chain, which, passing over two pulleys, is finally passed down the interior of the stand-pipe, and connected with a float which moves up and down in it. As the pressure of the steam increases in the boiler, the water is forced up the stand-pipe; this raises the float, and releasing the chain, the damper or valve at the mouth of the chimney is forced into its frame; the throat of the chimney is thus proportionally closed, the draught is diminished, the fuel in the furnace burns less fiercely, the pressure of steam is diminished, the water in the stand-pipe falls, and along with it the float; this tightens the chain, and the damper is pulled up.

In high-pressure engines, the chain of the damper passes over two pulleys, and is connected with a counter-balance weight, hung near the furnace door; the raising and depressing of the damper is done by hand.

In high-pressure boilers the water is supplied to the boiler by a force-pump, worked by the engine; the water being forced into the boiler against the pressure of the steam. A very ingenious apparatus for supplying high-pressure boilers with water, has been introduced by Mr. Turner of Ipswich. An elevation of this is given in fig. 75.

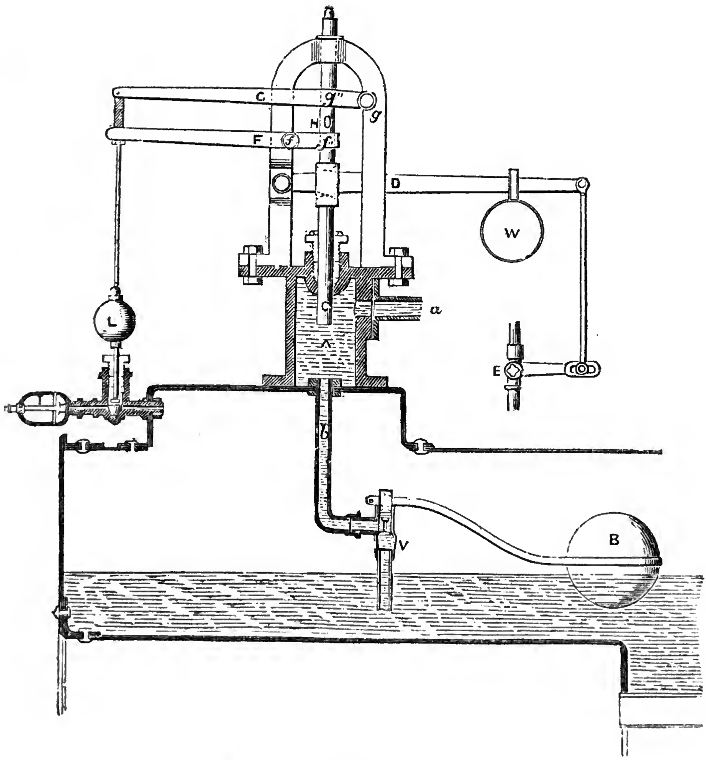


fig. 75.

This invention effects its object of rendering steam-boiler explosions arising from a deficiency of water next to impossible, by causing the boiler not only to regulate its own supply of water, but to sound an alarm almost instantly should the source of that supply fail; and to continue the alarm until its wants are supplied.

In fig. 75, A is a closed vessel, into which water is forced by the engine feed-pump through the pipe a; B is a portion of the boiler; V is a ball-valve for controlling the entrance of water from A; C is a ram of an area proportionate to the pressure and requirements of the boiler; D a lever carrying a weight W, which exerts a force upon the area of the ram considerably in excess of the force which the pressure of the steam would exert upon the same area; E is a small cock for admitting air to the pump; F and G are forked levers, having their fulcra respectively at *f* and *g*; H is a projection on the ram-guide, which acts upon the levers F and G; I is a steam-whistle; L a weight attached to the whistle-valve, exerting an upward pressure upon the lever F, and a downward upon the lever G. When the water in the boiler is at its proper level the valve is closed, and the water is forced into A; this raises the ram C and lever D, which turns the cock E, admitting air to the force-pump, and stopping its action. As the boiler takes its supply from A, the ram C descends, the air-cock E is closed, and the pump again brought into action.

In the event of the supply of water failing, the high-pressure maintained in A would rapidly fall to the same pressure as the steam in the boiler, owing to the communication through V remaining open. The excess of pressure from the weight W would thus be brought to bear upon the lever F; and counterbalancing the weight L, lift the whistle-valve, and sound an alarm. Should it happen that the air-pipe to the pump becomes choked, so that although the cock E be open the pump still continues to work, the pressure in A would rapidly increase, until sufficient to raise the lever G and the whistle-valve, thus sounding an alarm.

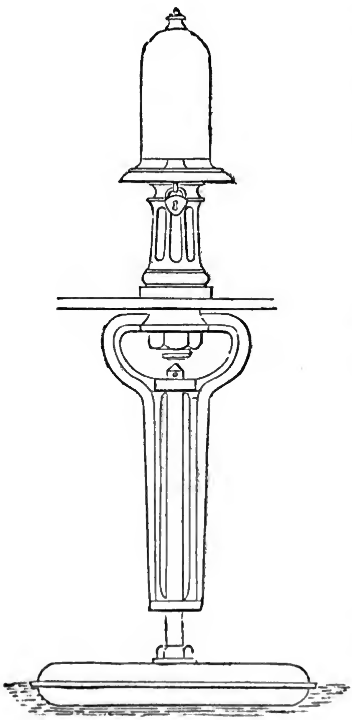


fig. 76.

A very ingenious apparatus for giving notice of the fall of the water in the boiler below its proper level, is that known as "Haley's safety signal for boilers."

The engraving, fig. 76, in which a part of the top of the boiler is shown in section, conveys a clear idea of this signal. The stand outside the boiler has a stem passing through a hole in the plate, screwed at the end, and provided with a nut. Inside the boiler it passes through the guide, and secures it and the stand at the same time; a copper float is screwed upon a brass spindle, working loosely through the guide, and which is hollow, except on the top, and is formed into a conical shape. A pin passes through this spindle near the top, to prevent its falling through the guide when the boiler is empty; and a little below, a small aperture admits steam through the hollow spindle into the interior of the float, by which means the inside and outside pressure are equalised; and being near the top of the spindle, water cannot enter the float. Immediately over the cone, through the stem of the stand, is a small aperture leading to a whistle locked up within the dome at the top. When the water is any distance above low-water mark, or the signal point, the float is lifted, and the cone presses against the aperture and closes it. When it falls below the warning-point, the float falls with it, and the aperture is opened, allowing steam to pass through it to the whistle.

The combined "safety-valve and water-indicator" of Messrs. Dangerfield and Bennet, is shown in figs. 77, 78; the former being an elevation,

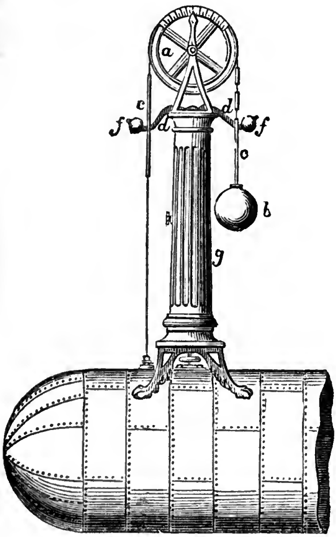


fig. 77.

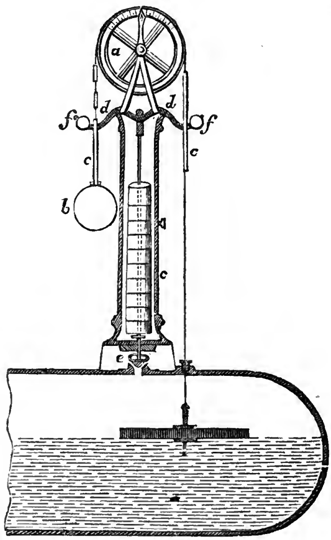


fig. 78.

and the latter a section of the apparatus. Should the water in the boiler fall or rise beyond a given level, the buoy or float attached to the float-chain, which works round the wheel *a*, and is balanced at its other extremity by the weight *b*, rises or falls with the water. If falling, the end of the long link *c* presses on the lever *d*, opens the valve *e*, and permits the steam to escape; the steam in escaping comes in contact with a bell which is placed over the valve *e*, and continues to give a loud and shrill whistle, until the water in the boiler is again brought to its proper level; or being neglected, the whole of the steam escapes from the boiler, which causes the machinery to cease working, stops the water from being forced into the boiler upon the hot plates, and thereby prevents an explosion. The water in rising produces the same action upon the opposite lever. The column *g* opens as a door down its entire length, to admit the weights on the valve *e*; the weights being put in proportion to the area of the valve, and the pressure the boiler is intended to carry. The weights on the valve *e* are securely locked in the column *g*, and cannot be interfered with to cause any undue pressure. The balls *f* balance the valve and levers when out of action. An index is fitted on the wheel *a*, which shows the height of the water in the boiler. This apparatus is very elegant in its general appearance, and has the merit of being self-acting.

In addition to these and other kindred contrivances, to notice all introduced for the last thirty years would take a goodly sized volume. The actual level of the water in the boiler is made visible by the contrivance known as the "water-guage;" this will be found described in the chapter on Locomotives. We pass on, therefore, to notice other appliances of the boiler. The pressure of the steam on the water in the boiler has been taken advantage of by Mr. Wilson, of Low Moor Iron Works, in his "safety apparatus for boilers," shown in fig. 79, which is part of a longitudinal section of a boiler with internal furnaces: *a* is a vertical pipe, like an ordinary feed water-pipe for low-pressure boilers. It is open at its lower

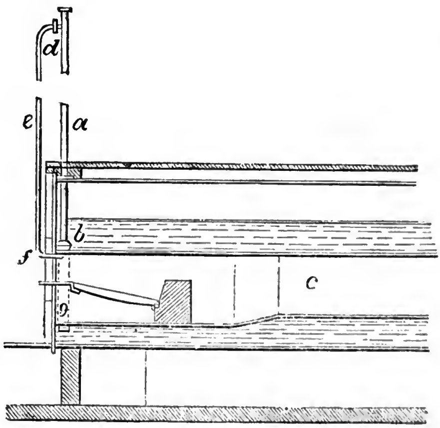


fig. 79.

end *b*, which is set about one inch above the top of the furnace-plates of the flue *c*, and passes up through the top of the boiler to a height sufficient to obtain a column of water rather more than equal to the greatest steam pressure at which the boiler is intended to be worked. Near the upper-end of this pipe, a branch *d* is formed upon it, forming a junction with the second vertical pipe *e*, which passes downwards outside the boiler-end; and its extremity is bent to terminate in the front of the furnace at *f*; or if two or more furnaces are fitted in each boiler, then a communication of the same kind must be formed with each of them. The height of the discharge-branch *d* is such, that at the ordinary working steam-pressure of the boiler, the water forced up the pump by this pressure shall stand at some point beneath the branch *d*. Should, however, the steam-pressure be increased by any means beyond the due working pressure, the water will rise higher up the pipe *a*, until, if the pressure increase, it reaches the branch *d*; when it will pass through the latter, descend the pipe *e*, and pour into the furnace.

This discharge of water will at once damp the fire, and therefore reduce the steam pressure; whilst, at the same time, it will draw the attention of the engine-attendant to the fact, that all is not right with the boiler. The open end *b* of the pipe *a* in the boiler is not exposed directly to the ebullition of the water, which would tend to derange the action of the apparatus; but is protected from this influence by insertion into a short length of wider pipe *g*, open at top and bottom, the water standing at the same level within it as in the boiler. In this way the water contained in the guard-pipe *g* is kept in a comparatively undisturbed state, the stilling effect of the pipe being further assisted by its expanded or funnel-shaped upper-end. In attaching this apparatus to a boiler, the branch *d* must be set at such a height as will allow of the obtainment of a column of water in the pipe *a*, of a head pressure a little more than the pressure to which the safety-valve *h* is loaded, so that the latter may have a short range to permit it to work freely when in good order, without the protector or water-discharging apparatus being brought into play. Thus, when the slight difference between the head-pressure in the water-pipe *a*, and that to which the safety-valve is loaded, is exceeded, owing to the sticking of the latter, or from any other cause, then the protector acts at once upon the fire. When the water-level in the boiler falls below the open end *b* of the water-pipe, which would endanger the overheating of the boiler-flues, a portion of the water contained in the pipe at the time will drop out of the end *b* into the boiler, whilst the remainder will be forced up the pipe by the steam pressure. As the upper-end of the pipe is closed, with only a small aperture to prevent its acting as a syphon when water passes down its branch *d*, the steam and water blown out will pass down the descending pipe *e*, and damp or extinguish the fire. This discharge of steam being so contrived that it shall take place before the parts of the boiler liable to overheating are quite bare, the damping of the fire will always remove all danger of explosion or injury to the boiler; which may be again set to work, after the supply to it of a proper quantity of water, which may be supplied at once without fear of any injurious effects. The advantages of this apparatus are, that it renders the dangerous accumulation of steam impossible, being entirely free from valves or connections, which are liable to derangement; whilst it can never fail to call the attention of the attendant to any objectionable increase of pressure, and it will remove the cause of the over-pressure unassisted."

Where the steam in boilers reaches a degree of pressure likely to be dangerous to its safety, what are termed "safety valves" are used. Mr. Fairbairn calls them the only "legitimate outlets" in circumstances such as the above. Two should always be provided to every boiler, of sufficient capacity to carry off the quantity of steam generated by the boiler. To prevent additions being made to the weight, Mr. Fairbairn recommends a "lock-up valve," as represented in fig. 80. *a* is the valve; *b* is a shell of thin brass,

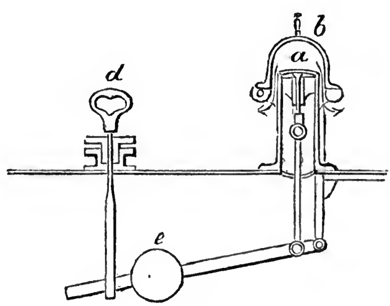


fig. 80.

opening on a hinge, and secured by a padlock; it is of such a diameter as to allow the waste steam to escape in the direction of the arrows. *c* is the weight, which may be fixed at any part of the lever to give the desired amount of pressure, but which cannot be fixed or altered unless the boiler is opened to allow a man to get inside. *d* is a handle, having a long slot, by which the valve may be relieved or tried at any time, to obviate the liability of its corroding or being jammed; but the engineer cannot put any additional weight upon the valve by this handle. The sticking of the valve in its seat is always a fruitful source of danger.

As a valuable aid towards obviating such disasters, we here illustrate and describe, in fig. 81, the very neat valve registered by Mr. James Nasmyth, of the Bridgewater Works, at Patricroft, which has met with very general and high approval, as uniting in a most simple combination all the qualities which can tend to the formation of a true and perfect safety-valve.

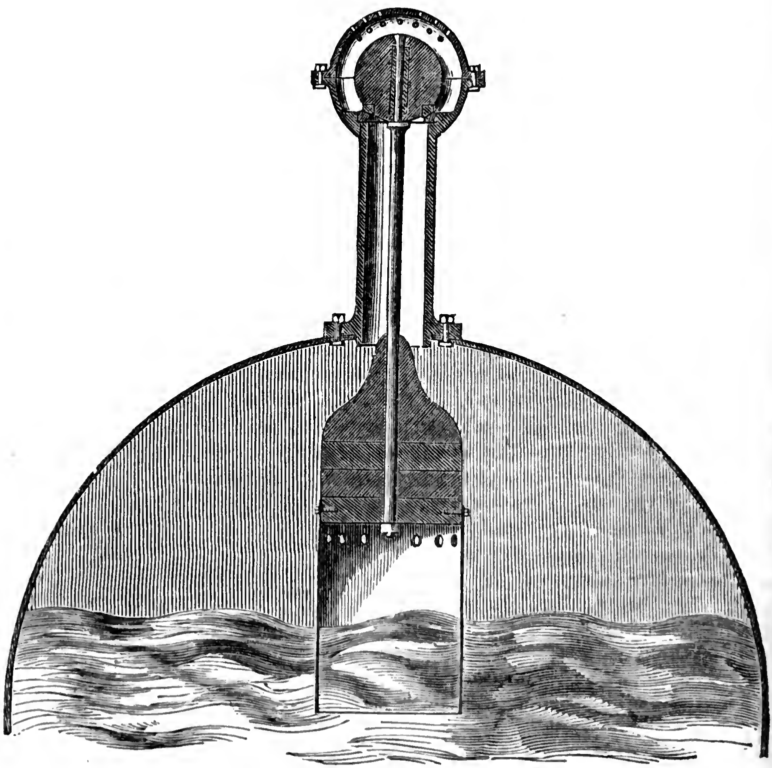


fig. 81.

The total absence of all spindles or other guiding agencies, which have hitherto proved so fertile a source of mischief and uncertainty in the action and permanent perfect condition of this vital part of a boiler apparatus, will be seen at a glance to characterise the design of this absolute safety-valve.

The chief feature of novelty, however, which distinguishes this improved safety-valve from all others hitherto proposed, consists in the peculiar and simple manner in which the motion of the water in the boiler is employed, as the agent by which the valve is prevented from ever getting set fast in its seat. The swaying to-and-fro sort of motion which at all times accompanies the ebullition of water in boilers, is made to act upon a sheet-iron appendage to the weight directly attached to the valve; and as the rod which connects this sheet-iron appendage and weight to the valve is inflexible, it will be easily seen how any slight pendulous motion given to the sheet-iron appendage is directly transferred to the valve; and as that portion of the valve which rests in the seat is spherical, the valve not only admits of, but receives, a continual slight motion in its seat in all directions, as the result of the universal pendulous motion of the appended weight, as acted upon by the incessant swaying motion of the water during ebullition. It will be seen that, as the spherical portions of the valve and seat are of equal width, the edges of their respective surfaces pass and repass each other continually, and so maintain and continually tend to improve the perfect spherical fit and agreement between the valve and its seat.

It may be proper to observe, that when the steam is nearly up to the desired pressure, the valve rests on its seat with a pressure next to no pressure at all, and is then, as it were, floating on steam. This action is common to all good valves; but the observation may tend to show how a slight movement of the water affects the valve in its seat. A pipe may lead the steam escaping from this valve to the manager's-office, and there give audible notice of its escape by acting in a steam-whistle there placed.

Still further to obviate the risk of boilers exploding from a dangerous pressure, "fusible plates" are introduced sometimes on the top of the boiler. These are made of a composition calculated to melt at a comparatively low temperature. Fusible plugs are also introduced into apertures on the boiler below water-line; these melting when the water gets too low, allow the steam to pass off. Little reliance, however, is to be placed on these contrivances.

All boilers are supplied with gauge-cocks, the nature of which has been already described; by these the level of the water in the boiler is ascertained.

Mercurial pressure-gauges are frequently used to indicate the exact degree of pressure in the boiler. A glass tube is placed in a small cistern filled with mercury; one end is closed, the other opens to the interior of boiler in the steam space: the steam passing down the tube presses on the surface of the mercury; by this means the air in the upper part of the tube is compressed, and in proportion to the compression so is the pressure in the boiler. In improved gauges, a scale is attached which shows the temperature of the steam as well as its pressure in the boiler. In fig. 82 an improved pressure-gauge is shown: *a a* is the pipe introducing steam from the boiler; *b* the pipe for leading off the water of condensation; *c c* the snugs for fixing the gauge in any convenient position. In mercurial gauges adapted for low-pressure boilers, the mercury is placed in a syphon tube, one end of which opens into the boiler, and the other is open to the atmosphere; the pressure of the steam raises the mercury in the short leg of the

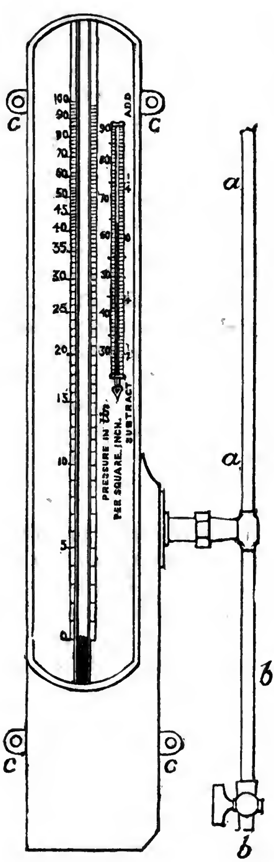


fig. 82.

syphon, and acts on a small plug floating on it; to this is attached a pointer, which shows on an index the degree of pressure. When the steam gets of very high pressure, the mercury is blown out of the tube; in this way acting as a safety-valve.

The consumption of smoke arising from the fuel used to raise the steam in the furnaces of boilers, has long been a favourite project among inventors; and the adoption of a good plan to effect this desideratum, always of importance, has more recently attracted earnest attention, from the fact of many Corporations making it imperative on those who employ steam-engines to consume their own smoke. We cannot pretend to notice all the plans introduced for this purpose, but must content ourselves with noticing only one; that, however, the most recently invented, and which has already taken a high place in the rank of effective plans. This, the invention of Mr. John Lee Stevens of London, is shown in the diagram in fig. 83. "The invention," says Mr. Lee, in his prospectus, from which our diagrams are taken, "consists in the combination of two sets of fixed fire-bars, the first of which is fed by the scoria and cinders voided from the second or upper set of fire-bars, with a calorific plate, as shown in the diagram; by which arrangement, the current of air entering at the lower part of the furnace passes through two strata of fire, and thence between the calorific plate and the bridge; and is thus so intensely heated, as continuously to produce the entire combustion of the gaseous products of the fuel, without the formation of smoke." In fig. 83, *b* the first and *a* the second set of bars; *c* the calorific plate, faced with fire-bricks; *d* the bridge, *e* the furnace-flue, *h* the furnace-door; *i* shows the direction of the current of air: this diagram shows the application of the principle to the Cornish boiler for land-engines. In fig. 71 the application is shown to marine boilers; the same letters of reference apply to this diagram as to fig. 83.

Still further to make the steam-engine automaton or self-acting in its arrangements, mechanism has been introduced by which the labour of the fireman or stoker is suspended, and the furnace supplied with fuel in proportion as required. Numerous contrivances have been introduced for this purpose; we shall only notice one, and that patented by Mr. Dean of Stockport, and in which neighbourhood it has been introduced with success. "It consists, first, of a double self-acting feed-apparatus, one side of which is caused to supply the furnace with fuel, whilst the other is at rest, and *vice versâ*, alternate; and, secondly, in placing a partition-wall in the furnace, between the fire doors and the bridge of the same, and employing two dampers, at or about the bridge, which are opened and closed alternately by certain levers and rods connected with the feeding apparatus." In

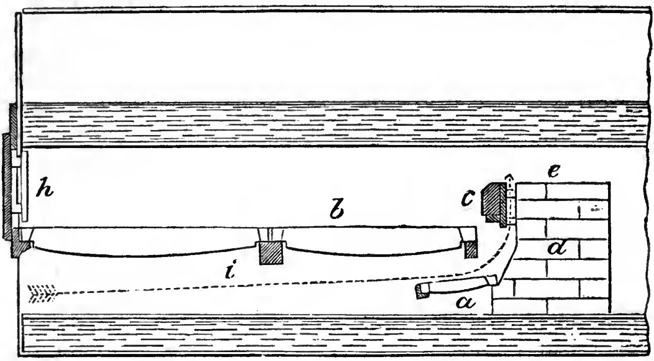


fig. 83.

addition, therefore, to acting as an automaton feed-apparatus to supply the furnace with fuel, it insures the combustion of the smoke and economisation of fuel. In fig. 84, we give an end view of a steam-boiler and furnace,

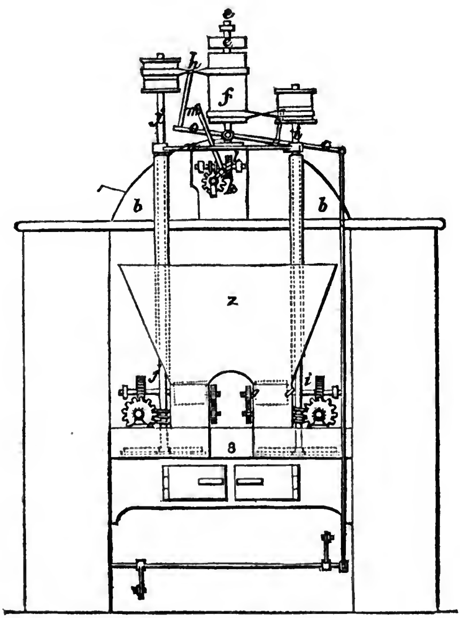


fig. 84.

with the feeding mechanism applied; in fig. 85, a plan or horizontal section below the boiler; and in fig. 86, a transverse section in front of the bridge of the furnace. "*a a* is the foundation brick-work supporting the boiler, *b b*, *c c* the 'dead plate' of the furnace, *d d* the fire-bars. *e* is the main driving-shaft, to which motion is communicated (by the engine) by a strap passing round the pulley *e′* at its upper-end, or by any other convenient means. Upon the main driving-shaft *e* is a pulley *f*, which, by means of the cross-belts *g* and *n*, drives alternately the shaft *i* of the right-hand feeding-apparatus, and the shaft *j* of the left-hand feeding apparatus. These shafts have each a fast and loose pulley at the upper-end; and the requisite shifting of the straps from the fast on to the loose pulley is effected

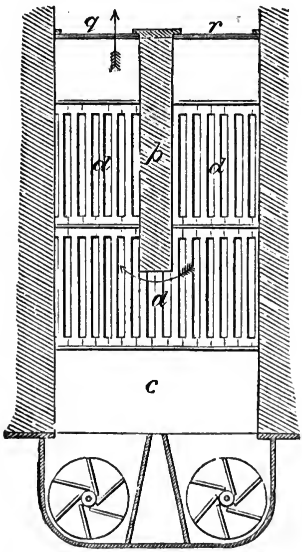


fig. 85.

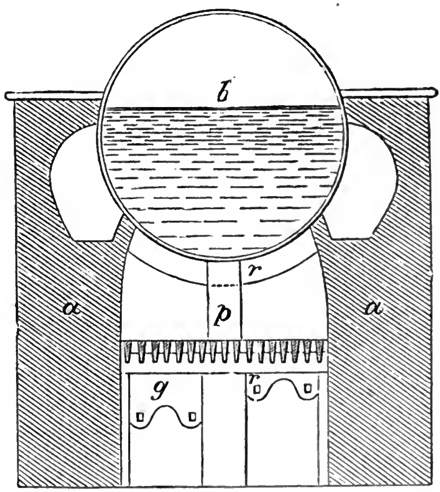


fig. 86.

in the following manner: A small crank *k* is caused to revolve by means of a worm on the driving-shaft *e*, actuating the worm gearing *l*; this crank *k* has a lever attached to it, furnished with two studs, *m* and *n*, which, as the crank revolves, causes the strap lever *o* to vibrate, and throw one strap on the loose pulley, and the other on the fast one, thus alternately setting in motion and stopping each feeding apparatus. It will be seen in figs. 85 and 86, that there is a partition-wall *p* in the furnace, reaching from the fire-bars to the bottom of the boiler; and extending from the bridge about half way to the fire-doors; and that there are two dampers *q* and *r* behind the bridge of the same, one of which is open and the other closed. The dampers are connected to the strap lever *o* by cranks and levers, so that when one side of the feeding-apparatus is supplying fuel to the fire, the damper upon that side is closed, and the damper on the other side open, and *vice versâ*. In the drawings the right-hand feeding-apparatus is represented at work, and that upon the left hand as stationary. The right-hand damper being closed, the smoke, &c. from the fresh coal will have to pass round the partition-wall *p*, and over the fire at the left hand

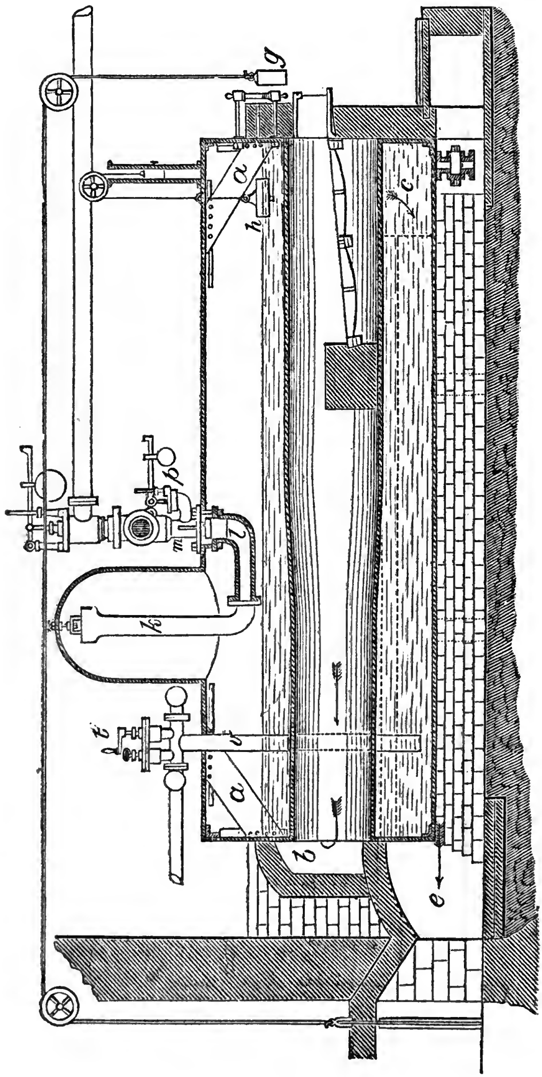


fig. 87.

of the furnace, and will thereby be consumed. It will be evident that, when by the revolution of the crank *k*, the feeding-apparatus and damper on the other side of the furnace are brought into action, the passage of the smoke will be reversed." The fuel is supplied to the hopper *z*, and is gradually spread over the furnace-bars from the centrifugal force generated by the revolving discs or plates.

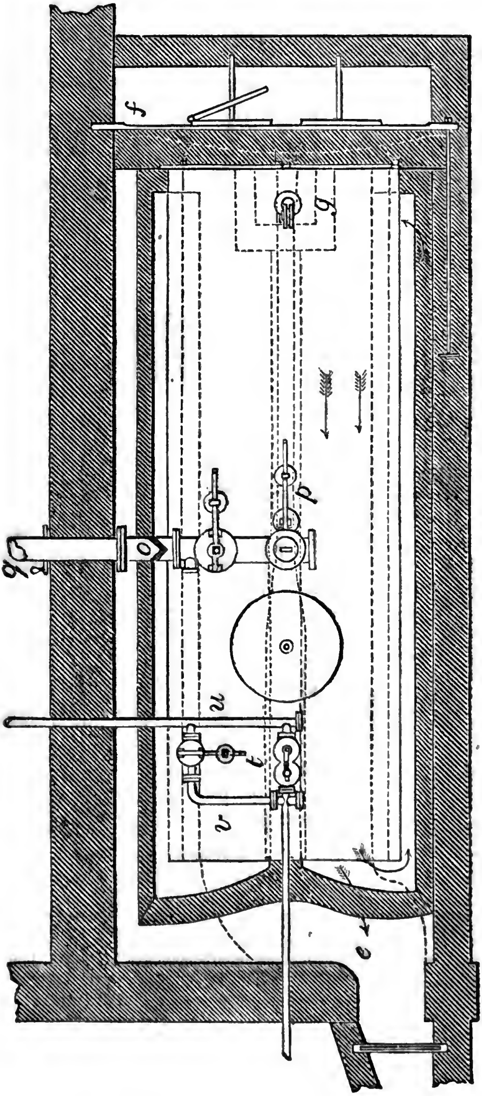


fig. 88.

As a conclusion to the present division of our work, we give drawings and description of a high-pressure boiler with improved fittings, for which we are indebted to the courtesy of Mr. William Johnson. Fig. 87 is a "longitudinal section" of boiler, fig. 88 a "plan," and fig. 89 an "end elevation." The boiler of which these are drawings, is that adapted to the engine on the double cylinder principle which we have illustrated in figs. 38, 39.

The class of boilers of which this is a good example, are considered by a competent authority to possess numerous features of economy and safety in working; and as affording an example of what a good high-pressure boiler should be, we give it here. The length of boiler is 22 feet by 7 feet 4 inches diameter; it has two internal cylindrical flues, in the entrances to

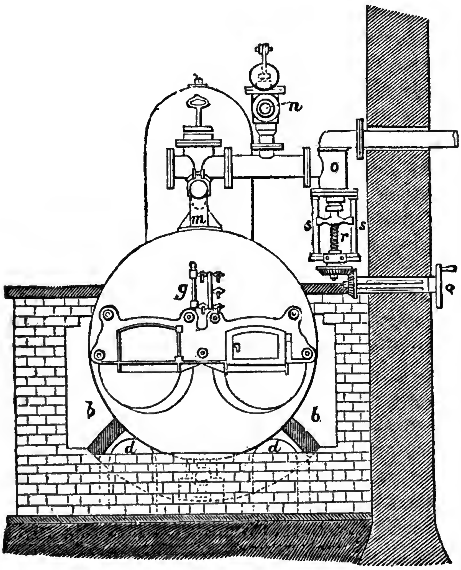


fig. 89.

which are placed the furnaces $6\frac{1}{2}$ feet long by 3 feet wide. The flues are each three feet in diameter for a length of 12 feet from the front, after which they taper off to 2 feet 8 inches, as seen in the longitudinal section fig. 87, and by the dotted lines in the plan. The whole of the taper of the flues is given in the inside edges; this admits of a greater space between the two, for the entrance of a man to clean and repair. These flues act advantageously as longitudinal stays to the flat ends of the boiler; but as the points of connection are below the centre of the ends, the upper portions are stayed from the top of the shell by strips of boiler plate *a a*, 12 inches broad and $\frac{1}{2}$ inch thick, and riveted at each end by angle irons. The arrows in the plan point out the direction of the current of flame, &c. The flame from the internal flues returns back by the side flues *b b*, thence passing by the side openings *c c* in the brick division into the separate bottom flues *d d*, running beneath the whole bottom of boiler, finally joining the main flue at *e*. By this arrangement, the most intense heat is confined to the parts where sediment is most likely to be deposited, that is, on the top of the internal flues; and this part being nearest the surface of the water, the steam evolved is carried off in nearly a dry state. To retain the front brickwork above the fire doors, a stout cast-iron beam *f* is passed across the boiler-end, each extremity of the beam being embedded in the boiler and engine-house walls. The state of the water-level in boiler may be observed either by the glass gauge *g*, or the index of the stone float *h;* or it may be tested by the set of gauge-cocks attached to the glass gauge. The index of the stone float is attached to the counterweight *i*, which works freely inside a cast-iron pillar frame slotted down the front for the passage of the index, and graduated in inches. Immediately before this pillar is placed an alarm whistle, which is rendered self-acting in case of want of water by being connected with the stone float. The steam is taken from the boiler by an open ended T-headed pipe *k*, which is cottered to a bolt-stud passing through the receiving dome. The lower end of this pipe has an elbow for bolting to a short elbow pipe *l*, the end of which is bored to receive the foot of the stop-valve chest *m*. The flange of the latter rests on the top of the boiler, and bolts pass through it to the flange of the pipe *l*, the socket of which is thus held up against the conical foot of the stop-valve chest. *n* is the main safety-valve, fitted on a branch of the cross steam-pipe connecting the valve chest *l* with the main stop-valve elbow *o*. A second safety-valve *p* is also fitted to a branch at the stop-valve chest; this valve is loaded to 5 lbs. per square inch more than the main valve, and is intended to act only in case of the latter getting out of order. The bearing faces of this valve *p* are flat instead of conical, and it has consequently less tendency to stick to its seat. The stop-valve for regulating the steam supply of the engine is worked by a round wheel *q*, on a shaft passing through the wall of the engine-house. This shaft carries a small bevil wheel, whose box acts as a nut for the screwed spindle *r* of the stop-valve, which is guided in its vertical movement by a cross-piece working between the side-rods *s s*. The hand-wheel *o*, being placed in the engine-house, directly opposite the starting-gear of the engine, the engine-man has perfect control over it without moving from his post. Should any accident occur to the engine whilst he is in the boiler-house, he can easily shut off the steam, without going round to the engine-house for that purpose. A double valve chest is also fitted at *t*, for the two purposes of regulating the feed of water and the blow-off. The feed-water is supplied by a pump worked from the side lever of the engine, the water being conveyed by the pipe *w* to the valve chest *t*, whence it passes into the boiler; the surplus water, when the valve in this chest is closed, being discharged by a branch pipe *v* fitted with a lever valve, weighing a little above the steam pressure. The second valve in the chest *t* is for blowing off the dirty water collected in the bottom of the boiler.

Cylinder-Valves and Pistons.—The steam is admitted to the upper and under sides of the piston by means of slide-valves generally, although in some cases lifting or poppet-valves are used. Slide-valves are of three varieties—the "three-port valve," the "long D valve," and the "short D valve." Figs. 90 and 91 show the arrangement of the "three-port valve." In the valve-facing of the cylinder, as *d d* fig. 90, three apertures are cut, as *a b c;* that at *b* ends by a channel shown in fig. 91 to the upper side of the cylinder, that at *c* to the lower side, and that at *a* to the atmosphere. A valve-casing, as represented by *e e e*, is secured to the face of the cylinder; and into this the steam is admitted by the pipe *c c* proceeding from the boiler; a valve *h h* slides on the face of the cylinder, and is moved up and down by the rod *g* actuated by the engine; the valve *h h* is of suf-

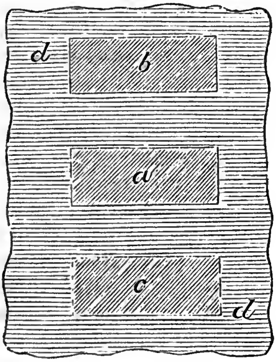


fig. 90.

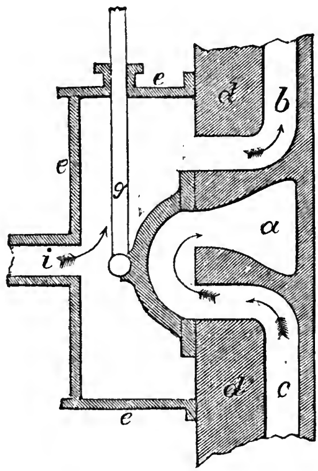


fig. 91.

ficient size to cover two of the ports, one of which is always the exhaust port *a*. In the diagram the valve is so placed as to be admitting the steam from below the piston—this being at the top of cylinder—to pass up by the port *c* in the direction of the arrows, and out to the atmosphere by the exhaust port *a a*. As the steam which fills the casing cannot pass either by *a* or *c*, as the valve *h h* covers both of the apertures, it passes up the channel *b* by the port *b*, and presses on the top of the piston. The valve *h h* is therefore always so arranged, that when the piston is at the top of its stroke, the valve will cover the lower steam-port *c* and the exhaust *a*; while it is at the bottom of its stroke, the valve will then cover the upper steam port *b b* and the exhaust. The valve-rod *g* is worked by an eccentric, as already explained in the work on *Mechanics and Mechanism*. The valve next to be described, and known as the "long D valve," is illustrated by the diagram in fig. 92. The ports for admitting steam to the upper and under sides of the piston are situated, one at top, as *a*, and the other at bottom, as *b*: the valve is semicircular, as at *m n*, and hollow at the back of the face *m*, which slides on the cylinder-facing. The valve is of length sufficient to cover the bottom and top ports *a d*; steam is admitted through the pipe *c* to the hollow space *p p*, situated between top and bottom faces of slide-valve. Supposing top and bottom faces, as *m*, to cover both ports *a d*, the steam from the boiler entering through the pipe *c* will not gain admittance either through *a* or *d*; but will remain only in the hollow part *p p*. But suppose the valve to be moved by the rod *s s*, so that the lower

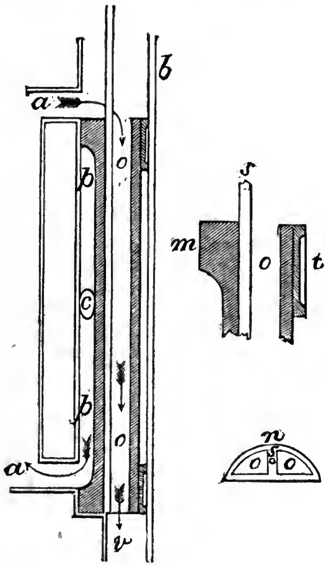


fig. 92.

port is opened, and a communication made between it and the condenser through the pipe *v*, at the same time the upper port is opened and a communication made between it and the hollow space *p p;* the steam then enters above the piston, depressing it. By means of the eccentric the slide-valve is moved in the contrary direction; the upper port *a* is opened, and a communication made between the upper side of the piston and the condenser, the steam passing down the hollow at the back of the valve as *o o;* the steam from the pipe *c* entering the cylinder by the port *d*, and the piston is turned up. By this arrangement it will be seen that an immediate communication is made between the condenser and under side of piston through the port *d;* but the steam from the upper side of piston passing through the port *a*, has to come down the channel along the whole length of valve before getting to the condenser by the pipe *v*. To prevent the steam from passing up or down as the ports are uncovered, the space between the back of valve, as *t*, and the inside of casing *b b*, is packed.

The "short D slide," which remains to be described, consists of two slide-pieces, *a b*, fig. 93, connected by two rods *c d*. In some cases only one rod is used, in others three; the section of this valve is similar to that of fig. 92, or the long D slide. In place of having one exhaust-passage, the short D valve "has two separate exhaust or eduction-passages fitted, to allow of the steam to pass to the condenser, one at the top of the slide-case, and the other at the bottom." Lifting or spindle-valves are similar in construction to those used by Watt in his engines. In working large engines, from the pressure of the steam forcing the valve against the working surfaces, considerable difficulty arises in starting the engine; in some instances a small engine is employed to work the slide on first starting, in others the steam is admitted to both sides of the valve. The "balance-valve" is sometimes used in marine engines. These are much easier to work than the slide-valve. The "equilibrium-valves," used in pumping engines, consist "substantially of a cylinder open at both ends, and capable of being moved on a fixed piston with an upright stem. The cylinder stands over the hole in the steam-

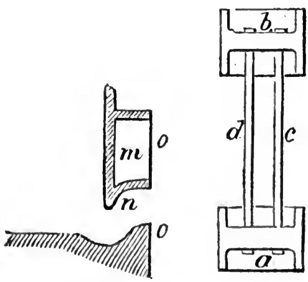


fig. 93.

box, and the piston prevents the steam from passing through it; but when the edge of the cylinder is raised from the bottom of the box, the steam then gains an exit, and it is clear that the cylinder can be raised without any considerable exertion of force, as it is pressed equally in all directions. Instead of the rubbing surface of a piston, however, two ground valve-faces are employed in practice; and the moving part of the valve is not a perfect cylinder."

In working expansively with the slide-valve, the steam is cut off by what is termed the "lap" of the valve. In engines not working expansively the steam is allowed to enter the cylinder during its whole stroke; in this case the length of the valve-face is just equal to the breadth of the steam-port. In working expansively the valve-face is lengthened, so that when the valve is at the middle of its stroke, there will be an excess of width of valve-face over the width of port. Thus in fig. 94, let *d* be the upper and *f* the lower port of a long D slide valve: in the method of allowing the steam to enter the cylinder during the whole stroke of the piston, the valve-face would just be equal to the breadth of port; but where the expansive system is adopted, the valve-face, as above stated, is lengthened at the parts *e e*, the dotted lines giving the portion *a a* where no lap is used. Generally the lap is given in what is called the "steam

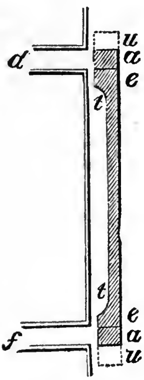


fig. 94.

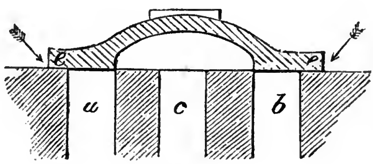


fig. 95.

side" of the port, that is towards *t t;* sometimes, however, the lap is made on the eduction side, as well as towards *u u*, shown by the dotted lines. The effect of the "lap" on the valve is to cut off the steam at an earlier portion of the stroke than would otherwise be the case. An inspection of the diagram in fig. 94 will explain how this is effected: suppose the part *u* to be equal to the face of valve *a* without any "lap" to it,—that is, equal to breadth of port *d*,—when the lower edge of valve at *u* arrived at the upper edge of the port *d* the port would be fully open; but if the valve happened to be lengthened to an amount equal to the part *c* below the dotted line, the port would in this case be closed a space equal to width of port *c*, instead of being fully open if the valve-face had been equal to *a*. In fig. 95 we give a diagram showing the lap of a locomotive or three-ported slide: *a b* the steam ports, *c* the exhaust; the lap is towards the steam side of the valves, as *e e*. In working engines, it is considered to promote their efficiency by giving what is called "lead" to the valve; this is done by making the port open a little before the termination of the foregoing stroke: thus, suppose the piston just about to terminate the up-stroke, the upper port is opened a little, thus admitting steam before the other stroke is quite finished, and in consequence of the lap in the valve the exhaust port is opened sooner; so that by the time the piston begins its down-stroke, the steam from below the piston is escaping freely. If this arrangement was not adopted, we can easily conceive of the engine in its down-stroke having to press against the steam below the piston, which would get slowly out, inasmuch as the valve opens but slowly at the beginning of its stroke. To have the full perfection of working in the cylinder, the escape or release of the steam should be instantaneous if possible; the less steam the piston has to encounter in its motion either up or down the cylinder the better. By the arrangement of the valves now described, the "lap" and the "lead," the speed of locomotives has been much increased.

To obtain the full efficiency of the expansive method of working, it is considered best to have the cut-off instantaneously effected—this the slide-valve cannot do: at the beginning of the throw of the eccentric the motion is slow, and is gradually accelerated; the valve is therefore both opened and closed slowly. In some cases, therefore, expansion-valves and gearing are adopted. One species of expansion-valve is identical in principle and construction with the "throttle-valve;" another form is shown in fig. 96, it is a species of double beat valve; when this is raised, the steam from the boiler passing down *d* goes past the upper and lower valves *b c*, and through *e* to the cylinder. The supply of steam from the boiler to the pipe *d* is regulated by the ordinary throttle-valve; the upper valve *b* is made somewhat larger than the lower *c*; by this arrangement the pressure is greater on the upper valve, and tends to keep it in its seat; it will be observed that little opening of this valve will admit a large supply of steam, and that it is easily worked. The expansion-valve is worked by a series of levers and a *cam*. In p. 81., fig. 156, *Mechanics and Mechanism*, a diagram is given explaining how the revolution of a cam gives a reciprocating motion to the rod *g:* now suppose this rod to be connected with the expansion-valve, in such a way that it can lift it and depress it at intervals, and that these intervals are so timed as to close the expansion-valve at the exact period when the cut-off is to be effected, the system of expansive-working with an instantaneous cut-off will be carried out. It only remains for us to describe how the rod *g* is actuated on at the intervals required. Suppose the pulley *c*, attached to the end of the lever *a*, fig. 156, *Mechanics and Mechanism*, p. 81, to be in contact with the circular part *a* of the cam; it is obvious that no motion of a reciprocating kind would result. But supposing the circular part to be only continued for a certain distance of its circum-

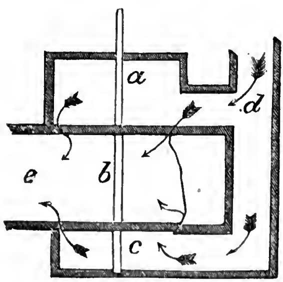


fig. 96.

ference, and that at one part the face of *a* swells abruptly out, when the pulley *c* came in contact with this portion it would be forced out, and the lever with which it is connected would have a reciprocating motion; this would act on the expansion-valve and raise it, admitting a certain portion of steam to work the piston. As soon, however, as the swelled portion of the cam, by its revolution, passed the line of the pulley *c*, the lever would be put into another position, and the valve would be instantly closed, thus effecting the cut-off. By having along the face or breadth of the cam a variety of swells or projections, and by mechanism by which the pulley can he brought in contact with one or other of these " steps" or " grades" as they are termed, any amount of expansion can be effected. The steps are so arranged as to cut off the steam at a certain period of the stroke; and thus the engineer can command any degree of expansion required, by making the desired step come in contact with the pulley: this is done by means of a screw. The pulley can also be disconnected from the cam.

In a form of expansion-valve adopted in locomotives, a supplementary valve to effect the cut-off is placed above the ordinary three-ported slide. This arrangement is shown in the diagram in fig. 97: *a a* is the ordinary slide-valve, *c b* the steam-ports, *d* the exhaust, and *a a* the valve; the valve-casing is at *e e*, *f f* the valve-casing of the supplementary valve. This valve consists of a solid plate with two apertures; these, when opposite the ports in the cover *e e*, admit steam to the

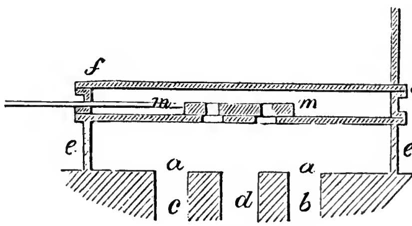


fig. 97.

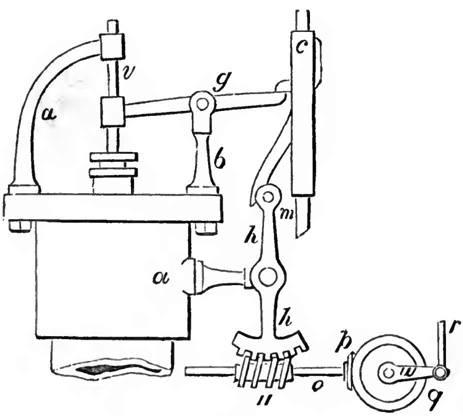


fig. 98.

ordinary valve-casing; the travel of the valve *m m* can be altered at pleasure, so as to cut off the steam at any desired point.

In some cases the expansion-valve is worked by the governor acting on the cam, as in Maudsley's and Whitelaw's engines. We here give diagrams explanatory of a "self-regulating motion for expansion-valves," the invention of Mr. Howson of Manchester.

In referring to the drawings, fig. 98 is a general view of the apparatus. Figs. 99 and 100 are enlarged views of tappet-rod and levers, showing the different positions they assume: *a* is a case or nozzle containing a common

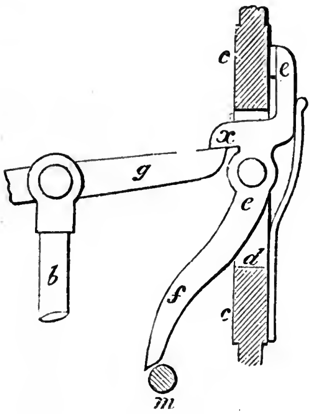


fig. 99.

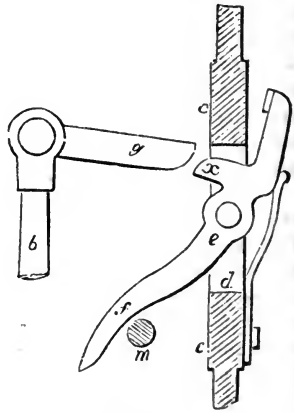


fig. 100.

equilibrium or double-beat valve, through which the steam is admitted through the pipe *i* in connection with the boiler to the cylinder; *v* is the valve-spindle, *u* its guide; *g* a lever for lifting the valve, having its fulcrum on the pillar *b* secured to the nozzle; *c* is a tappet-rod, having an upward and downward motion, and actuated by any suitable means from the motion of the crank-shaft, taking care that for one stroke of the piston there are two of the tappet-rod. A recess or slot *d* is cut in the tappet-rod *c* for the reception of the lever *e*, which has its upper end supplied with a notch *x* and a projection or stopping-piece *e*. The lower tail of the lever *e* forms an inclined plane *f*, which, when required, is allowed to come in contact with and slide against the adjustable stud *m*. This stud projects from the upper tail of the double lever *h*, which has its fulcrum on a pillar fixed to the nozzle, the lower tail being furnished with a series of teeth forming the segment of an ordinary worm-wheel; into this gears the worm *n*, keyed in the shaft or spindle *o*. On the same shaft is the bevil-pinion *p*, which gears into the bevil-wheel *q* fixed to a second shaft, to which a partially rotary motion is communicated by the governor-rod *r* and lever *w*. The operation of the machinery is as follows: The engine being in motion, and the tappet-rod *c* at the extent of its upward stroke, the valve will be down, and the levers *c* and *e* in the position shown at figs. 99 and 100; but on its descent, the notch *x* on the lever *e* will come in contact with the point of the lever *g*, thereby raising the valve. On the further descent of the tappet-rod, the lower end or inclined plane of the lever *e* slides against the stud *m*, and has a tendency to throw the former into the position shown at fig. 10. The lever *g* having its point then released from the notch *x*, the valve drops by its own weight, and, consequently, the supply of steam is cut off from the cylinder, the lever *g* assuming its former position as at figs. 8 and 9. On the return or upward stroke of the rod *c*, the upper part of the notch *x* sliding against and passing over the rounded or under part of the lever *g*, immediately assumes its proper position, preparatory to its making another descent. In order to prevent noise as much as possible, the projection *e*, which prevents the notch *x* from taking too great a hold on the lever *g*, is furnished with a small leather buffer. The variable motion obtained from the centrifugal force of the governor-balls through the action of the governor-rod *r*, lever *w*, wheel and pinion *q* and *p*, and worm *n*, communicates a like variable motion to the lever *h*, and, consequently, to its projecting stud *m*. It will now be easily perceived that the inclined plane *f* on the lever *e* will come in contact with and slide against the stud at different positions in the descent of the rod *c*, and the valve have varied lengths of time for remaining open; and consequently, varied quantities of steam will be admitted to the cylinder, according to the variations of the governor. The vibratory motion required for the stud *m* is so small, and the means for effecting it so powerful, that the most trifling alteration in the action of the governor will be communicated to the stud *m*; while the adoption of the worm and segment will form an infallible and solid bearing for the pressure of the inclined plane.

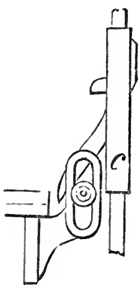


fig. 101.

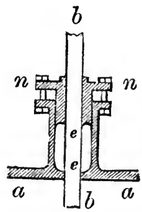


fig. 102.

Fig. 101 is a sketch in which the governor connection is dispensed with altogether; the stud *m* being adjusted by hand to a bracket fixed to the nozzle, the side of the slot in the bracket having a scale to which an index on the stud may be pointed, in order that the engineer may at once place it in a position that the steam may be cut off at the particular portion of the stroke required.

The piston-rod, in moving up and down through the cylinder-cover, is kept steam-tight by what is called a "stuffing-box." This is shown in fig. 102: *a a* is part of the cylinder-cover; a cylindrical hollow cup or box is cast on this of a much larger diameter than the piston-rod *b b;* this is curved inwards, as shown in the diagram; the aperture in the cylinder-cover is a little larger than the piston-rod, to admit of its easy working; packing, composed of plaited hemp, is wound tightly round the piston-rod *b b*, at the part *e e;* the stuffing-box "cover" *n n* is placed above this packing, and screwed tightly down by the screws.

The piston, as originally made by Watt, was kept tight by hempen packing; metallic pistons are now almost universally used. That known as Goodfellow's is extensively used in Lancashire. In fig. 103 we give a transverse section of this: *a a* is the body of the piston, with shoulder turned on it at *e*; an annular ring *o* is placed loosely round the piston;

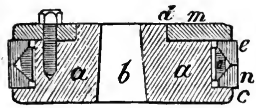


fig. 103.

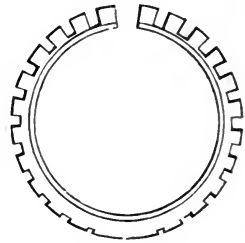


fig. 104.

a plan of this ring is shown in fig. 104; this is turned eccentrically, and worked on its edge; this gives a uniformity of action to the whole circumference: its upper and lower edges are bevilled, as shown in fig. 106; these bevils bear or press against other rings *n n*, the interior of which are similarly bevilled, as shown in fig. 105. The outer springs *n n* are


fig. 105.

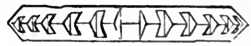


fig. 106.

accurately ground to the upper and lower plates *m* and *c*, and the whole secured by the screw-bolts as shown. The outer rings *n n* are kept pressed against the cylinder by the action of the internal ring *o o* lying loosely on the plate *c*. These diagrams will sufficiently explain the peculiarity of a metallic piston; for notices and illustrations of other varieties we must refer the reader to other and larger works.

We have already illustrated the mode of connection of condenser and cylinder, and the condensation by a jet of water admitted to the condenser; in fig. 107 we give a sectional diagram of an improved form of injection-valve for condensers introduced by Mr. Cowper, and described by him at the Institution of Mechanical Engineers. The object of this valve "was to maintain the full pressure of the water at the point of entrance into the condenser, and to obtain a more efficient distribution of the jet of water, without danger of getting it choked." In the diagram, fig. 107, *a* is the condenser, *b* the eduction-pipe leading from the cylinder, *c* the air-pump, *d* the cold water cistern in which they are immersed; the injection-valve is a conical one, rising a little above the bottom of the condenser, with a perforated cup below in the cistern. As shown in the drawing, the valve is lifted up by the screwed rod; and the injection-water can be regulated with the utmost nicety. The water enters the condenser in a fine sheet all round the valve, which sticks to the sides of the condenser, and fills the whole space with a fine spray. Mr. Cowper has also modified the air-pump; the bottom drops into a well, as in the drawing, in the bottom of the condenser, and the water rises up the space when the air-pump bucket

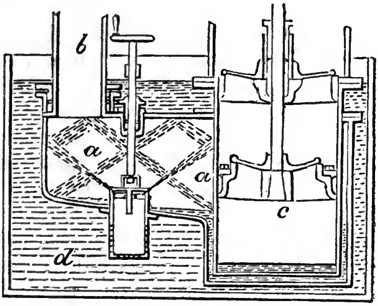


fig. 107.

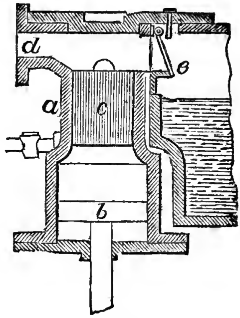


fig. 108.

dips into it, forming a water-valve instead of the ordinary foot-valve, and giving pressure enough to insure the bucket-valve opening if there was any obstruction.

In place of passing the steam into a receptacle, and being condensed by coming in contact with cold water, in other forms of condensers, as Hall's, the steam is passed down a series of copper-pipes externally surrounded with cold water; the condensed water falling into a box beneath, from which it is pumped away. By this arrangement the water used for raising steam can be again returned to the boiler. Mr. Pirson, of America, has recently introduced a condenser known as the "Fresh Water Condenser."

The peculiar feature of this condenser, which distinguishes it from all others previously known to the public, is the placing of the condensing tubes horizontally within the ordinary shower-condenser, which is made of enlarged dimensions for the purpose. By this arrangement, the water required for condensation is admitted through the ordinary injection-cock, and rises to the top of the external condenser; where it is discharged on a scattering-plate, from whence it passes directly on to the tubes of the internal condenser, which are below it, and arranged in three ranges or sets, one above the other. The steam from the cylinder is admitted into the upper range, and passes through the three before being discharged at the bottom. The fresh water produced by the condensation of the steam is pumped out by a small pump, and immediately returned to the boilers; while the water used to produce condensation is taken out by the air-pump of the engine. The internal condenser is not attached to the external one, but merely laid in it. The three ranges are separately made, and the outlet from the upper slips loosely into the one below it; so that when the whole internal condenser is together, it may be moved from one-eighth of an inch to one-fourth of an inch in any direction. This freedom prevents any liability to fracture from unequal expansion; and the tubes being in vacuum relieves them from all pressure. As the condensing water reaches the bottom of the tubes, it is immediately pumped out; so that there is not at any time any water around the tube other than the thin sheet passing over their surfaces. On the *Osprey*, the vacuum within the tube of the internal condenser is twenty-six inches, and the same in the external one; the internal vacuum is the result of condensation, while the external vacuum is produced by the air-pump. The *Osprey* has made three passages, or 2,750 miles in all, and has no trouble in keeping a full supply of fresh water in her boilers. This condenser has been used with considerable success on board the above-named vessel. Our account is extracted from a paper read by Mr. Bartol, at a late meeting of the Franklin Institute of Philadelphia.

Mr. Siemans, of Birmingham, an engineer well known for his ingenious inventions, has recently introduced a form of condenser highly spoken of, and known as the "Regenerative Condenser." At a meeting of the Institution of Mechanical Engineers, Mr. Siemans stated that the origin of this condenser was a suggestion to the author, by Mr. Graham of Mayfield Works, "to recover the heat from the condensing in the form of a reduced amount of boiling hot water." It consists of an upright rectangular trunk, *a*, of cast-iron, the lower end of which is cylindrical, and contains a working piston, *b*, which performs two strokes for each one of the engine. In the trunk is a set of copper plates, *c*, upright and parallel to each other; the intervening spaces being the same as the thickness of the plates, viz. between $\frac{1}{12}$th and $\frac{1}{16}$th of an inch.

The upper extremity of the condenser, fig. 108, communicates on the side, *d*, to the exhaust-port of the engine; and on the other, through a valve, *e*, to the hot well. The plates are fastened together by five or more thin bolts, with small distance washers between each plate. There is a lid at the top of the trunk, by removing which the set of plates can be lifted out. Immediately below the plates the injection-pipe enters.

The action of the condenser is as follows: Motion is given to the piston. At the moment that the exhaust-port of the engine opens, the plates are completely immersed in water; a little of which has entered the passage above the plates, and is, together with the air present, carried off by the rush of steam into the hot well, the excess of steam escaping into the atmosphere. The water then, in consequence of the downward motion of the piston, recedes between the plates, exposing them gradually to the steam, which condenses on them. Their upper edges, emerging first from the receding water, are surrounded by steam of atmospheric pressure, and become rapidly heated to about 210°. The immersion of the plates still continuing, the steam is constantly brought into contact with fresh cool surface, by which the greater portion of it is condensed; until, as the piston descends, the injection enters, and completes the vacuum. This is done by the time the working of the piston of the engine has accomplished one-seventh of its stroke. The upper extremities of the plates become heated to near 210°, and the lower to about 160°.

Taking the initial temperature of the condensing water at 60°, the final temperature at 210°, the latent heat of steam at 212° 960 units, the quantity of water required is 6·6 lbs. to condense 1 lb. of steam of atmospheric pressure. The common injection condenser (supposing the temperature of the condensed steam to be 110°) requires 21·2 lbs. in place of 6·6 lbs.

In fig. 109 we give a drawing of the ordinary vacuum gauge, used in connection with condensers in order to ascertain the degree of vacuum attained. The mercury is contained in a cast-iron cup open to the atmosphere; in this is placed a glass tube, open at the lower end and closed at its upper. A small iron tube is provided with a stop-cock, and connected with the condenser; this tube passes through the mercury in the cup, and up the interior of the tube near to its top. The air is exhausted from the

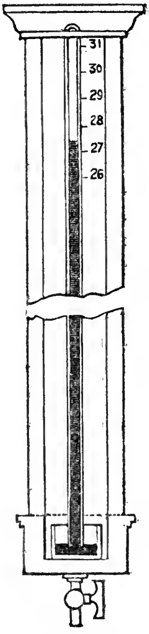


fig. 109.

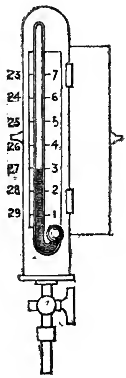


fig. 110.

glass tube through the iron tube connected with the condenser, as the mercury rises in the glass tube in proportion to the difference between the pressure of the uncondensed vapour in the condenser and the pressure of the atmosphere. To show the higher vacuums of 29 and 30, the height of this gauge must be nearly three feet. To obviate the inconvenience attending this form of gauge, the short vacuum gauge is used, as in fig. 110. A small glass tube contains the mercury, and is filled carefully as an ordinary barometer; it is bent upwards at the bottom, and ends in a bulb, which is provided with a small orifice at the upper side. The tube is attached to a scale, and entirely enclosed in a glass case, which is carefully cemented to a brass cup, terminating in a stop-cock and pipe connected with the condenser. The air in the interior of the glass case is always of the same density as in the condenser. In the long vacuum gauge, in fig. 109, the mercury is driven frequently out of the cup, if the stop-cock is left open while blowing through previous to starting. The short vacuum gauge, although possessed of many advantages, as shortness and compactness, has also disadvantages; these are, first, the vapour from the condenser deposits frequently a mist in the glass case so dense as to obscure the scale; and secondly, if the stop-cock is not shut while blowing through, the case becomes filled with steam or with hot water; and its safety is thereby endangered. To obviate these inconveniences, Mr. Bramwell, of London, has designed an improved vacuum gauge, which he described before the Institution of Mechanical Engineers, and of which we give the diagram in fig. 111. "Instead of immersing the whole of the tube and scale in a glass chamber connected with the condenser, the bulb only is enclosed in a brass cup with a screw lid, on which the scale is cast; and the rest of the mercurial tube is passed through a st ng-box in the middle of this lid, protecting it from injury by pushing it in a depression in the scale like a common thermometer. On the bottom of the brass cup is a stop-cock, with the pipe by which connection is made with the condenser; the same density is always preserved in it and the cup; and thus, the pressure being removed from the surface of the mercury in the bulb, it of course falls according to the rarefaction, a fall that can always be observed, as the tube containing the mercury is totally uncovered. By this means, the first and great objection to the short vacuum gauge is done away; and likewise the second, which is common to both long and short, viz. the risk of the stop-cock being left open while blowing through; as with this gauge it is a matter of perfect indifference whether it is open or not, as the only thing that can take place if it is open is, that the brass cup is filled with steam; but this can neither blow out the mercury nor damage the gauge."

fig. 111.

In the companion volume to this treatise, *Mechanics and Mechanism*, we have described pretty fully the details of construction of the various parts of steam-engines, as connecting-rods, cranks, &c. and the method of putting the various parts together; we are, therefore, spared the necessity of here giving them, and proceed to the consideration of other matters worthy of notice.

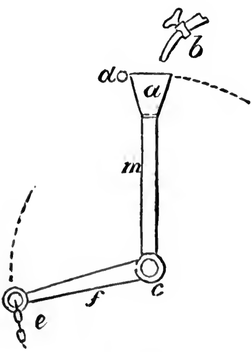


fig. 112.

Of contrivances for regulating the speed of steam-engines, the centrifugal-governor is the best known: the arrangements and method of attachment of this mechanism we have already, in *Mechanics and Mechanism*, fully described. In the pumping-engine the ordinary governor is not used, but a contrivance known as the "cataract" is adopted instead. This was in use prior to the period of the introduction of Watt's engines, and has since been much improved. The principle of the original cataract will be easily understood by an inspection of the diagram in fig. 112. Suppose *a* to be a vessel for containing water; on the end of the lever *m*, jointed at *c*, another lever, *f*, is attached to and forms part of the lever *m;* water is allowed to pass into the vessel *a* through the pipe *b*; as soon as the *a* fills, it tilts over in the direction of the arrow, and lifts up the end of lever *f*, as shown by the dotted lines: to the end of *f* a chain *e* is attached; this is connected with the end of the lever opening the injection-valve. The vessel *a* can only tilt over in the one direction, the stud *d* preventing it from falling the wrong way;

when empty, the vessel *a* is brought up to its original position by the weight of the lever *f*, &c. The whole is contained in a box, from which the water is led away after working the cataract. The number of times the injection-valve is opened determines the number of strokes the engine makes in a given time; and the falling of the box or vessel *a*, which opens the injection-valve, is regulated by the quantity of water allowed to pass through the pipe *b*; this quantity of water is therefore proportioned to the quantity to be drawn from the mine, or the work to be done by the engine. The reader will find descriptions of forms of improved cataracts in the *Artisan Treatise on the Steam-Engine.*

In cotton-mills, and in cases where the engine is loaded to a certain extent, accidents frequently occur by parts of the machinery breaking down. The engine, thus relieved of a certain part of its load, "runs away," as it is termed, at a greatly increased speed, endangering the stability of the whole apparatus. The ordinary mechanism of the throttle-valve and governor is not found capable of making the engine recover its usual speed. An ingenious contrivance, highly esteemed, is given in the following diagram, fig. 113. The main object of this invention is to prevent damage by the accidental alteration of load, and to regulate the speed of steam-engines. It is intended to supersede the common throttle-valve, and prevent variation of speed and the many breakages arising from accidental alterations of weight. The valves can readily be connected with ordinary governors; and when attached, are so sensitive, that should a shaft break, or any weight be suddenly thrown on or off, the engine will recover its usual speed in less than two revolutions, without any interference by the engineer. This will be obvious, when it is considered that there are two valves fitted to the same spindle; and consequently, that each of them need be opened to only one half the extent, as if there were one valve. The result is, a throttle-valve of extreme sensibility, half an inch being the utmost amount of play allowed to the spindle between wide open and quite shut; therefore, a very slight change in the position of the governor-balls produces considerable change in the amount of opening afforded by the valves.

The governor is connected with the valve-spindle by a fork, in the usual manner, which, by means of a crank-lever, gives a slight motion on its axis to a bar, provided at the other end with another crank-lever connected with the valve-spindle. It may be attached to all ordinary governors. In the case of two fifty-horse engines coupled together in Sir C. Armitage's mill, at Pendleton, near Manchester, the result of a trial by throwing off the whole weight was the recovery of the usual speed in $1\frac{3}{4}$ revolutions. The load on these two engines consisted of 20,000 throstle-spindles, 13,000 mule-spindles, and 250 power-looms, with all the necessary apparatus for working the mill.

In fig. 113 we give a diagram illustrative of this apparatus, so capable of instantaneously regulating the performance of engines. *a* is the steam-pipe from boiler, *c c* the double-beat valve; when this is raised by the lever actuated on by the lever *d* of the connecting-rod, the steam passes from *a* in the direction of the arrows to the steam delivery-pipe *b*.

The "hydraulic motion regulator" is an American invention, recently introduced into this country, and which has already taken a high place as an effective governor for steam-engines; we give a diagram and description of this apparatus, taken from the inventor's circular (Mr. Pitcher).

The principle of the invention consists in working a small pump, the water delivered by which acts in the plunger of a second cylinder or barrel: the

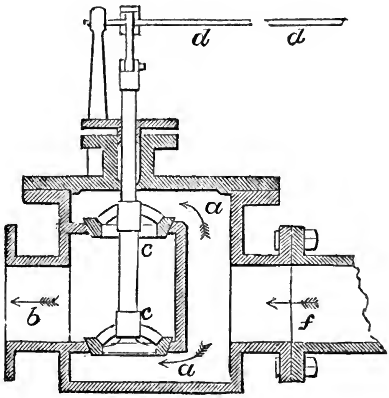


fig. 113.

water from the pump escapes through an aperture of a certain area; this is calculated so as to maintain the plunger at a certain height in the cylinder. Should, however, the speed of the engine increase beyond its regular working speed, the pump is in consequence worked faster, and a greater quantity of water delivered to the plunger cylinder: but the aperture for its escape remaining unchanged, it cannot get away, it therefore fills the cylinder to a higher level; this raises the plunger, which, connected with the regulating-valve or throttle-valve, lessens the supply of steam to the cylinder and reduces the speed. The pump is worked by the engine by any of the ordinary methods of connection. In fig. 114, *e* is the pump worked by the engine; *c* the suction-valve, through which the supply of water is obtained, *b* the delivery-valve, supplying the cylinder *f*. To prevent the plunger from rising higher than necessary, a small hole, *g*, is made in the cylinder; when the plunger rises above this the water escapes by it, and the plunger rises no higher. The piston-rods pass through the bonnet or cover of the external casing *jj;* cups *i k* are used to return any water that may be drawn up through the stuffing-boxes; the piston-rods are thus lubricated, or made to work smoothly, with water surrounding them. The whole apparatus is enclosed in the casing *jj;* so that the same water is used over and over again. A spring is coiled round the piston-rod of plunger *f* at *z;* this prevents its falling further than necessary. The opening by which the water ordinarily escapes is made just above the delivery-valve *b;* and the amount of opening is regulated by a handle or lever which passes through the cover *h*, according to the speed at which the engine is desired to run. In place of the ordinary throttle-valve, the inventor prefers to use a regulating valve similar in principle to the disc-valve employed as the "regulator" in locomotive engines.

In calculating the power of steam-engines, there are two terms used—the "nominal power" and the "actual, or effective power." By the term "nominal power," reference is made to an engine having a cylinder of given diameter, a given length of stroke, with a uniform pressure upon the piston of 7 lbs. per inch. Watt calculated the effective pressure on the piston in small engines at 6·8 lbs. per inch, and in large—as 100 horse-power—at 6·94; 7 lbs., however, is the effective pressure calculated. By the term "actual" power, is meant the number of times 33,000 lbs. the engine is capable of lifting 1 foot high per minute. By the term "duty" of an engine is meant the amount of work done in relation to the amount of fuel consumed.

In calculating the nominal horse-power of an engine, the following rule is adopted: "Square the diameter of the cylinder, and multiply the number of square inches thus found by the cube-root of the length of the stroke in feet, and divide the product by 47; the quotient is the number of nominal horse-power of the engine."

By the term "horse-power," as introduced by Watt, was meant the mechanical force necessary to lift 33,000 lbs. 1 foot high per minute. Prior to the extended introduction of steam-engines, the work at mines, &c. was frequently done with horse-power; it became, then, of importance to be able to state the amount of work done by a steam-engine, as compared with a given number of horses. The power of a horse, as calculated by Watt, was equal to the raising of 33,000 lbs. 1 foot high in a minute. Engines now, however, calculated at this rate, really exert a greater power than the nominal power; it is, therefore, of importance to be able to calculate the effective or actual power of an engine, without reference to its nominal power. This is ascertained by means of the "indicator," which gives the effective pressure on the cylinder of the engine: from this is deducted a pound and a half of pressure absorbed in friction, &c.; the velocity of the motion of the piston in feet per minute is thus ascertained: this is done by multiplying the number of revolutions of the engine per minute by the length of stroke. These data having been ascertained, the

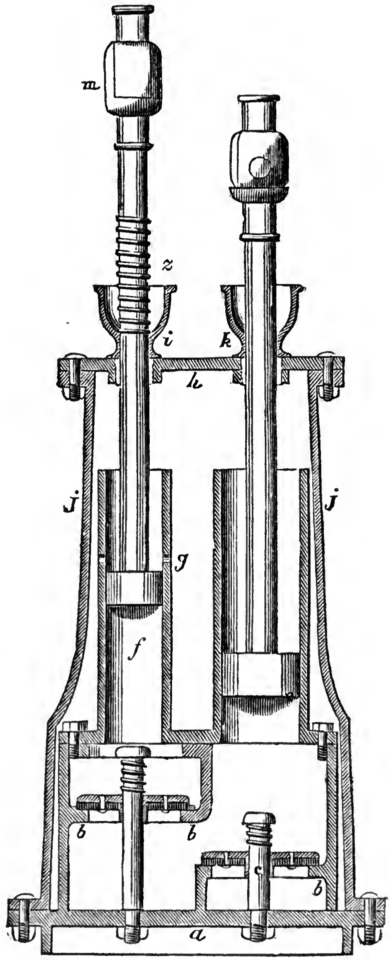


fig. 114.

following rule will give the effective power of the engine, calculated on Watt's data: "Multiply the area of the piston in square inches by the effective pressure (found as above) and by the motion of the piston in feet per minute, and divide this by 33,000; the quotient is the actual number of horse-power." For each horse-power of an engine it is calculated that 33 cubic feet of steam is expended per minute, or an evaporation of 1 cubic foot of water per hour. The combustion of 1 lb. of coal is calculated to raise 6 or 8 lbs. of water into steam; Watt reckoned 7½ lbs. of water to be evaporated by the combustion of 1 lb. of coal. In the modern Cornish engines, the same quantity of fuel evaporates 10 lbs. of water. Land engines are generally calculated to consume 10 lbs. of fuel per hour for every nominal horse-power, or 5 or 6 lbs. for each actual horse-power. In the Cornish engines the duty of an engine is "expressed by the number of millions of pounds raised one foot high by a bushel, or 94 lbs. of Welsh coal;" a bushel of Newcastle coal will only weigh 84 lbs; and, in comparing the duty of a Cornish engine with the performance of an engine in some locality where a different quality of coal is used, it is necessary to pay regard to such variations." In the engine at Long Benton Colliery, erected by Smeaton, the duty performed was equal to 9·45 millions of pounds, raised 1 foot high by the consumption of 1 bushel of Newcastle coal. In the present time, what with improved engines and boilers, and the extensive adoption of the principle of expansive working, the duty of Cornish engines is estimated at 60,000,000 lbs.; and in some instances the duty has increased to the large amount of 100,000,000 lbs. raised 1 foot by the consumption of 94 lbs. of fuel. For much valuable practical information on the power of engines, the heating surface for each horse-power, &c. &c. we refer the reader to Bourne's *Catechism of the Steam Engine.*

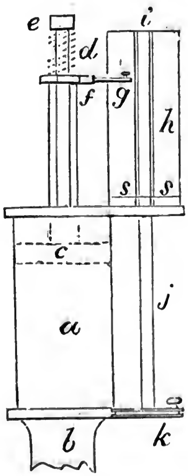


fig. 115.

We now, in concluding the present division, give a description and diagrams of the important instrument, the "indicator," so essentially necessary in computing the effective power of steam-engines. A small cylinder, as *a*, fig. 115, is placed in connection with the interior of the cylinder, either above or below the piston,—generally it is screwed into the aperture made in the cylinder-cover; a stop-cock is placed in the pipe *b*, by which the connection between the interior of steam-engine cylinder and that of the indicator can be closed or opened as required. Into the cylinder *a* a piston works; within the interior of the rod *c* of this, which is made hollow on purpose, a spiral spring is placed; the lower end of this is fixed to the piston, and the upper to a small cross-head, *e*, supported by side-rods, connected with the cylinder, *a a*. To the top of the piston-rod a pencil, *f g*, is attached; the point of the pencil works in contact with a slip of paper wrapped round the small cylinder, *h*, and kept in contact with it by the vertical strip of brass, *i i*, on which is marked a scale. The axis of this cylinder, *h*, is continued downwards, and provided with a pulley, *k*. This pulley is connected with the parallel motion, or other reciprocating part of the engine, by which motion is given to it, causing it to revolve only in one direction: the cylinder, *h*, makes its return motion to its original position by a spring coiled up in the bottom near *s s;* the direction of the cord, after leaving the pulley, is changed by a guide-pulley not shown in our diagram. The effect of the two motions, namely, the up and down motion of the piston, and the revolution of the cylinder, *h*, is to cause the pencil, *g*, to describe a curve, varying in its outline. Before the connection is made between the interior of cylinder *a a* and the steam-engine cylinder, what is called the atmospheric line is drawn on the paper; this is effected by pulling the cord, or allowing the engine to act on the pulley. The cock at the pipe *b* is then opened, when the piston is at the top of its stroke: the steam acting on the cylinder (steam-engine) piston acts also on that of the indicator; this will therefore rise, and with it the pencil, which is made to press slightly on the surface of the paper by a small spring; at the same time the roller, or cylinder, revolves. A line is thus traced on the paper, "which rises higher up on the cylinder as the pressure of the steam increases, and comes lower upon it as the steam-pressure subsides."

The method of ascertaining the pressure on the piston of the engine, from the diagram thus obtained, is very simple, and will be easily understood by reference to fig. 116. Suppose *a b c d* to be the slip of paper, on which the indicator diagram has been taken, and *e f* the atmospheric line, the divisions at the ends, as at *b c*, correspond to the divisions of the scale *i* on the indicator, fig. 115. Divide the length of the diagram into any number of equal divisions, and through these draw lines at right angles to the atmospheric line *e f;* measure the lengths of the spaces thus formed by the intersection of the diagram with the lines, as the length from *m* to *n*, and from *r* to *s*, and so on (the measurements must be taken from a scale corresponding to that in the indicator-scale), and all the lengths together ; divide this by the number of spaces, and the quotient is the mean effective pressure on the piston in pounds per square inch. We have already described the rule for calculating the effective pressure of the engine. The indicator is not only useful to ascertain the amount of power exerted by the strokes of a steam-engine, but it serves also to point out particular defects in the working. Thus the nearer the diagram attains to the form of a parallelogram, the more perfect is the working of the engine. Where certain deviations from the square at the corners are indicated on the diagram, certain defects are made known.

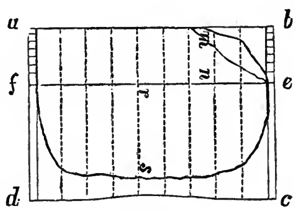


fig. 116.

For full information on the practical working of the indicator, and the method of ascertaining the defects as indicated by the diagram, we must refer the reader to other and more practical works—as the *Indicator and Dynamometer*, by Professor Main and D. Brown ; published by Hebert, Cheapside.

CHAPTER IV.

ROTATORY ENGINES AND OTHER VARIETIES.

The obtaining of a rotatory motion by the direct action of the steam, without involving the use of reciprocating motion as in the piston-rod of a cylinder engine, has long been a favourite problem with many mechanics, on the supposition that the various parts of an ordinary engine, as the piston, beam, connecting-rod, and crank, were not merely inconvenient, but that they acted as counteracting agencies to the full development of the power of the engine. Numerous attempts have been made to substitute an engine in which the main shaft received motion directly from the action of the steam; this acting on certain mechanical arrangements, placed within a case or exterior covering. The great objection which the advocates of the rotatory class of engines have raised, is the assumed loss of power sustained by the use of the crank. It is, however, an easy matter to prove the fallacy of this opinion; suffice it to state, that the opinion that there is a loss of power by the use of the crank, arises from a misconception of the principles of its action. There is no doubt that an efficient rotatory engine would be highly useful for certain applications, as the driving of a screw-propeller, where direct action is required; and a great saving of space and material would also be effected; but so far as the assumed gain of power which would result from their introduction is concerned, it may be taken as a general truth, supported by the best mechanical authority, that no advantage of this kind is possessed by them over the ordinary reciprocating kind. The great desideratum now hoped for, by the introduction of a rotatory engine among those mechanics who devote their time to its attainment, is not a gain of power, but only a simpler and more convenient mode of applying it. "Such a gain," says the reporter to the jury, section A. class v. Great Exhibition, "might indeed result from a freer access of the steam to the piston, from a diminution of the friction or the jar of the working parts, or from a more complete expansion; but, thanks to the more general diffusion of information in mechanics, practical men now know that there is no more possibility of increasing the work of an engine by merely altering the direction of any of its working parts, than there is of increasing the quantity of water which a reservoir will supply, by varying the pipes which serve to distribute it."

Although eminent authorities on engineering matters have expressed opinions inimical to the idea that a good rotatory engine will be introduced to the superseding of the reciprocating engine; still it is right to state that others, perhaps of equal standing, hold the contrary. The result, however, of the various discussions entered into on the point, seems to be that, if the engines can be kept tight, and the uniformity of wear in the packing effected, the great difficulty attendant on bringing them into practical operation will have been obviated. That this difficulty is one of no ordinary kind, may be gathered from the statement of one of our most practical engineers, that "he would as soon think of inventing perpetual motion, as of overcoming it."

We now proceed to illustrate the principle of a few of the most celebrated engines of this class yet introduced.

Rotatory engines are of several kinds; the Æloipile of Hero, already described, is an engine of the reaction species. A modern modification of this is exemplified in Avery's engine, introduced by Ruthven of Edinburgh, and to which at one time considerable attention was attracted.

This engine consists of two hollow arms *a b*, fig. 117, attached to a central pipe *c*, which revolves on its axis, and gives motion to the pulley *e*, from which the power is distributed as required by a belt; at opposite sides of the extremities of the pipes or arms *a b*, apertures are made, and the steam issuing from these in contrary directions, as in Hero's, cause the arms to revolve with great rapidity: steam is admitted to the arms through the pipe *d*. The arms are enclosed in a case *f f;* and the steam, after working, is let off to the atmosphere by a pipe communicating with the bottom of the case *f f.* The cold-water pump is worked by an eccentric on the horizontal shaft. Although several engines of this class have been introduced, and, according to the patentee, with marked success,

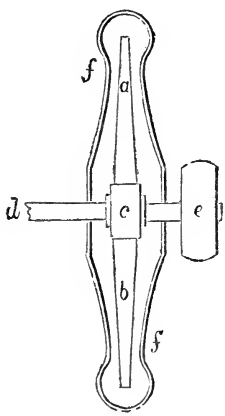


fig. 117.

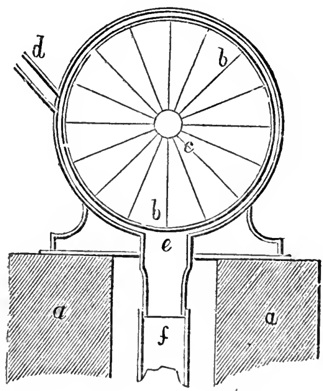


fig. 118.

as simple and economical, yet their number is by no means increasing. One great objection to it is the high pressure of the steam employed, and the limit to the power of the engine set by the difficulty of increasing the length of the arms *a b*, so as to obtain increase of power; the amazing velocity at which the arms revolve, 3000 and 4000 times per minute, makes it liable to speedy disarrangement of parts.

Rotatory engines are sometimes made on the impulse principle, as exemplified in Branca's steam-wheel, already noticed. A modification of this principle is carried out in the rotatory engine patented in 1841 by Corde and Locke.

In fig. 118, *a a* is the foundation on which the steam-wheel is supported, *bb* the steam-wheel, provided with floats or buckets at the extremities of the radial arms; the shaft of this, as *c*, is carried through the outer-casing in which the wheel revolves through stuffing-boxes; the pulley or toothed wheel for communicating motion to the apparatus to be worked by the power of the engine is placed on this shaft outside the casing of the wheel. A vacuum is made in the interior of the casing by the medium of the condenser *f*, to which the steam is conducted by the pipe *e*. The exhausting is carried on by a small double-acting cylinder-engine working the air-pump. Attention has been much directed to this invention, principally through a very favourable report as to its working capabilities by Josiah Parker, the consulting engineer to the Royal Agricultural Society of England. A novel fact was elicited in the course of the experiments—namely, that when the steam, after working an ordinary reciprocating cylinder-engine, is admitted to the exhausted case, and made to impinge upon the floats of the wheel before finally passing to the condenser, an additional power is obtained equal to one-third, or 33 per cent; and this without any increase of fuel or increase of condensing apparatus.

The next class of rotatory engine to which we will direct the reader's attention, is that in which the piston is made to revolve round its axis. In the patent granted to Watt in 1769, he included a claim for a rotatory engine; and, from his own statement, it appears that "a steam-wheel moved by force of steam, acting in a circular channel against a valve on one side, and against a column of mercury or other fluid metal on the other side, was executed at Soho upon a scale of six feet, and tried repeatedly; but was given up, as several objections were urged against it." This failure did not, however, influence Watt to give up his trials; but in 1782 he took out a patent for two engines on a similar principle: one of these we here append an illustration of. In fig. 119, *a a* is a circular casing, *b* an axle passing through stuffing-boxes at the ends of the casing, *c* a piston revolving in the case, *d* a valve which, turning on a hinge like a door, passes into the recess *e; f* the pipe admitting the steam to the casing, *g* that leading to the condenser. The valve *e* extends the whole depth of the cylinder. On steam being admitted to the casing, it presses on the piston *c*, and causes it to revolve; on reaching that part of the casing near the eduction-pipe *g*, the piston strikes the valve *d*, and forces it into its seat *e;* the steam-entrance is thus closed, and the steam in the casing rushes to the condenser through *g*. On the piston passing *e*, the valve *d* falls open, as before, admitting steam to the casing to act on the piston. From the force with which the piston strikes the valve *d*, the machine rapidly falls into disrepair.

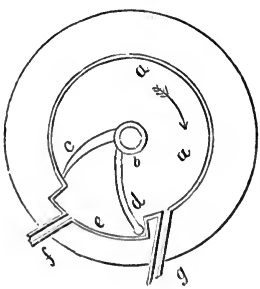


fig. 119.

Murdoch, an engineer, employed under Mr. Watt at Soho, introduced a rotatory engine, of which, in figs. 120, 121, we give drawings; the steam is admitted by the pipe *e*, and acts upon the projecting arms *b* of the rollers *a a*, placed within the casing *d d*. The steam, after working the rollers, passes into the condenser by the pipe *f*; the air-pump was worked by a crank fitted on the end of axis *a*. Packing is introduced into cavities at the end of each projection, as at *b*, to keep them steam-tight during the revolutions. There is much leakage in an engine of this kind, and the friction is great.

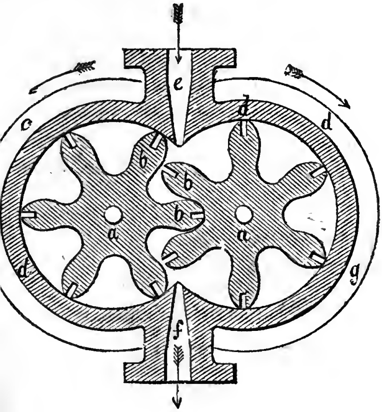


fig. 120.

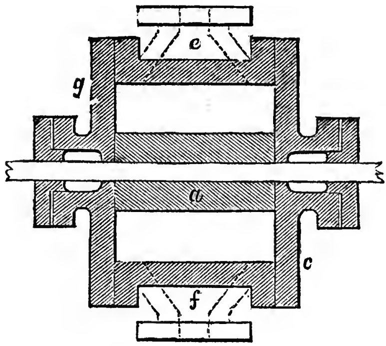


fig. 121.

From the great variety of rotatory engines of this class which have been introduced from the time of Watt till now, it is quite an impossibility for us to notice even a small proportion of their number; we must refer

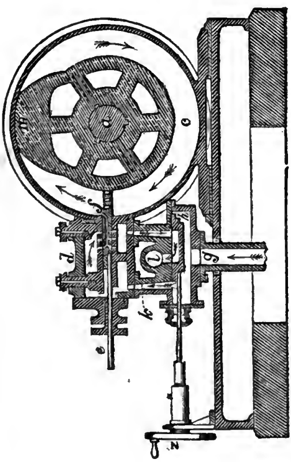


fig. 122.

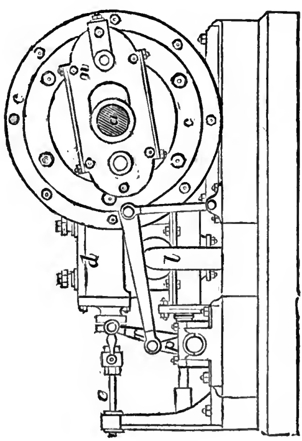


fig. 123.

the reader to larger treatises, where several of the most ingenious are illustrated. We propose only giving illustrations of one or two of the most recently introduced, and which, from their admirable arrangement of parts, and their general efficiency, are likely to be introduced on a comparatively extensive scale.

A form of rotatory engine, which has been spoken highly of by competent authorities, is that invented by Mr. Isaiah Davies of Birmingham. Through the courtesy of William Johnson, Esq., editor of the *Practical Mechanic's Journal*, we are enabled to present our readers with a description and illustration of this (as well as of the one following this) ingenious rotatory steam-engine. In fig. 122 we give a transverse section of the engine, which is of the duplex construction. Fig. 123 is an external end-elevation corresponding, showing the arrangement of the cam motion for working the valves. Fig. 124 is a plan view, showing an engine or cylinder in elevation; the other in section. *a* is the main shaft of the engine, which

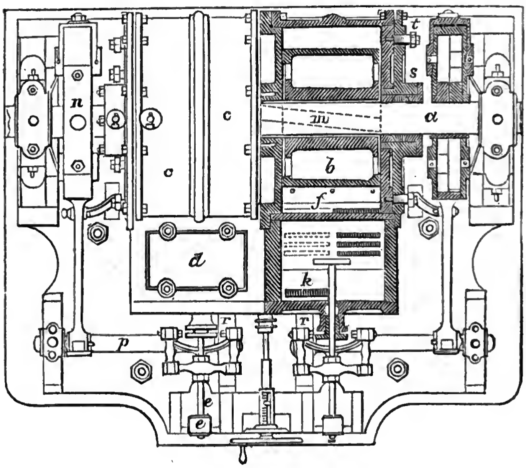


fig. 124.

both directly receives and transmits the power. Two pistons *b*, are carried loose on this shaft on three feathers; by this arrangement the pistons are carried round by the revolution of the shaft, but are allowed a certain amount of play laterally; that is, they can move backward and forward a slight extent on the shafts. It is in this point that the main objections to rotatory engines have been overcome; this side to side movement of the pistons preventing all wear and injurious binding of the piston: and by means of the end set-up plates the surest adjustment of parts can be obtained, thus obviating the excessive wear found in other engines of this class on the surface of the piston and the ends of the cylinder. The pistons, *b*, are cylindrical for the greater portion of their circumference, but have each projections cast as in fig. 123, these receiving the actuating pressure of the steam. The axes of the pistons coincide with the centres of the cylinders; and the diameter of the former being less than that of the latter, an annular space is left all round as at *c*. The pistons are placed on the shaft in such a manner that the projections are exactly opposite each other. The cylinders, *c c*, are bolted down on the same axial line upon a cast-iron foundation-plate, carried by a light stone foundation. Each cylinder is flanged at both ends, and the two are bolted together by bolts passing through a central partition plate placed between them to divide the spaces of each, the shaft being passed through a central hole in the plate. The transverse section in fig. 122 explains the valvular arrangement employed for the induction and eduction of the steam. The steam-chamber, *d*, is cast in one piece with the cylinder, and is provided with a movable cover and adjusting-screws, by which to adjust a metal plate placed at the back of the steam-valve to take off the pressure of the steam. The steam-valve is worked by a spindle, *e*, standing out in front of the engine, and which is actuated by a cam motion of a peculiar nature, presently described. The flat steam-stop, *f*, which acts as an abutment or movable partition, against which the steam re-acts in urging round the piston, is in one piece with the flat steam-valve. The supply steam is brought by the pipe *c*, which is bolted by flanges to the lower side of a receiving-chest containing an inverted *d* or single cup-valve, employed for stopping or reversing the motion of the engine. The valve is worked by a small hand-wheel, 2, on a screwed spindle, working into a socket on the spindle of the valve. By this means the valve may be adjusted to any desired position with the greatest nicety. As arranged in the diagram, the steam passes as shown by the arrows from the lower valve-chest up through the uncovered port *k*; and thence by the port at the front of the working valve-chest to the space above the top plate, which bears upon the upper face of the steam-valve. From this point it passes by the narrow gridiron slots in the plate to a similar series of slots in the upper side of the steam-valve; these slots extending across one half of the valve surface, and communicating with a narrow channel cored out of the centre of the valve's thickness; and finally terminating in a larger port, which in fig. 122 is represented as conducting the induction-steam into the cylinder above the end of the valve forming the stop-piece. The exhaust steam is meanwhile returning from that portion of the cylinder which is continued between the back of the projection and the lower side of the stop-piece *f*, by an exactly similar set of ports and slots, occupying the remaining half of the valve, as seen more clearly in fig. 124. The main exhaust channel, in the thickness of the valve, communicates, by means of three narrow slots in the lower surface of the valve, with a corresponding series in the bottom-supporting surface of the valve-chest, and the steam exhausts thence into a passage leading into a hollow of the reversing valve, and finally escapes by the exhaust port *l* into a waste pipe bolted to the side of the *stop* valve-chest. It is easy to understand how the passage of the steam may be entirely reversed, by setting the reversing valve to cover the front port and open the back one, when the steam will be immediately admitted, by what were before the exhaust valves, to that portion of the cylinder below the steam stop-piece *f*; the exhaust likewise taking the place of the former steam-ports on the upper side of the valve. The steam may also be entirely shut off from the cylinder, by placing the reversing-valve in the centre of its stroke, so as to cover both ports on its face. The action of this valve is essentially different from that of ordinary steam slide-valves, for it has to fulfil conditions of a very different character. It has to remain in one position for a long period during each revolution of the engine, to admit steam to urge round the piston; it must afterwards be quickly withdrawn, merely to allow of the passage of the projecting part of the piston; after which it is again passed inward. To produce these peculiar movements, Mr. Davies has applied an ingenious arrangement of cams, which work inside the frame *n* (see the elevation in fig. 123), in one piece, with an actuating rod partially supported by a link *o*, jointed to a stud on the foundation plate; the extremity of the actuating rod being jointed to the end of a short lever *p* keyed on the valve rocking-shaft. The rocking-shaft works in pedestals carried by the foundation-plate, and has keyed on it a lever with a forked upper end, connected by short links to a cross-head on the valve-spindle *e*. In an improved form of this engine, the inventor has substituted double-acting pistons for the single-acting ones, as in fig. 122, having two projections instead of one. The two projections are set opposite each other on the pistons, the latter being so placed on the shafts that the projections of each stand at right angles to one another; thus balancing both their own weight and the actuating pressure of the steam. Steam-stops, with the requisite valves, are provided for each projection on opposite sides of the engine; the two stops for one piston being simultaneously worked by one cam motion. In place, therefore, of describing the single motion of the engine in fig. 122, we shall explain that adapted for the engine with duplex projections. Fig. 125 exhibits a side elevation of this arrangement, in which the two dotted lines *a*, *b*, *c*, *d* are supposed to stand in planes coincident with the centre lines of the piston projections. The throw of the cams having been settled, the first thing to be done in setting out their curves is, to form the dotted square *e*, *o*, *p*, *h*, with diagonals drawn through it. To find the diameter of the anti-friction rollers *k l*, against which the cams work, the throw of the cams is added to the thickness of the roller studs, allowing about one-eighth of an inch clearance between the extremity of the cams and the roller studs. The true curve of the actuating cam surface is a matter of great nicety, as upon its exactitude depends the correct working of the valve-stops against the piston projections. The breadth of the end *m*, *n*, of the smaller cams, is determined by the piston projections themselves, as the two must correspond. On moving the rollers in the direction of the arrows, it is evident that no rectilineal motion will take place until the point *n* is gained; and the nature of the movement subsequent to this is thus determined. On the horizontal line *a b*, a semicircle with a radius equal to half the throw is delineated at *a*, and this is divided into any given number of equal parts; and from these points ordinates are drawn to the diametrical line. Thus, from the centre of the shaft the arc *a d* is described, being bisected by one of the diagonals before mentioned.

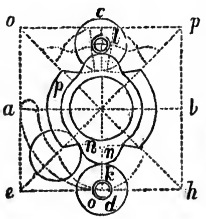


fig. 125.

That portion of the arc contained between the point *o* and the diagonal line is divided into the same number of parts as these micircle at *a*, drawing radial lines to each, and describing concentric arcs, commencing at the ordinates of the semicircle *a*. A line then traced through the points of intersection of these arcs with the radii will indicate the centre of motion of the traverse of the roller *d*, the periphery of which gives the required shape of the cam. The large cam *p* is of course formed so as to act in concert with the small one, which we have just described. In fig. 122, it will be seen that the actuating projections of the pistons which work up against the circumference of the cylinders are fitted with a packing-piece of metal m, placed obliquely across the face of the piston, so as to facilitate its passage across the slot in the cylinder. This stop-piece is kept up to its working face by the pressure of the steam behind it, a slight blade-spring being provided as an additional safeguard. The action of the cam motion is such, that at each revolution, when the projection m approaches the steam slide the latter is drawn back at such a rate as to keep its inner-faced end just clear of the approaching curved surface; and just at the instant of the passage of the face of the projection, the slide for an instant stops, and is then similarly pushed inwards, to fill up the space gradually left by the receding of the projection. The working-face end of the steam slide is fitted with a tongue-piece of brass, with a spring behind it, to work upon the cylindrical portion of the piston. The action of this tongue is clearly shown in the details of valve in fig. 126. To support the slide, fig. 122, against the pressure of the steam when stretched across the annular space of the cylinder, it is let into a groove in the centre partition and end set-up plates, thus providing it with a solid foundation. The adoption of the system of divided steam-ways in the slide removes all objectionable frictional wear at that part, as it is only for a quarter of an inch movement in each stroke that the steam-pressure in the valve is unbalanced. The instant the communication is opened on both sides of the stop, the pressure is equipoised, and the remainder of the valve's stroke is performed under a pressure not greater than that resulting from the mere weight of metal. At each revolution, a portion of the steam contained between the after curved side of the projection and the cylinder, which steam has before done its duty in carrying round the piston, is shut in by the steam-stop, to be again made use of in the succeeding stroke or revolution. Fig. 126 is an enlarged view of the steam-valve and partition-slide. In this view it is working in the same conditions as in fig. 122, the steam entering above the partition and escaping from below it, as before explained. Again referring to fig. 124, which, as a combined view of the whole engine, gives the clearest explanation of the arrangement, we shall now show how the difficulties attending the end wear of the piston have been effectually got rid of. A favourite argument of many writers, holding views adverse to rotatory engines, was that of supposing two plane circular discs of metal to be working together, revolving upon coincident centres. Experience had gone to show that the plates in these conditions would inevitably wear untrue, by reason of the much greater space passed through by the circumference of the discs, as compared with the space near the centre of motion. After working some time, the surfaces were no longer planes, but by the law of relative velocities became cones, the centres of which remained in contact, whilst the circumferential portions parted. Applying this result to the end wear of rotatory engines, it was held to be an invincible argument against their success; for the evil only increased by continued working. We shall now explain how this evil does not obtain in the engine under consideration. The end covers are double, the outer

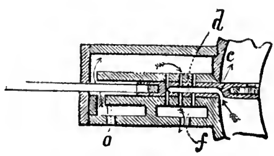


fig. 126.

one only being bolted to the cylinder flanges; the inner one is a plain disc, nicely fitted to the internal diameter of the cylinder, and faced for the circumferential portion of the piston to work against. This plate is capable of the most accurate adjustment by means of screws, which are of a peculiar arrangement; two screws, a hollow and a solid one, being employed. A hollow bolt screwed on the outside is first fitted into threads in the external cover, so as to project slightly through into the interior, and press against the exterior surface of the inner set-up plate. Through the centre of this hollow bolt a solid one is passed, and screwed into the disc by a thread cut for a short distance near the end of the bolt. By this contrivance the hollow bolt presses firmly against the back of the set-up disc, whilst the inner solid bolt, when turned, pulls the disc tight against the former, and enables the engine-attendant to set it accurately, so as to work with the least possible friction in the piston. The latter being used out, and only a narrow ring of metal being left near the circumference for frictional wear, the irregularity of wear found in the action of two plain discs of great area is not found here, as the difference in the distances passed through by the outer and inner portions of the bearing ring of the piston is quite inappreciable. Under a pressure of steam of $22\frac{1}{2}$ lbs. the engine made 70 revolutions per minute, consuming 2 cwt. of slack coal in $2\frac{1}{2}$ hours, having a power of 12 horses. We have been thus particular in describing this engine, as it may be taken as an excellent type of this peculiar class; one abounding in high ingenious mechanical contrivances, and one, moreover, which has passed the ordeal of practical working with a high degree of satisfaction.

The "elliptic rotatory engine" is one of the most successful examples of the modern attempts to apply steam-power directly to a revolving crank-lever, so as to economise steam, lessen the weight, simplify the constructive details, and convey the power directly to its work. Such an engine is, indeed, practically equivalent to the causing the steam to lay hold of and actuate the crank or revolving shaft, just as the hand turns round a winch, without the intervention of joints, levers, and connecting-rods. It is the invention of Mr. William Hyatt, the engineer to Champion's extensive Vinegar Works, of Old Street Road, St. Luke's, London, and is being carried out by him, in conjunction with Mr. Wright, the managing proprietor of the works. The essential peculiarity of the engine is to be found in the fact, that the steam-cylinder is bored elliptically, in order that the revolving piston within it, when set upon a shaft disposed eccentrically in relation to the minor axis of the ellipse, may fit accurately to the elliptic surface throughout the entire revolution. This is a peculiar and unlooked-for characteristic of the elliptical figure. The true action is only to be secured when the amount of ellipticity is exceedingly slight, the centre of motion of the revolving piston-shaft being in a line intersecting the minor axis, at about one-third the length of such axis. That such an engine does work in the most satisfactory manner, is now practically exemplified at the Old Street Vinegar Works, where the engine, from which our drawings, in figs. 127, 128, and 129, were made, is in daily operation. (1853.)

Fig. 127 is an external longitudinal elevation of the engine in working order. Fig. 128 is a corresponding end-elevation at right angles to fig. 127, the front end cover of the cylinder being removed to show the piston within. Fig. 129 is a plan of the engine.

The short steam-cylinder, *a*, open at each end, and fitted with two end-

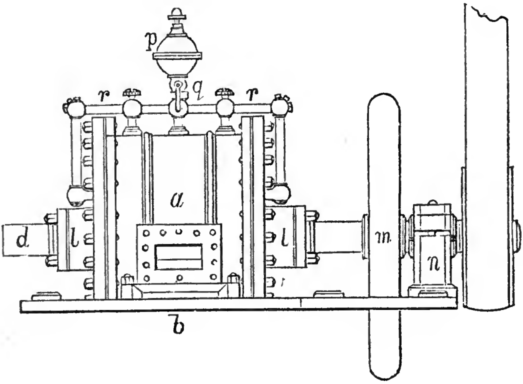


fig. 127.

covers, is placed with its axis horizontal upon the base-plate *b*, being bolted down thereon by four projecting eyes *c*; the horizontal piston-rod, or

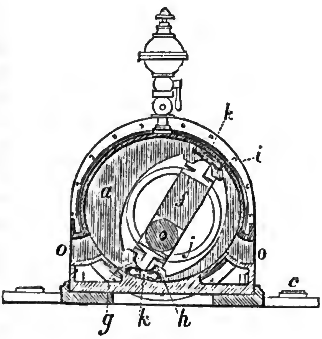


fig. 128.

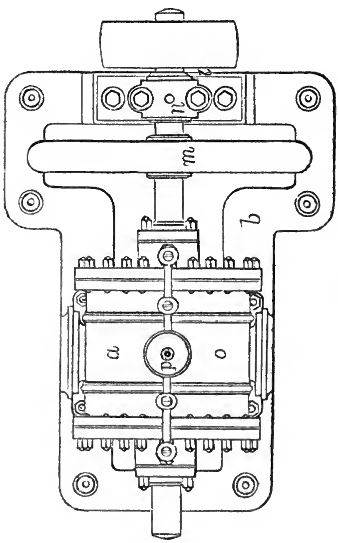


fig. 129.

main-engine shaft, *d*, is passed eccentrically through the cylinder, and in the vertical line of the minor or conjugate axis of the ellipse. The cast-iron rotatory piston *e* is suitably fitted with packing-pieces, and slotted transversely at *f*, to fit the piston-rod, the transverse section of which at that part is rectangular. The slot *f* is for the purpose of allowing of the self-adjustment of the piston during its revolution in working, by sliding laterally over the squared shaft or rod *d*; or, instead of this more direct sliding action, a frame may be introduced to carry anti-friction-rollers, working upon the shaft-surface, and adjustable by the aid of screws and wedges. The packing of the piston—which packing is, at the same time, a portion of the working steam-pressure surface—consists of two metallic strips or ribs, *g*, of the length of the cylinder, the outer projecting surface of such ribs being rounded, whilst their inner flat sides are fitted into shallow groves *h*, formed diametrically opposite to each other along the piston, and in its axial line. The actual working packings are strips of metal, *i*, fitted on their inner sides to the external rounded surfaces of the pieces, *g*, whilst their outer surfaces bear against the interior of the cylinder. These outer-rubbing surfaces of the packings, *i*, are considerably rounded in transverse section, the radius of curvature being slightly less than that of the quickest curve of the cylinder's bore, so that the packing may work round the sharpest elliptic curves with facility; and helical springs are set in behind the packing-pieces, to admit of a free adjustment during working. The flat-end packing, for keeping the piston steam-tight at its two ends, is composed in each case of the brass-ring *j*, let into the end of the piston, and having two projections, *k*, upon it, passing through slots in the end of the strips *g*, thus forming a simple and effective end-packing. A small brass-plate, *k*, is let into the end of the strips, *i*, to complete the end-packing. The piston-rod is supported in a stuffing-box, *l*, on the outside of each cylinder end-cover; and the engine in the present case being a single one, the shaft has a fly-wheel, *m*, keyed upon it, the heavy rim of the wheel being cast hollow at certain parts to balance the overhang of the piston. That end of the shaft which passes away to the machinery to be driven is supported in a pedestal, *n*, bolted down on the base-plate; this bearing, in conjunction with the pair of stuffing-boxes, being the only bearings requisite. When one end only of the shaft is used for driving, no working valves are required in this engine, the steam being admitted in a constant stream by either of the two opposite ports *o*, the only variation of the current being when the slot *f* is horizontal, this being the dead centre of the engine; and both ports are then closed. Or, by another slight modification, the steam and exhaust ports may be made to extend a long way round the cylinder, in order that the engine may have no dead point, the steam being admitted to the back of the revolving piston-blade before it is entirely shut off from the front side. For reversing, an ordinary three-way cock answers every purpose, one cock being set on each side of the cylinder, and put in connection by means of two double-branched pipes; so that either side may be made the steam ingress side. The steam acts equally well in both directions of revolution, the effective pressure being that upon the overhang or eccentricity of the piston, which is constantly varying in effective area throughout the revolution; the piston being, indeed, a direct-acting crank-lever for turning the shaft. For lubrication, an oil-reservoir, *p*, is set on the top of the cylinder, a stop-cock, *q*, being fitted beneath it to command the flow through the pipes *r*, which have each two branches for lubricating the bored portion of the cylinder and the flat-end cover-surfaces. The length of the axial line of the cylinder of the engine is 24 inches, whilst its diameter or bore is to be defined by an ellipse with a major axis of $20\frac{1}{8}$ inches, and a minor axis of $18\frac{5}{8}$ inches. This engine is called a 30-horse, whilst with a pressure of 32lbs. of steam the indicator has shown a power of 50 horses. Our readers may judge of its compactness by comparing this power with the area actually occupied, as shown in our drawing.

"We think we may safely point to Mr. Hyatt's engine, as being the simplest and most compact of the really effective existing examples of the direct-pressure rotatory class. It is evidently applicable for all the purposes to which the ordinary engine can be applied, as well as to many which are beyond the reach of the old form. With an actuating power applied to its shaft, it at once becomes a forcing or exhausting pump; and, slightly modified, it becomes suitable for the purposes of locomotion. As a railway engine, it is proposed to use two cylinders—one on each driving axle—the axles being thus made the engine piston-rods; whilst the dead points are of course avoided by the usual expedient of setting the lines of greatest effect at right angles to each other, the axles being coupled in the common way. But the most obvious application of the engine is for screw propulsion. The screw-shaft becomes the piston-rod; and as there is no reciprocation about it, any reasonable speed is attainable, whilst the power is conveyed direct to the screw. Indeed, the practical valve of this motor is, in our opinion, as great, as its peculiar mechanical action is elegant."

A steam-engine, to which much attention has been directed of late, is that known as Simpson and Shipton's Reciprocating Steam-Engine. To an arrangement of parts of simplicity in detail, it adds the novelty of a movement remarkable for its originality. Although in many respects resembling at first sight an engine of the rotatory plan, it is nevertheless a reciprocating engine, only differing, in the words of the inventors, from the ordinary engine in the means adopted for obtaining the revolving motion direct out of the rectilinear, the principle through which power is obtained being the same as in the ordinary reciprocating engine; a piston acted upon by steam being propelled in a rectilinear direction in a cylinder or steam-chamber, which, in the present case, is square or rectangular instead of circular, the germ of the engine being "an eccentric revolving in its own diameter;" and which is, in fact, the piston and crank combined in one body; this having in itself two distinct motions, rectilinear and revolving. The following is derived from the inventors, descriptive of the principle and arrangement of the engine. In fig. 130 suppose *a* to be a crank filled up completely between the sides of the steam-chamber *e f*; when steam is admitted above the crank *a*, as shown by the arrows, it moves into the position shown by *b*; in that position, however, it will be observed that the crank will be too short to fill up the chamber, and the steam would consequently rush past it to the lower part of the chamber; it therefore becomes necessary to change the form of the crank, making it such that, at every position, the space between *e f* may be filled up; this form resolves itself into the circle *g g*, with the shaft or axle *c* passing through it out of the common centre; this is therefore an ordinary eccentric. When steam is brought

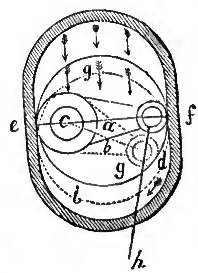


fig. 130.

to act on its surface, it is propelled into the dotted position *i i;* and from its being eccentric, a revolving motion is obtained during its pro-

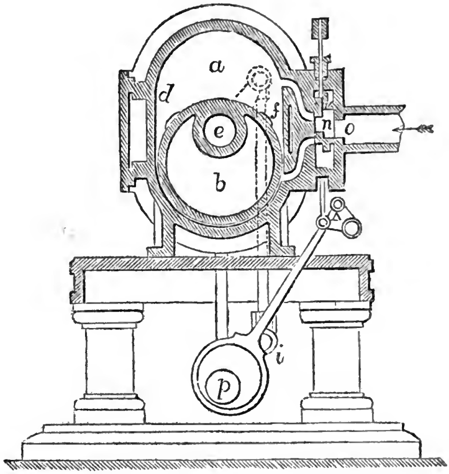


fig. 131.

pulsion. In fig. 131 is a transverse section, and in fig. 132 a longitudinal section, showing the arrangements by which this principle is carried

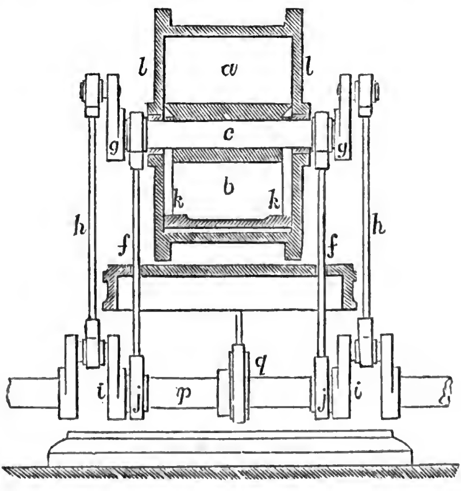


fig. 132.

out. *a* is the steam-chamber or cylinder; *b* the piston, keyed on eccentric to the shaft *c*, and carried on the rods *f f*, vibrating from the crank-shaft pedestals. This piston is turned true on the periphery; and in each end are turned conical seatings, in which are fitted rings of metal *k k*, cut open on one side, leaving a lap-joint to prevent escape of steam. These rings are capable of being adjusted by bolts passing through the side plates *l l*, and are thus easily adjusted. The cranks *g g* are keyed on the shaft at right angles to each other, equidistant from a line drawn through centre of shaft and centre of piston; these cranks convey the power to the lower cranks, *i i*, by rods or drag-links *h h*. The vibrating rods *f f* are carried on the pedestal *j j*. The ends of the cylinder *a* do not require to be bored, as the whole wear takes place on the plates *d* and *e*. The plate *e* is dovetailed in and fitted fast; *d*, being loose in its parallel recess, which allows it to follow up the piston as it wears; the plate *d* is kept up to the face of the piston by springs behind it, or by admitting steam into the recess at the back of it. This plate serves another useful purpose; this is the prevention of priming in the cylinder: as the water increases in the cylinder, it forces back the plate, and rushes from one side of the piston until it escapes. Steam is admitted to act on the piston by means of a valve *n* through the steam-ports *m m*, open to the top and bottom of the piston alternately; the valve is worked by an eccentric *o* keyed on the crank-shaft *p*. This valve is on the equilibrum principle, and exhausts through the back, and works between two parallel planed surfaces; the wear that takes place being accommodated by a ring of metal *o*, similar to that employed for packing the piston. This form of engine is being employed in numerous instances, and with marked economical effect.

As the concluding portion of the present division of our treatise, we propose briefly describing the principles of action of two varieties of engine which have been successfully introduced into practice; these are the "Cambrian" and the "Disc Engine."

In the Cambrian engine the piston has a semi-rotatory motion given to it by the following arrangement: Let *a a*, fig. 133, be the external casing or cylinder; *c b* the arms of a piston vibrating on the axle *d*; the steam space is divided into compartments by the triangular abutments *e f*; the pipe *g* admits steam to the compartment *m*, and *h* into *s*; the steam is exhausted through *o*. By passages cut in the piston-shaft, diagonally, as in *x*; steam is admitted from the space *s* into *t*, and from the space *m* into *n*. The steam, on being admitted to one of the spaces, as *m*, passes into the opposite space *n*, and thus presses on both ends of the piston *b* and *c*, but on opposite sides; the strain on the working parts is by this arrangement much reduced. By this pressure on the alternate sides of the piston a reciprocating motion is produced in the piston-shaft *d*, which is communicated to the crank-shaft in the usual manner. A large number of engines on this principle have been successfully introduced.

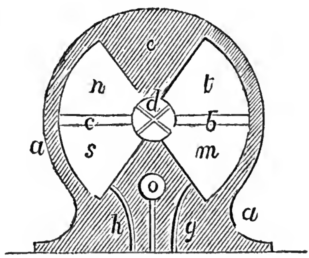


fig. 133.

The movement of the "disc engine" is very peculiar; the most lucid exposition of its principle we have met with is that given by a "practical engineer," himself a well-known and able inventor, in the pages of the *Expositor*. We here append it: "The vessel in which the piston moves, the fixed recipient for the action of the steam, is the section of a hollow sphere, such as would remain after two equal opposite segments were cut off. In this is fitted the piston, called from its form and peculiar movement a disc. The centre of the disc coincides with that of the sphere; and as its diameter is equal to that of the inside of the sphere, it can have no direct movement like the common engine piston; but it may perform an oscillatory motion, such as a top or a teetotum describes when their spinning force is nearly

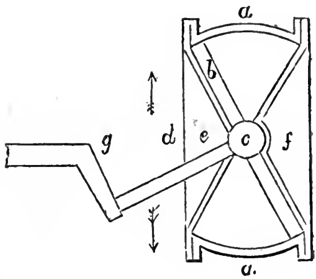


fig. 134.

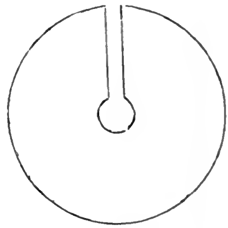


fig. 135.

exhausted; that is to say, each point in the periphery successively dips; and the lowest point seems to proceed round the periphery, though there need not necessarily be (nor is there in this engine) any absolute rotation. Like a wave each point in the disc in its turn rises and falls; and like the wave also, there is no onward motion. To understand the action more perfectly, we refer to the following diagram (fig. 134): *a a* is the spherical case we have described, *b* is the disc, and *c* a ball concentric with the axis *d*; *e f* are two conical covers, *g* is a crank, into which the end of the axis *d* is inserted. If the crank be now turned round, it will be seen that every part of the disc *b* will successively be brought into contact with the cones at two opposite radial lines; but the rotation of the axis of the crank need not necessarily cause the disc to perform any other than the oscillatory one we have described, and, as we have said, it cannot do so. There is a slot in the disc thus (fig. 135), and there is a partition in the engine extending from the outside to the ball and fitting the two cones. When we turn the two cranks, therefore, the oscillatory motion will be performed by the disc and axis, the side of the slot rubbing up and down on the surface of the partition." It is difficult to describe the way in which the disc receives the effort of the steam; but it may be sufficient to state, that the struggle or force of the steam to enter and escape, passing through an entrance made in one of the conical covers on one side of the partition to the exit-pipe placed on the other side of the partition, forces the disc partially round, and acting on the ball *c*, makes the lever *d* rise and fall in the direction of the arrows, and thus communicates motion to the crank *g*.

The first patent for the disc-engine was taken out by a Mr. Dakeyne in 1830. His engine was not, however, put in practice. Henry Davies was the next inventor who turned his attention to this engine. He took out three patents, each combining successive improvements in its action, his last patent being taken out in 1844, in which his improvements had reference to working the engine expansively. He introduced a variety of improvements in the details of this engine; indeed he may with all truth be termed its inventor. In this form of engine, in order to insure the utmost efficiency of working, it is necessary that the contact between the surfaces of the conical ends and the sides of the disc should be as perfect as possible, to prevent the passage of the steam between the surfaces of the plate or disc and the cones. To make this more perfect, Davies formed a series of ribs or cogs on each side of the disc, radiating from the central ball to the outside of disc, and a similar series of cogs in the interior surfaces of the conical ends; these cogs on the disc and cones being so arranged that they work into one another like the teeth of pinions, the cogs being ground so as to insure as perfect contact as possible. He fitted up the sides of the slot in the disc with metallic packing, making them rub on the sides of the partition; by this arrangement he was enabled to work the engine expansively. The disc engine, as thus improved by Davies, was carried into practice pretty extensively, and a company was formed at Birmingham for introducing it on a large scale. From some cause this company ceased soon to exist, and the disc engine fell into comparative obscurity, until Mr. Bishopp, in 1844, introduced a variety of improvements, and, aided by the admirable mechanical resources of eminent engineering firms, he has succeeded in placing it in a comparatively high position among economical and compactly working engines. Mr. Bishopp has dispensed with the cogs or ribs on the disc and cones, and substituted a series of strips of metallic packing, forced outwards in contact with the face of the disc, which is quite plain in its surface, by a series of springs. To insure the perfect action of the sides of the slot in the disc against the partition, Mr. Bishopp adopts a semicircular bow which extends over the engine, its two extremities being attached to the opposite ends of the axis. A pin is carried by the bow, a rectangular truss being attached to this pin, and moving from side to side in a groove made in the outside of the engine, and which groove is concordant with the plane of the partition. By this arrangement, the centre line of the slot in the disc always moves in the same plane; the packing presses equally on the face of the partition, and any degree of expansion used as may be required. "Thus improved, these engines," remarks an authority, "are now no longer experimental. They have been adopted (1851) in about fifty cases, and are found to be both economical and durable." We have before us both the reports of Messrs. Terrey and Parkes, both of whom pronounce in their favour. Mr. Terrey, alluding to some comparative experiments made at Lewisham with a disc engine, and one erected by Messrs. Penn and Son, states that he is of opinion, from what he has seen of the improved disc engines, that their performance is equal to that of the best engines of the construction in common use, in the like conditions of pressure of steam and extent of expansive action. Mr. Parkes reports a considerable economy in fuel.

CHAPTER V.

RAILWAY LOCOMOTION AND LOCOMOTIVE ENGINES.

Previous to describing the modern mechanism of the locomotive engine, so called *par excellence*, in contradistinction to the "steam-carriage for common roads," which properly is also entitled to the distinctive appellation of locomotive, we propose giving a rapid sketch of the history of its introduction, and a notice here and there of the most striking of the machines from time to time introduced, ending in the comparatively perfect machine now in daily use on our railways. We must premise, however, that the nature of our treatise does not admit of our going into the history of the introduction of railways, or an explanation of their construction; it is with the engine, its history and construction, that we have alone to deal. The subject of railways belongs more exclusively to the treatise on "civil and mechanical engineering," and which may hereafter be added to the series of works of which the present forms a part.

It is difficult to decide to whom the honour is due of having suggested the use of the steam-engine for the purpose of propelling carriages. Savery hints at its use in this way, at least he considered that it was possible to apply it. Dr. Robison, the gentleman who was the means of directing the attention of Watt to the steam-engine, "threw out the idea of applying the power of the steam-engine to the moving of wheel-carriages;" but other occupations withdrew his attention from the subject, and nothing further was effected. In the patent taken out by Watt in 1784, he described the application of the steam-engine to the propulsion of carriages. "The boiler of this apparatus he proposed should be made of *wooden staves* joined together, and fastened with iron hoops like a cask. The furnace to be of iron, and placed in the midst of the boiler, so as to be surrounded on every side with water. The boiler was to be placed on a carriage, the wheels of which were to receive their motion from a piston working in a cylinder; the reciprocating motion being converted into a rotatory one by toothed wheels revolving with a sun and planet motion, and producing the required velocity by a common series of wheels and pinions. By means of two systems of wheel-work differing in their proportion, he proposed to adapt the power of the machine to the varied resistance it might have to overcome from the state of the road. A carriage for *two* persons *might*, he thought, be moved with a cylinder of seven inches in diameter, when the piston had a stroke of one foot, and made sixty strokes per minute. Watt, however, never built a steam-carriage." Such is the account given by one authority. Another, however, affirms that Watt did at least construct a model, of which we give a diagram in fig. 136, illustrative of its construction; and further states, that Messrs. Bolton and Watt constructed a steam-carriage, which was made to run on the roads of Cornwall in the years 1785-1786. We are, however, inclined to think that the model of the locomotive carriage, as here attributed to Watt, and which the writer states was made by Mr. Murdoch, Watt's assistant, was not only made by him, but owed its creation to the inventive genius of Murdoch himself. In a life or biographical sketch of Murdoch, read some two years ago at the Institution of Mechanical Engineers, it is there stated that Murdoch constructed the model of a steam-carriage while residing at Redruth in Cornwall, and the details and general arrangement of which resembles those in the diagram

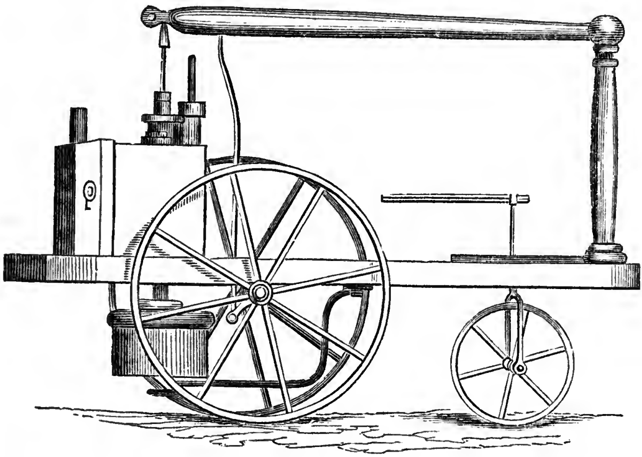


fig. 136.

now given very closely. Leaving this matter to be decided by more competent authorities, we hasten to the other points of the present division.

Another claimant for the honour of having introduced the first steam-carriage is the celebrated William Symington, the engineer now acknowledged to be the first introducer of a practically-working steamboat. As early as 1784, it occurred to him that steam might be applied to the propulsion of

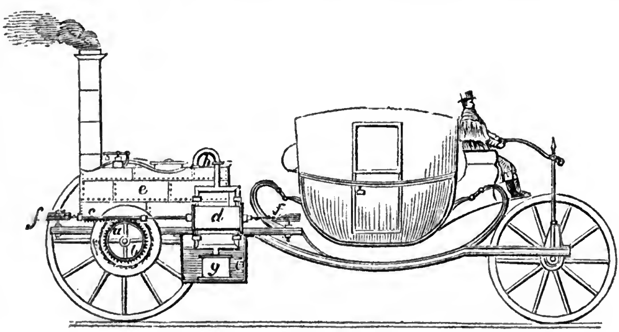


fig. 136*a*.

carriages. He commenced experiments, with a view of perfecting the idea; and in 1786, submitted to the inspection of the professors, and other scientific gentlemen of Edinburgh, a working model of a steam-carriage. This gave such proofs of practicability, that he was urged to carry the machine into practice. Such, however, were the difficulties to be overcome in this, that he conscientiously stated his scruples to those anxious to aid him in the matter, advising them not to proceed with it. In fig. 136 *a* we give a lateral of the steam-carriage model as constructed by Symington; *d* the cylinder; *e*, boiler, supplied from the condenser; *ff*, direction pulleys; *g*, condenser; *h*, steam-pipe; *i*, water-tank; *a*, drum fixed on the hind axle; *b*, tooth and ratchet-wheels; *c*, rack-rods, one on each side of the drum, the alternate action of which upon the teeth and ratchet-wheels produces the rotatory motion.

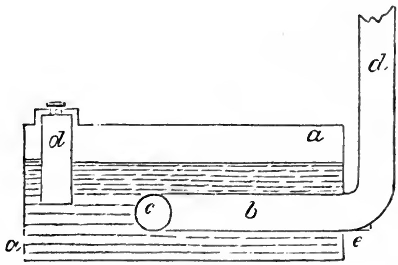


fig. 137.

In a previous chapter, we described the high-pressure engine patented by Messrs. Trevethick and Vivian; in the patent they claimed its employment in "propelling wheel-carriages of every description." In 1804, Mr. Trevethick set an engine to work on a very indifferent railroad at Merthyr Tydvil Colliery, in Wales; this worked very satisfactorily, and up to 1830 or 1831, it was the form which, more or less modified, was working the railroads on which steam was employed. "The advantages," says Trevethick in his evidence before the Committee of the House of Commons on carriages for common roads, "gained by this improvement, were a detached engine, independent of all fixtures, working with five times the power of Bolton and Watt's engine, without condensing water, and the fire enclosed in the boiler surrounded with water, and a force-draught created by the steam for the purpose of working on the roads without a high chimney; and from this was copied all the boilers for navigation-engines, which without could not have been available, this being independent of brick-work, light, safe from fire, and occupying little room." The following is a description of this engine: the boiler is cylindrical, as *a a*, fig. 137; *b* is the fire-place; *e* the fire-door; *c* the entrance of the flue, which is turned before entering the chimney. By this arrangement the economy of fuel effected was very considerable, the greater portion of the heat being given out by the furnace and flue to the water surrounding them. The lower part of the cylinder was placed within the boiler, as at *d*, and the upper portion was surrounded by a jacket, in the space between which and the cylinder the steam from the boiler was allowed to circulate freely; the loss of steam from condensation was by this means obviated. The steam was admitted above and below the piston by the four-way cock already described; and after working the piston, instead of passing it to the atmosphere, it was led by a pipe to the chimney. By this arrangement the draught of the furnace was greatly increased, and a convenient means established of getting rid of the waste steam. Had this plan been patented, the inventor would have probably reaped a golden harvest from this alone.

The piston-rod had a cross-head attached to it, as *e*, fig. 138, sliding in the parallel guides *f*, attached to the upper end of the cylinder, and steadied by a stay as at *g;* from both ends of this cross-head connecting-rods *d* proceeded, and were connected to the crank *e*, fixed on the centre *b* of the driving-wheel *a;* the axis of the driving-wheel passing with the carriage, and immediately beneath the cylinder. The principle of this arrangement is shown in fig. 151, p. 79, *Mechanics and Mechanism.* This engine, on its first trial, in which the propulsion was effected by the adhesion of the wheels on the rails, drew ten tons of bar-iron, besides the carriages, for nine miles, at the rate of five miles an hour, without stopping, and carrying its heavy load of fuel and water.

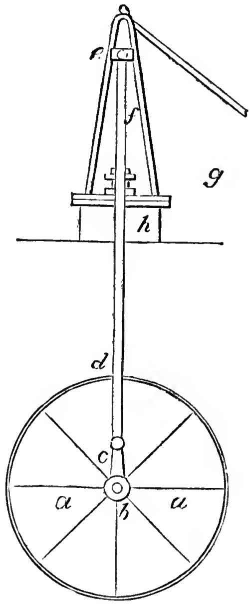


fig. 138.

We have now to notice the ingenious mechanism introduced to obviate an inconvenience in engine propulsion which only existed in imagination. With reference to this point, Dr. Lardner remarks: " It is a singular fact, that in the history of this invention, considerable time and great ingenuity were vainly expended in attempting to overcome a difficulty, which in the end turned out to be purely imaginary. To comprehend distinctly the manner in which a wheel-carriage is propelled by steam, suppose that a pin or handle is attached to the spoke of the wheel at some distance from its centre; and that a force is applied to this pin in such a manner, as to make the wheel revolve; if the face of the wheel and the surface of the road were absolutely smooth and free from friction, so that the face of the wheel would slide without resistance upon the road, then the effect of this force, thus applied, would be merely to cause the wheel to turn round; the carriage being stationary, the surface of the wheel would slide or slip upon the road as the wheel is made to revolve. But if, on the other hand, the pressure of the face of the wheel upon the road is such as to produce between them such a degree of adhesion as will render it impossible for the wheel to slide or slip upon the road by the force which is applied to it, the consequence will be, that the wheel will roll upon the road, and the carriage will be moved forward through a distance equal to the circumference of the wheel each time it performs a complete revolution. It is obvious that both of these effects may be partially produced; the adhesion of the wheel to the road may be insufficient to prevent stopping altogether, and yet it may be sufficient to prevent the wheel from slipping as fast as it revolves. Under such circumstances the carriage would advance, and the wheel would slip. The progressive motion of the carriage during one complete revolution of the wheel would be equal to the difference between the complete circumference of the wheel and the portion through which, in one revolution, it has slipped When the construction of travelling steam-engines first engaged the attention of engineers, and for a considerable period afterwards, a notion was impressed upon their minds that the adhesion between the face of the wheel and the surface of the road must necessarily be of very small amount; and that, in every practical case, the wheels thus driven would either slip altogether, and produce no advance of the carriage, or that a considerable portion of the impelling power would be lost by the partial slipping or sliding of the wheels. It is singular that it should never have occurred to the many ingenious persons, who for several years were engaged in such experiments and speculations, to ascertain by experiment the actual amount of adhesion in any particular case between the wheels and the road. Had they done so, we should probably now have found locomotive engines in a more advanced state than that to which they have attained."

Space will not allow of our illustrating all the mechanisms introduced to obviate this imaginary difficulty,—indeed, this, for the purposes of our treatise, is not at all necessary;—we shall merely glance at the nature of a few of the most ingenious of these. Trevethick and Vivian, in their patent, claimed the plan of making, in *certain cases*, the external periphery of the driving-wheels "uneven, by projecting heads of nails, or bolts, or cross grooves, or *fittings to railroads* when required: and that *in cases of hard pull* we cause a lever bolt, or claw, to project through the rim of one or both of the said wheels, so as to take a hold of the ground." But, so far from adopting these contrivances at all times and under all circumstances, as a means of overcoming the imaginary difficulty before alluded to, they on the contrary expressly stated, that "in general the ordinary structure or figure of the external surface of these (the driving) wheels will be found to answer the intended purpose."

In 1811 Mr. Blenkinsop patented "certain mechanical means, by which the conveyance of coals, minerals, and other articles is facilitated, and the expense attending the same rendered less than heretofore." In this arrangement, a rack or toothed rail was laid down along one side of the railway; into the teeth of this rack a large toothed wheel worked, this receiving a circular motion from a steam-engine; the boiler and engine working this being supported by a frame on four wheels. By this means the engine was pulled along the rails, and was enabled to ascend gradients of considerable incline. The boiler was placed on a wooden or cast-iron frame; through the interior of the boiler a large tube was passed, containing the furnace; this tube was continued through the other end, and bent upwards to form the chimney. Two cylinders were placed at the top of the boiler, and the pistons were connected by cross-heads and connecting-rods, *f*, *e*, fig. 139, to the cranks, *c*, *d*, fastened in the centre of two toothed wheels represented by dotted circles. These worked into a large toothed wheel placed in the inside of the cogged wheel *a;* the cogs in this working into the teeth or cogs placed along one side of the railway *b b*. The engine was long used on the Middleton Colliery Railway, near

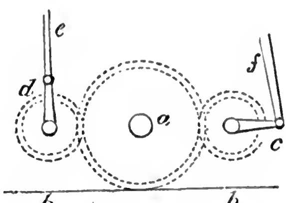


fig. 139.

Leeds. The following particulars were forwarded by the patentee to Sir John Sinclair:—With two eight-inch cylinders, the engine weighs five tons, "consumes two-thirds of a hundredweight of coals, and fifty gallons of water per hour; draws twenty-seven wagons, weighing ninety-four tons, on a dead level, at three and a half miles per hour; or fifteen tons up an ascent of two inches in the yard; when 'lightly loaded' it travels ten miles an hour, does the work of sixteen horses in twelve hours, and costs 400*l*."

We now approach the period at which two men appeared in the arena of invention; men who, up to the period of their death, were intimately connected with railway mechanism, and who were destined, during long and active lives, to be the means of introducing improvements in this branch of engineering, so effective as to cause quite a revolution in the art of travelling; these men are the well-known George Stephenson and Timothy Hackworth. To the former we are indebted for the system of railways as now established; to the latter nearly all the improvements in the locomotive which formed it the powerful and effective machine we now see it, owed their origin. And in thus paying to Hackworth part of the tribute of praise which has hitherto been nearly always allotted to Stephenson, we by no means detract from the high praise due by the world to the latter. Whatever may have been the improvements effected in the locomotive as a distinct mechanism, it never could have arrived at the height of its present efficiency as "a space and time annihilator," had not the improvements in the "iron way" been simultaneously effected. Without the improved system of rails introduced by Stephenson, the locomotive engine would have been comparatively useless; and without the speed attained by the improved locomotive, the improved system of rails would have been so commercially unremunerative as to have been altogether set aside. These were the elements of high velocity, "each of which formed the absolute condition of the existence of the other." "I am, I think, safe in saying," remarks Mr. Scott Russell, in his eulogium on George Stephenson, "that the wrought-iron railroad (Stephenson's) was essentially dependent on the locomotive engine. But that the modern locomotive engine could not subsist without the wrought-iron rail, and its multifarious appendages of chains, keys, locks, sleepers, switches, crossings, sidings, and turn-tables, is too evident to need proof. Without the smoothness of the rail, the engine would be jolted to pieces; and without the easy motion which it gives, the engine could not be made to draw a sufficiently profitable load to pay; and further, unless made of wrought-iron, it would be impossible to attain the high speed of the locomotive without imminent danger. It therefore appears, that the continuous wrought-iron railway and the locomotive engine were inventions intimately related to each other, and each a condition of each other's success. To Stephenson we are indebted for the chief features of improvement in both. It was the joint perfection of the road and the engine which created the Liverpool and Manchester line, and all the progeny of that wonderful and gigantic experiment, an experiment whose complete success now bears incontrovertible testimony to the genius of the man." Historical evidence, recently made public, proves most decidedly that to the inventive genius of Timothy Hackworth the locomotive engine owed nearly all the improvements which made it an efficient machine; improvements, too, effected at a time "when every thing had to be learned,—when, indeed, engineers were utterly thrown upon their own resources." Those who are desirous to enter into an investigation of the point, and to be made aware of the extent to which Stephenson was indebted to the ability and experience of Hackworth in locomotive mechanism, should read the article in the *Practical Mechanic's Journal*, p. 49, vol. iii. 1850-1, entitled "A Chapter in the History of Railway Locomotion," and the "Memoir," p. 225, same volume. We think that an unprejudiced perusal of these interesting papers will induce the reader to coincide with the opinions of the writer as therein expressed. "If George Stephenson deserved the title of the 'Father of Railways,' we think we may at least claim for Timothy Hackworth that of the 'Father of Locomotives.'"

In 1814 George Stephenson constructed a locomotive, Lord Ravensworth, of the Killingworth Colliery, having assisted Stephenson with money to conduct his experiments. This was tried on a tram-way at Killingworth. In 1815, in conjunction with another party, he took out a patent for "various improvements in locomotives." In this engine two cylinders were used, one at each end; the connecting-rods were attached to pins on a spoke of the wheels; they were placed at right angles to each other; by this means the motion was rendered continuous, one crank or pin receiving the full leverage of the connecting-rod while the other was at its dead point. A toothed wheel was placed on each axle inside the wheels, and round the two wheels a peculiar kind of endless chain was stretched (see p. 50, *Mechanics and Mechanism*); this chain was so constructed as to furnish a series of rectangular apertures, into which the cogs in the toothed wheels entered; by this arrangement, as the wheels revolved the chain was passed along, and one wheel could not revolve without the other; the relative positions of the cranks or pins (namely at right angles) was thus preserved. In the year 1816 he took a patent, in conjunction with Mr. Losh, which embodied many of his notable improvements in the construction of railways. In this patent one claim having reference to the construction of locomotives was included; this was a very ingenious method of "sustaining the weight, or part of the weight, of the engine upon pistons movable within cylinders, into which the steam or the water of the boiler is allowed to enter, in order to press upon such pistons, and which pistons are, by the intervention of levers and connecting-rods, made to bear upon the axles of the wheels of the carriage upon which the engine rests." In fig. 140 we give a transverse section, exhibiting the improvements here mentioned, and the arrangement of the parts of the engine at this period. The boiler is at *n n*; *b*, the internal furnace; *c*, the flue or chimney; *d*, the cylinder; *e*, the

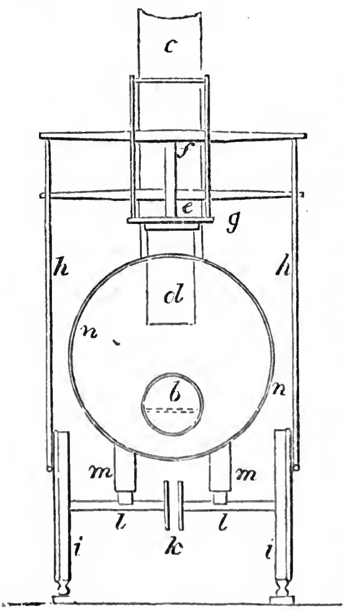


fig. 140.

cross-head of one piston, at the dead point of the turn of the crank; *f*, that at the full leverage; *g g*, the piston cross-head guides; *h h*, the connecting-rods; *i i*, the driving-wheels, running on the fish-bellied edge-rail, one of the improvements in railways included in the patent; *k*, the toothed wheel and endless chain; *m m*, the cylinders and pistons for acting on the axles as already described.

Engines on this plan were introduced by Stephenson on the Killingworth and on the Hetton Colliery Railway; and although every exertion was made by him to render them efficient and economical, and to get them into use on the different railways which began at that time to be formed, it is the opinion of competent authorities that they did not possess "those advantages which the inventor had anticipated."

On the 27th of September, 1825, the Stockton and Darlington line of railway, twenty-five miles long, was opened for public traffic. Twenty miles of this was worked by locomotives and horses, the powers of each being put thus in close competition. At this early period of the history of a line of railway, the first ever laid down on the improved principles as introduced by Stephenson, and which formed the nucleus of the railway system, the locomotives employed on it were five in number, four having been manufactured by Messrs. Stephenson at their factory at Newcastle, and one by Mr. Wilson of the same town. Such, however, was their inefficient working condition, that the power of steam was about to be abandoned, and the railway conducted by horses. Timothy Hackworth, to whom we have before alluded, and who, through the intervention of George Stephenson, had been appointed manager of the working department of the railway, stepped forward at this critical juncture, and proposed to construct an engine capable of working the line to the extent already mentioned. His offer was accepted, and he forthwith began his operations. The boiler of the engine made by Wilson, already alluded to, was taken as the boiler of the new machine. "This boiler was a plain cylinder," says the account from which we quote, in the *Practical Mechanic's Journal*, "thirteen feet in length, and four feet five inches diameter. The heating surface was obtained from a double tube of malleable iron in the form of the letter W, traversing the whole length of the boiler. One side of this tube was made available for the fire-grate, and the heated vapour being passed through it was returned by the opposite one to the chimney, which was actually a vertical continuation of this end. With this contrivance the engine had a heating surface double that of any other engine of its time. She was carried on six four-feet wheels, four of them being spring-mounted, and was the earliest of the six-wheel coupled class. The cylinders, eleven inches in diameter and twenty inches stroke, were placed vertically at what is now the smoke-box end of the engine, and worked directly upon the first pair of wheels. At the same end was attached a malleable iron cistern, into which the water passed from the tank previous to being introduced into the boiler, the driver having the power of regulating the supply; and a pipe from the steam-exhaust was led into the cistern for the purpose of admitting steam at pleasure to heat the water. Another pipe was provided for the purpose of leading off a steam-jet from the exhaust-pipe at the chimney end for discharge beneath the grate; the intention being to facilitate the combustion. In addition to its being the original of a class of engines now so universal, this engine was the first which had a blast-pipe fitted to it, the whole of the exhaust steam, excepting only such a portion as was required for the purposes before alluded to, being conveyed into the centre of the chimney, and then thrown out in a *jet* from a *conical pipe*." Trevethick led his waste steam to the chimney by a a pipe, no conical or blast-pipe being used to send it up the chimney in the form of a *jet*. Although Trevethick, before a committee of the House of Commons, claimed the use of the waste steam passing into the chimney as a means of quickening the draught, one writer on locomotive engineering states, that he had "no intention or expectation of improving the draught of the chimney thereby." How this holds with the fact it is now difficult to determine; but to return. The engine thus constructed by Hackworth was named the "Royal George," and commenced running in October 1827. The following statement affords an evidence of its power as compared with that of horses, with which it competed. The cost of the engine was 425*l.*; in one year (1828) she conveyed over twenty miles 22,442 tons, at a cost of, including all repairs, and maintenance, and interest on such capital at 10 per cent, one farthing per mile: "an economy in working which is rarely exceeded at the present day." The cost of the same work performed by the horses was 998*l.*; thus showing a difference of 532*l.* in favour of the engine over the animal power. "The points in the improvement," says the same writer, "in the 'Royal George' which conduced to this important result, evidencing not only her great superiority over her compeers, but the vast resources of the imperfectly developed locomotive system, were simply these: the increased evaporative surface of the boiler; the perfect command over heavy loads in all states of the weather, by reason of the superior tractive adhesion derived from the six-coupled wheels; and the introduction of the blast-pipe, an invention which alone will carry down the name of Hackworth to future ages in connexion with early locomotive history. Up to the period of which we write, no really efficient locomotive was in use, as the steam pressure invariably fell, in spite of the best efforts of the driver; and the superiority of the 'Royal George' in this respect alone at once elevated it far above its contemporaries, for it was capable of maintaining a speed of nine miles per hour throughout its run of twenty miles." Hackworth introduced other improvements in this engine, as the short-stroke force-pump, and the substitution of the adjustible springs to act on the safety-valves instead of weights.

We now approach that period in the history of steam locomotion at which the great impetus was given to the perfection of the engine. We allude to the opening of the Liverpool and Manchester Railway in 1830. In considering the means to be used for working the line, the choice of the directors lay between the employment of stationary steam-engines and locomotives. It is unnecessary here to enter into detail as to the investigations which the company deemed requisite to be instituted in order to ascertain the most efficient and economical method of working the line; suffice it to state that, in opposition to the Report of the engineers appointed to investigate the matter, Messrs. Rastrick and Walker, who recommended stationary engines, the directors ultimately resolved to adopt locomotive power; and offered for the best engine a prize of 550*l.*, to be decided by a public competition. It is generally understood that the opinion of Robert Stephenson in favour of locomotives induced the directors to adopt this power; and it is nothing derogatory to the great fame of Robert

Stephenson to state that it appears he was much indebted to Timothy Hackworth for a variety of sound practical information; indeed, Hackworth was the only person at this period who had any thing like a practical knowledge of the whole bearings of the case.

In offering the above reward for the best locomotive, the directors made the following stipulations: "the engine was to consume its own smoke; to be capable of drawing after it three times its own weight *at ten miles an hour*, and have not exceeding 50 lbs. pressure upon the square inch on the boiler; two safety-valves, one locked up; engine and boiler to be supported on springs, and rest on six wheels if it should exceed four and a half tons; height to top of chimney not more than fifteen feet; weight, including water in boiler, not to exceed six tons, but preferred if of less weight; boiler, &c. proved to bear three times its working pressure, and pressure-gauge provided; cost of machine to be not more than 550*l.*" The following is a description of the public trial of the competing engines: The "Rocket," constructed by George Stephenson, and of which we give a representation in fig. 141, weighed 4 tons 5 cwt., and the tender, with water

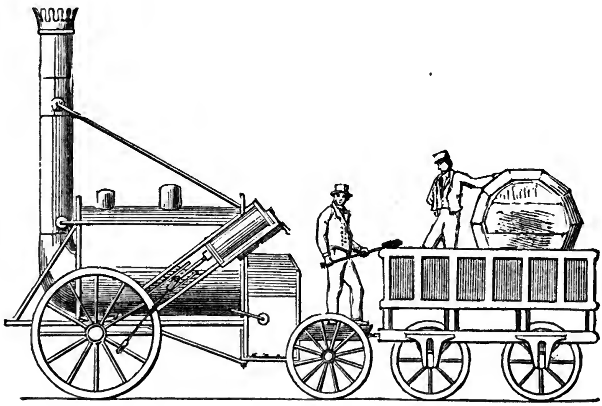


fig. 141.

and coke, 3 tons 4 cwt. 2 lbs.; it had two loaded carriages attached, weighing 9 tons 10 cwt. 3 qrs. 20 lbs., thus making the whole weight to be moved equal to 17 tons. The velocity attained by this engine was 14 miles an hour, with an evaporation of 114 gallons per hour, and consumption of coke equal to 217 lbs. per hour. The greatest velocity attained was at the rate of $24\frac{1}{6}$ miles per hour. The "Sanspareil," by Timothy Hackworth, and of which we give a representation in fig. 142, was the next engine tried, although from its not having been made in strict accordance with the specified rules, it was scarcely competent to enter the lists of competition. The weight of the engine was 4 tons 15 cwt. 2 qrs.; the tender and water and fuel being 3 tons 6 cwt. 3 qrs.; the loaded carriages, three in number, attached to it being equal to 10 tons 19 cwt. 3 qrs.; the whole weight to be moved being equal to 19 tons 2 cwt. The engine in her eighth trip became disabled through the feed-pump becoming disordered in its action, the level of the water in the boiler got low therefore, and the leaden plug, which was used as a safety-valve, getting melted, an end was thus put to the experiment. Her rate of speed was however satisfactory, being equal to conveying $19\frac{1}{2}$ tons at fifteen miles per

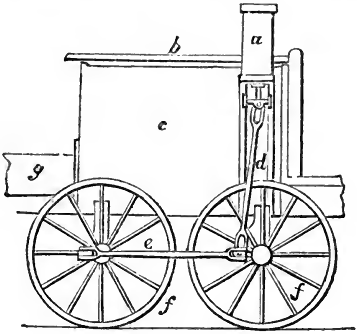


fig 142.

hour. The greatest velocity attained was $22\frac{2}{3}$ miles per hour. The consumption of fuel was very great in this engine, being equal to 692 lbs. per hour; this was in consequence of the great draught induced by the steam-blast in the chimney.

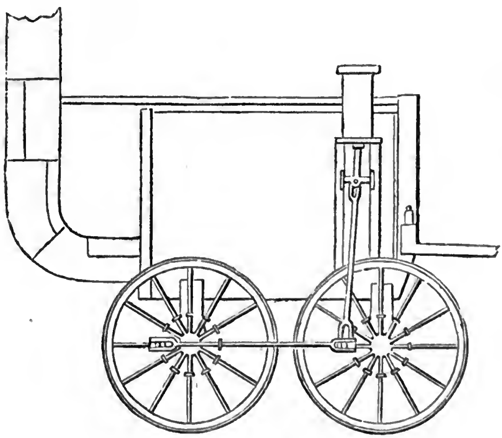


fig. 143.

The third engine, the "Novelty," by Messrs. Braithewaite and Erricson, and of which we gave a representation in fig. 143, carried its own water and fuel, and weighed 3 tons 1 cwt. The weight of the tank, water, and fuel, being 16 cwt. 14 lbs.; the two loaded carriages being 6 tons 17 cwt.; the total weight being 10 tons 14 cwt. 14 lbs. In consequence of successive accidents in the working arrangements of this engine, it was withdrawn from competition; its performances, however, were very satisfactory so far as they went.

Another engine, named the "Perseverance," constructed by Mr. Burstall, was also entered for competition; but being unsuited to the railway, was at once withdrawn. The judges on this interesting occasion were Mr. Nicholas Wood, Mr. Rastrick, and Mr. Kennedy. The prize was awarded to Mr. Stephenson for his engine the "Rocket."

The "Rocket" undoubtedly owed its efficiency, at least in an economical point of view, from the construction of the boiler, and the large amount of surface which was presented to the action of the heated air. This was obtained by introducing twenty-five copper tubes, three inches diameter, into the interior of the boiler, at its lowest diameter; these tubes opened at one end into the space below the chimney, and at the other into what is now termed the fire-box; by this arrangement, the flame and heated air passed through the tubes, which were surrounded by the water in the boiler. The furnace or fire-place was an external box, about three feet deep and two wide; the furnace was provided with an external casing; into the space thus formed the water from the boiler passed: a large additional amount of heating-surface was also thus obtained. The boiler or flue-tubes—"which has since proved to be the main-stay of the modern locomotive"—was the invention of Mr. Henry Booth, the secretary of the railway; a gentleman "to whom railways are indebted for much of their practical efficiency." From the invention not having been patented, Mr. Booth did not receive the great pecuniary advantages which might otherwise have resulted from this highly valuable improvement. We understand, however, that he received a pecuniary reward from the directors of the railway on account of it. As will be seen on inspection of the diagram, the cylinders were placed outside the boiler, near the fire-box, and inclined at an angle; and the piston-rod of which is connected with the driving-wheel by means of a connecting-rod.

In the "Sanspareil" of Hackworth, the cylinders were inverted and placed vertically; the piston-rod cross-head worked between parallel guides; and to the cross-head was attached the connecting-rod which communicated motion to the hind wheels; the fore and hind wheels were coupled by a connecting-rod. The boiler was cylindrical, with the flue returned to the front, where it entered the chimney; the flue was of course entirely surrounded with water.

The "Novelty" possessed some arrangements of considerable merit, the most distinguished feature being the construction of the boiler and ire-place. This will be seen by an inspection of the diagram in fig 144: *l* is the furnace placed inside the boiler, and surrounded with water; fuel is supplied to the fire-place *c* by the tube or funnel *e*, passing through the dome of the boiler, and covered with a lid or cap. Air is forced into the fire, to maintain combustion, by a small pair of fanners worked by the engine, through the pipe *b* communicating with the ash-pit *c*. The heated air is forced along the series of pipes *f g* to the chimney *h*, the steam space being at *i i*. By this arrangement a large amount of heated surface is obtained; the fireplace not only being surrounded with water, but the long range of pipes *f g*. The peculiar arrangements of the engine will be seen by the diagram in fig. 143. Mr. Stephenson not only obtained the prize, but the appointment of engine-manufacturer to the company. The attention of the firm was now devoted to the perfecting of the mechanism of the locomotive. "Each engine that issued month by month from the factory was an improvement on its predecessors, and the fourteen and twenty miles of the 'Rocket' were raised to sixty and seventy miles; and the Newcastle factory became the largest and most famous in the world." Other manufacturers entered the field of competition, and the vast amount of ingenuity and practical experience brought

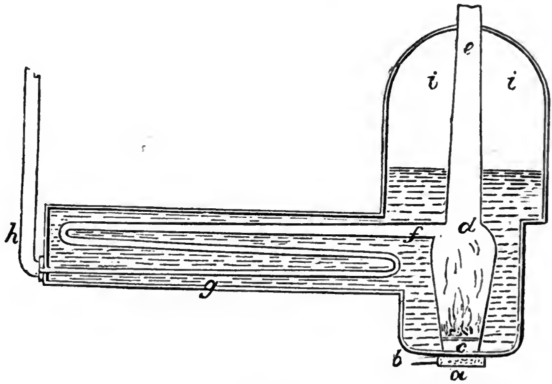


fig. 144.

to bear on the mechanism of the locomotive by such eminent firms as those of Hawthorn and Company; Sharp, Roberts, and Company; Bury, Curtis, and Kennedy; and last, though not by any means least, of Timothy Hackworth, soon resulted in bringing the locomotive engine to its present high state of perfection.

We now proceed to give illustrations of locomotive engines, showing the majority of the improved arrangements as now introduced. It is impossible to notice the whole details so fully as we should wish in a short treatise like the present; we hope, however, that the illustrations we give will enable the reader pretty closely to understand the arrangements and operation of this beautiful machine.

For the purposes of description, we shall divide the locomotive into two parts:—the fire-box, smoke-box, and boiler; and the moving parts of the engine which give motion to the whole.

The fire-box, as may be seen by inspection of the longitudinal sections of engines hereafter given, at *c c c c*, fig. 147, is enclosed on all sides except the bottom; at this part the fire-bars are placed on which the fuel rests; and at the side next the funnel or chimney, this side is pierced with holes, into which are passed the smoke-tubes *d d*. To prevent the dispersion of the red-hot ashes from the fire, a plate-iron tray or receptacle is placed beneath the fire-bars. Fire-boxes are of two kinds, square and round, as in figs. 153, 155. The round top is recommended by some, as being best calculated to withstand the pressure of the steam. In both methods of construction, however, it is imperatively essential to strengthen the parts by numerous stays or bolts. The fire-box door (see longitudinal sections) is double, to prevent loss of heat; and the outer and inner boxes, between which the water of the boiler is allowed to flow, are here joined. The fire-bars are placed loosely in a frame, so as easily to be lifted out when required to be renewed. In some instances the fire-bar frame is suspended by catches; when these are withdrawn, the fire-bars and fuel above them are precipitated into the ash-tray.

The smoke-tubes are generally made of brass, but malleable iron ones are now becoming largely used. The number of tubes in each engine varies from 96 or thereabouts to 134. Great care is necessary to fit the tubes into the fire-box end, and also that of the smoke-box. They must be fitted water-tight. The diameter of the tubes is generally about one inch and a half. The communication between the fire-box at one end and the smoke-box *s s*, figs. 153, 155, is kept up entirely by means of the smoke-tubes *d d*. This is formed of plates of iron of the same shape externally as the fire-box. Access is had to the interior of the smoke-box by a door at the front of the engine; this is made in various ways: in some instances it is hinged at bottom and opens downwards; in others it is in two leaves, like ordinary folding-doors. The smoke-tubes pass through the side of the smoke-box nearest the fire-box. The cylinders are in many instances placed inside the smoke-box; by this arrangement, the loss by radiation and condensation of steam is avoided. The steam, after working the cylinder, is ejected up the chimney through the blast-pipe *h* fig. 153, and *e e* fig. 155. The diameter of chimney is about 13 inches, and the height is limited to about 7 feet above the boiler, to allow it to pass under the railway bridges.

The fire is moderated by a damper placed in the chimney; this is generally made of the "throttle-valve" species, being a plain disc, *a a* fig. 145, turning on an axis *d* somewhat out of the centre; it is provided with

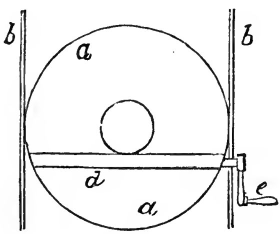


fig. 145.

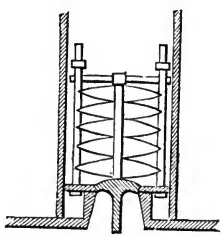


fig. 146.

an aperture through which the end of the blast-pipe passes, when the damper is wholly shut, the end of the blast-pipe projecting above it; the damper is moved by the lever *e*, actuated on by a long lever under the control of the engine-man. This lever is furnished with three slots, which take into a rest; according as the lever rests on either of the slots, so is the opening of the damper regulated. The upper orifice of the chimney is sometimes covered with a wire-netting; this is in order to arrest the sparks. This contrivance is, however, fast falling into disuse, and a perforated iron plate is placed below the blast in the smoke-box. In American locomotives, where wood is extensively used for firing, a "spark-arrester" is adopted; this gives a degree of size to the chimney unusual in locomotives in this country. This will be described hereafter.

The water is supplied to the boiler by means of a small force-pump, placed under the boiler and near the fire-box; this pump is worked by a lever from one of the engine eccentrics; in some instances the pump is worked from the piston cross-head. The water is drawn from the tank in the tender through a pipe properly coupled, by a ball-and-socket joint, at the part where the engine is attached to the tender; and the water is delivered to the boiler in some instances at the smoke-box end, a little below the water-level; at others near the fire-box, and in others again near the centre part of the boiler.

There are various appliances connected with the boiler. The safety-valve is generally placed above the fire-box, as in figs. 153-155, and is pressed down by a lever, the pressure being regulated by a spring balance. The nature of the arrangements of this kind of valve is explained at p. 45, fig. 66, *Mechanics and Mechanism.*

Lock-up safety-valves are falling into disuse, as, from not being easily

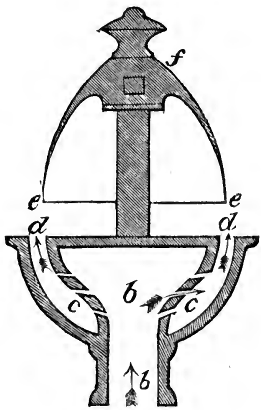


fig. 147.

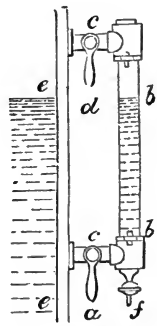


fig. 148.

got at, they are apt to stick in the seat and become inoperative. In some engines a valve, as shown in fig. 146, is used. This is loaded a little above the usual pressure; this being obtained by the bent springs forcing down the valve into its seat.

The contrivance known as the steam-whistle is placed on the dome or top of the fire-box; this is shown at *b*, fig. 147. The peculiar noise elicited is caused by the steam rushing up the tube *b b* connected with the boiler; and the admission to which is regulated by a cock actuated upon by a handle or lever within reach of the engine man. The steam passes through the apertures *c c* and out at *d d*, and strikes the thin edge *e e* of the circular cup *f*, producing the sound so well known now-a-days in almost every district of the kingdom.

The level of the water in the boiler is ascertained by gauge-cocks, which are placed at different heights to indicate different levels at which the water stands. In addition, a glass water-gauge is attached to the front casing; the arrangement of this apparatus is shown in fig. 148. The tubes *c c* are in communication with the interior of the boiler; a strong glass tube *b b* connects the two tubes *c c;* the upper tube *c* communicates with the part of the boiler which should contain steam, the lower with that containing water. On opening the upper and lower handles *a a*, the water rises in the glass-tube to the same height as in the inside of the boiler. The oscillations of the water which would take place in the tube *b b*, from the rapid movement of the engine, is in some measure prevented by making the communication between the boiler and tube of a small size. A small cock, as *f*, is placed at the bottom tube, to clear the tube of its accumulated water. Entrance is obtained to the interior of the boiler by means of a man-hole door of similar construction to that described in another and preceding chapter.

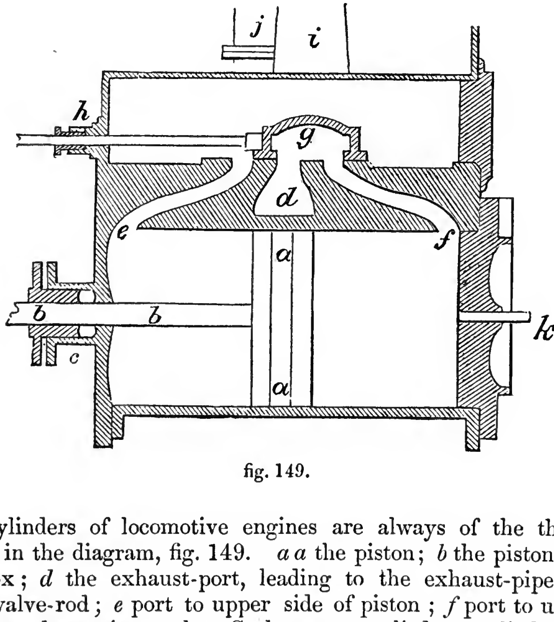


fig. 149.

The cylinders of locomotive engines are always of the three-ported species, as in the diagram, fig. 149. *a a* the piston; *b* the piston-rod; *c* the stuffing-box; *d* the exhaust-port, leading to the exhaust-pipe *i*; *g* the valve; *h* valve-rod; *e* port to upper side of piston; *f* port to under side; *k* cleansing and greasing-cock. Cocks are supplied to cylinders in some instances at top and bottom of cylinder: these are opened when required by levers within reach of the engine-man, to allow the water collected in the cylinders from priming and condensation. The steam is passed from the boiler to the cylinders by a pipe, the entrance to which is at the upper part of a cylindrical vessel O N, fig. 153, or within the dome; above the fire-box, as in fig. 155, the entrance to the pipe is placed thus far above the water to prevent priming as much as possible. The supply of steam to the cylinder is regulated by what is termed a "regulator." Various contrivances for this purpose are adopted. Fig. 150 explains a form much introduced. Two circular discs work in contact, one of which is fixed, and

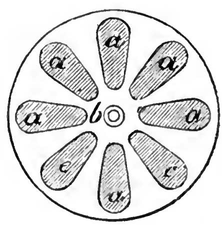


fig. 150.

the other is made to revolve by a lever connected with it, and actuated on by another lever or handle outside the casing. Apertures are made in both discs to correspond with each other in shape and position; when the apertures in both plates coincide, a free passage is given to the steam; but when the movable disc is turned round, so as to present the solid parts of its face opposite the apertures in the fixed disc, the entrance for the steam is lessened in proportion as the apertures in the fixed disc are closed. The discs are fixed on the entrance to the pipe which passes the steam to the cylinders.

The reciprocating motion of the piston-rod is changed into the circular one of the driving-wheel by means of a connecting-rod, as in fig. 151: *a* is the piston-rod; *b* the connecting-rod, the brasses of which embrace the cranked axle of the driving-wheels *n n*, as explained in p. 87, fig. 169, *Mechanics and Mechanism*; the cranks are placed at right angles to each other, so that the motion is continuous. The slide-valves of the cylinder for admitting the steam to both sides of the piston are worked by eccentrics, as explained in p. 82, *Mechanics and Mechanism*, the position of which is shown in fig. 151.

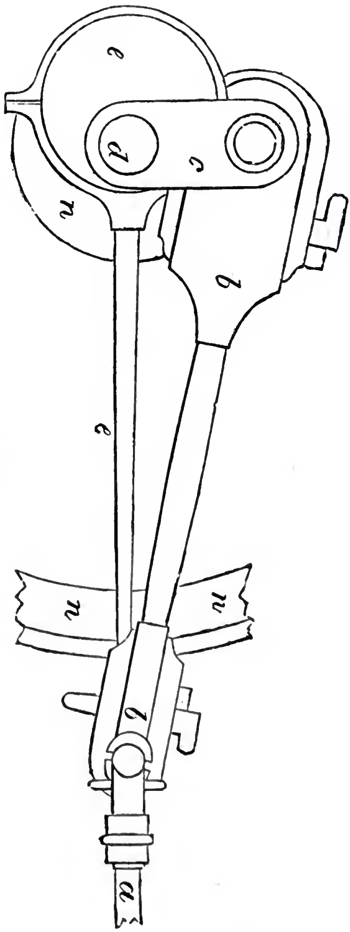


fig. 151.

In order to give the necessary facility for working the engine so as to make it move backwards or forwards as desired, various ingenious arrangements have been introduced: it will suffice for our purpose to describe one of these, and that the most generally adopted. It is known as the "link-motion," and owes its invention to Mr. Stephenson. The movements are effected by four eccentrics, two to give the backward, two the forward motion of the engine; two eccentrics to each cylinder. Let *b c*, fig. 152, be the two eccentric-rods, *b* the backing eccentric, and *c* the forward eccentric: these are connected to the curved link *a a*, the radius of which is equal to that of a circle described by each eccentric-rod revolving round the centre of its eccentric. The backward and forward eccentric-rods are attached to the extremities of the links. The valve-rod which works the slide-valve of the cylinder is provided with a piece of metal which slides between the grooves made in the interior faces of the links ; the links are kept at a proper distance apart by bolts. The links are capable of being lifted up by means of the lever *g*, and connecting piece *f*. When the slide-valve is out

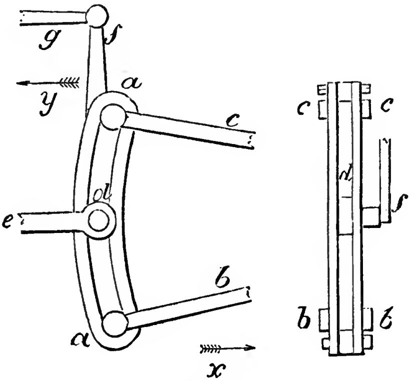


fig. 152.

of gear, the eccentric-rods are in the position shown in the diagram, the line of valve-rod bisecting the angle formed by the eccentric-rods. In this case, if the engine is in motion, as just in pulling up at a station, the eccentric-rods merely make the link oscillate or vibrate in the centre, of the valve-spindle, in and out alternately, as shown by the arrows *x y*. But if the valve is required to make the engine go ahead, or forward, the link is raised up by means of the handle *g*, until the forward eccentric-rod *b* is in a line with the valve-rod; and by this means the throw of the eccentric will be communicated to the valve-rod, and the engine will go forward. To reverse the engine, all that is necessary is to lower the links until the upper eccentric-rod *c* is placed in a line with the valve-rod, when the engine moves backward.

Having sufficiently, for the elementary purposes of our treatise, given the details of the locomotive, we now proceed to give illustrations of engines, showing the connexion of the various parts. The first we give is the longitudinal section of a "fast passenger-engine," constructed by Mr. Hackworth; and for the drawing of which, and description, we are indebted to Mr. W. Johnson, fig. 153. She has been expressly designed for fast passenger trains, having driving-wheels 6 feet 6 inches diameter, with leading and hind wheels of 4 feet diameter. Her weight, in working order, is 23 tons 15 cwt., and this is distributed in the following manner : on leading wheels, 8 tons 6 cwt. ; drivers, 11 tons 4 cwt. ; and hind wheels, 4 tons 5 cwt. The crank axle, A, is carried in bearings in the inner frame, whilst those of the leading and hind wheels, B and C, are in the outer frame ; the length from centre to centre of the latter pairs being 13 feet 6 inches ; these proportions having been laid down with a strict reference to the stability of the leading wheels, without an undue detraction from the tractive adhesion of the drivers. The barrel, D, of the boiler presents the novelty of welded longitudinal seams : it is composed of five

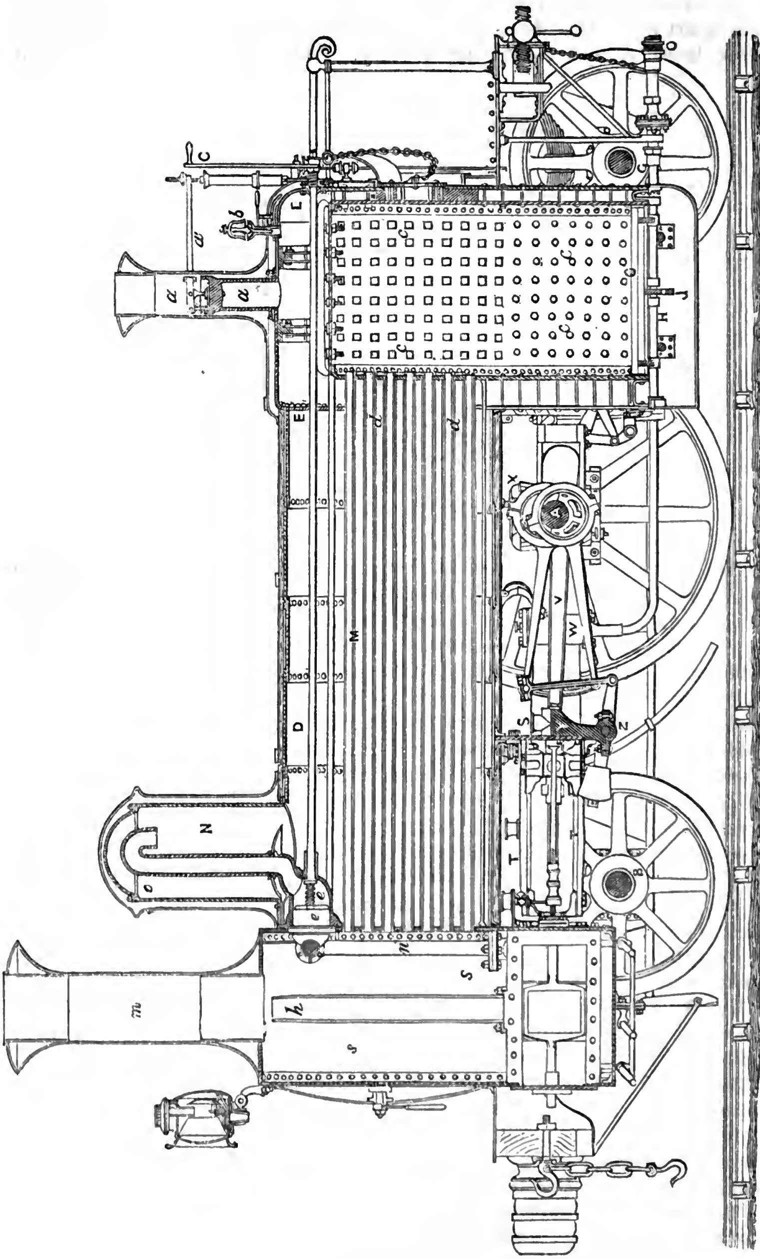


fig. 153.

plates, turned into rings, each being welded longitudinally, whilst their transverse junctions one with another are riveted in the ordinary way. The junctions, E E, of the two ends, with fire-box and smoke-box, are formed by angles or flanges welded on, instead of by separate angle irons riveted: these were turned and faced in the lathe to a true surface, for the bearing against the fire-box at one end, and the cylinder foundation-plate at the other, thus affording great accuracy in these details. The original idea of welding the boiler-plates is claimed by Mr. Hackworth, who, it appears, had actually made a boiler on this principle long prior to the date of the construction of the "farmer's engine" by Mr. Willis. The example of construction now before us is a very beautiful one; indeed, it is unrivalled as a specimen of this class of workmanship. The lagging, or cleading, of the boiler is covered with sheet iron, giving the surface a smooth appearance.

The plate, F, forming the back corners of the fire-box, is 14 inches broad, and was originally made in three pieces for the convenience of setting; but, after the completion of the process, they were welded together, so as to form a single plate. The grate bars, G G, are arranged longitudinally, and are carried on two transverse bearers, supported on projections on a pair of longitudinal shafts, H H, at the bottom of the fire-box, and worked by a lever, I, standing up from the foot-plate, so that the driver may drop the whole set of bars instantaneously into the ash-box, J. The latter may also be dropped independently of the bars, by releasing the suspending bars, K K, on each side.

The fire-door, L, is provided with a regulator for the admission of air into the fire-box at pleasure, the baffle-plate being perforated with small apertures for its dissemination in the interior. The boiler tubes, M, are of brass, 2 inches in external diameter, and are 221 in number. At the smoke-box end of the tubes a baffle-plate is also fixed opposite the tube ends; it is perforated with holes $1\frac{1}{8}$ inch diameter, the under sides of which correspond with the bottom line of the tubes, so that the hotter portion of the vapour is retained at the upper side, inducing a superior evaporative action. This addition does not interfere in any way with the cleaning of the tubes, as it may be removed with great facility. The dome, or steam chest, N, is formed out of a single plate, welded longitudinally, the flange for riveting it to the boiler being worked out of the same plate. The upper flange at O is welded on internally, being turned and faced to form a steam-tight joint with the convex cover, which is similarly formed, and is removable for obtaining access to the boiler.

The pistons also involve some novelties both in design and construction: they are made entirely of wrought-iron, with the rods forged on them; so that whilst there is thus a gain in lightness and strength, the dangers resulting from occasional looseness are completely removed. The inner framing, Q, consists of two wrought-iron slabs extending the whole length of the boiler's barrel, and attached at one end to the fire-box by $\frac{5}{8}$ inch angular plates riveted on. The peculiar advantage of this arrangement of frame is, that it yields to the expansion and contraction of the boiler, preserving a constantly uniform length between the cylinder and crank axle, and obviating the very common tendency to work loose, and cause leakage. The frame-plates extend from the centre of the crank axle, so as to counteract the effect of the strain of the engine at the most effective point; and a stiff connexion is formed with the barrel of the boiler by a strong central transverse plate, riveted on by means of stirrup angle-irons. At the smoke-box end, a foot, or flange, is formed on each frame-plate, for abutting against the tube-plate, to which it is riveted and bolted, the connexions being passed through the cylinder flanges.

The outer framing consists of a wrought-iron slab, 9 inches deep and 1 inch thick, extending the whole length between the buffer bars, the axle guards being forged with it in one piece. The transverse junction-plate, S, forms a very important feature of the engine; it is riveted to the boiler by double angle-irons, and extends across and between the inner and outer frame-plates, forming an effective fixed point for the pressure of the working gear.

The piston-rod motion consists of a pair of slide-bars, T T, attached at one end to protecting flanges cast on the cylinder cover, and at the other to the transverse junction-plate, S. The cross-heads, or motion-blocks, U, each consists of a malleable iron double eye-piece, with a box at the inner end, into which the piston-rod is keyed; and on the upper and lower sides of the double eye are bolted the brass slides, with protecting flanges to guide them on the motion-bars.

The connecting-rods, V, are of a plain rectangular section, and are attached to the cross-heads by a steel pin passing through them and through the double eyes, secured by a nut on the outside. The feed-pumps are placed in a line parallel to the piston-rods. The rams are of malleable iron, passed through and secured by a nut to the cross-head pin. The pumps are of brass; they are attached to the inner frame and transverse junction-plate.

It is an ascertained fact that, in too many cases, very little regard is paid to the obtainment of a sufficient area in the valve-cases for the admission of feed-water to the boiler. Owing to the contraction of this space, the valves are made of small size, and thus a great rise is absolutely necessary to admit a due supply of water; and this, coupled with their great rapidity of action, is frequently the occasion of great inconvenience in point of derangement and wear. Where the contraction exists in excess, the defect is heightened by the absorption of power in forcing the feed through the passages.

In the "Sanspareil," the valves and valve-boxes, W, are made very large, so as only to require $\frac{1}{8}$th inch lift of valve.

The eccentric sheaves are made with the smaller divisions of wrought-iron, having pins forged upon them, to connect them with the larger or prominent eccentric sides, which are of cast-iron. The eccentric rods and straps are of wrought-iron, and the rods are forged on the front halves of the straps, the latter being lined with brass. The back halves have an oil-vase, X, forged on each, with a syphon-pipe on each side the bolt, for lubricating the sheave. The slide-spindles are guided in brass bearings, in a bracket, Y, fixed to the transverse junction-plate; and the bottom of this bracket, at Z, forms a bearing for one end of the reversing weigh-bar.

The ordinary link motion is adopted for the slide and reversing gear, the lifting links for reversing being placed inside the motion links, and connected with the forward eccentric pins; and the levers on the reversing weigh-bar are forged on.

The fire-box is at *c c*, the smoke-tubes at *d d*, the balanced spring safety-valve at *a a a'*; *b* the steam-whistle; *s s* the smoke-box; *h* the blast-

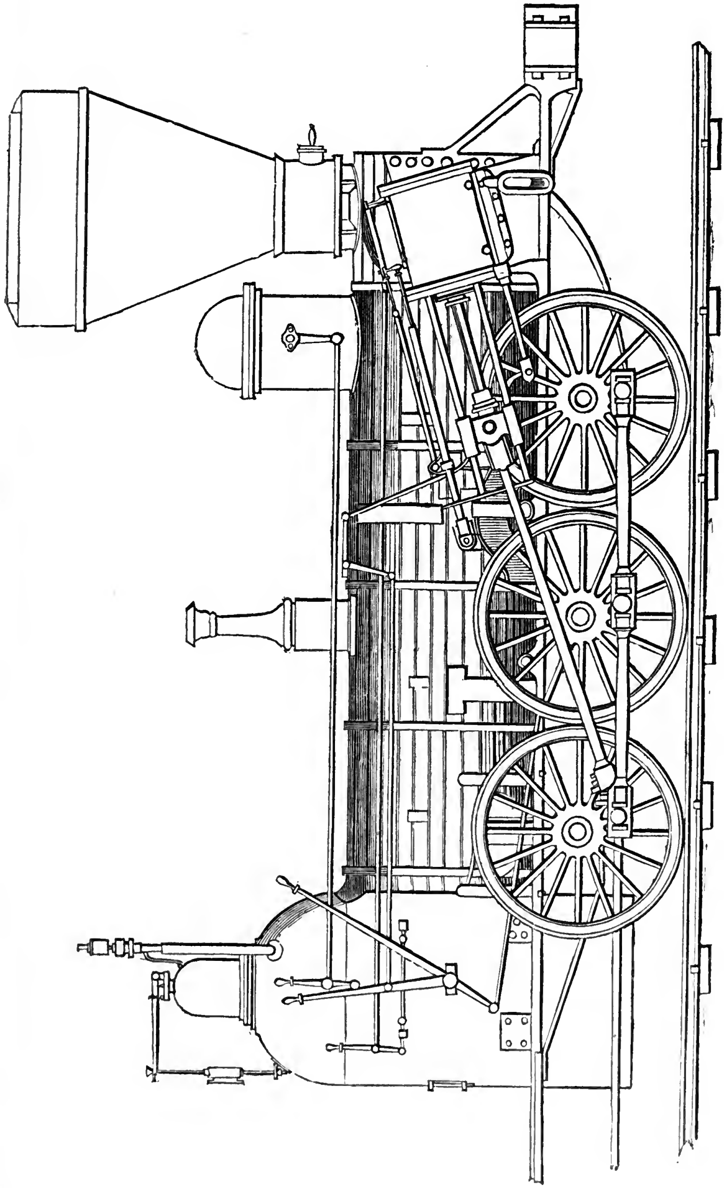


fig. 154.

pipe; *m* the chimney; *e e* the regulator; *c* the regulator-handle; *n* the pipe supplying steam to one cylinder; *o* the feed-pipe to supply boiler with water from tank in tender.

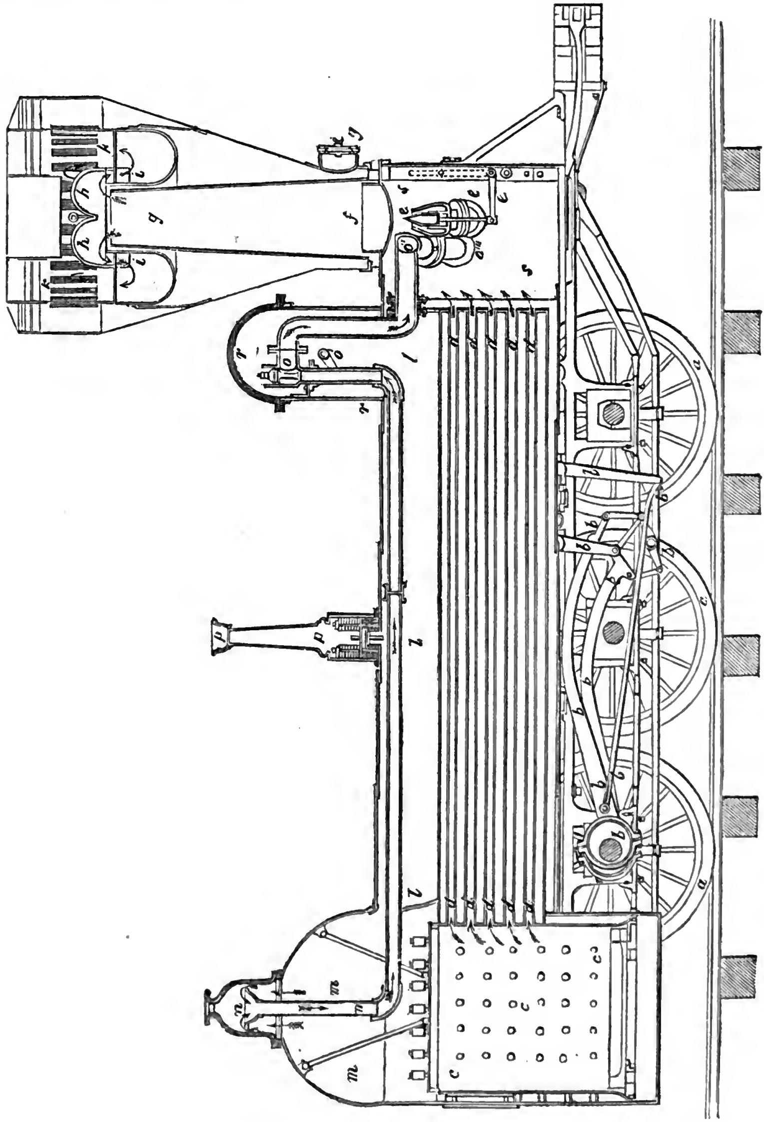


fig. 155.

In fig. 154 we give the elevation of an American locomotive, with outside cylinders; and in fig. 155 a longitudinal section of the same. *c c* the fire-box; *d d* the flue-tubes; *s s* the smoke-box; *e e* the conical blast-pipe, the opening of which is regulated by the levers as in the drawing; *m m* the steam-dome; *n n* the steam-pipe; *r r* the regulator dome; *o* the regulator, consisting of a spindle-valve, actuated on by the

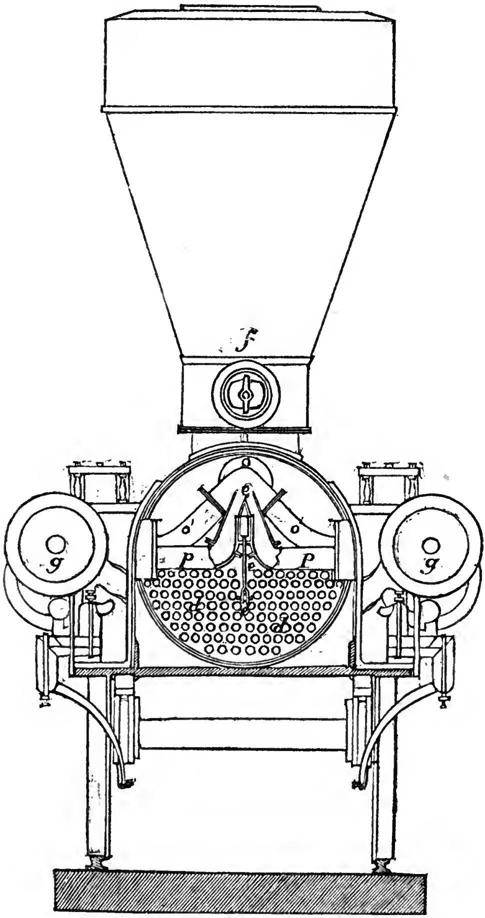


fig. 156.

lever *o'*, admitting steam to the cylinder through the pipe *o'' o''*; *l l* the steam space above the tubes; *p p* the lock-up spring safety-valve; *f g* the funnel; *i i*, *h h*, *k k*, the "spark-arrester." The curved arrows show the direction of the heated air; the sparks being deposited in the curved vessels *i i*, the heated air and steam passing out at the vertical apertures *k k*. The eccentric-rods and gear for working the valves, &c. are shown at *b b*.

In fig. 156 we give a transverse section of same engine at smoke-box end. *d d* the tubes; *e* the lever for working the conical blast-tube *e e*; *o* the steam-pipe ; *o'* the pipe leading to the cylinders ; *p p* the pipes leading to the blast ; *g g* the cylinders ; *f* the funnel or chimney.

In fig. 157 we give the back or fire-box end elevation of the same engine. *c c* the fire-door ; *d d* the starting handles and levers for working the eccentric motions, &c. &c. ; *e e* the gauge-cocks ; *f f* the spring-balance safety-valve ; *h g* the steam-whistle, actuated by the lever *i; m m* the crank-pins, on the driving-wheels, to which the connecting-rods are attached ; *i i* the house or covering for sheltering the engine-men (this arrangement is

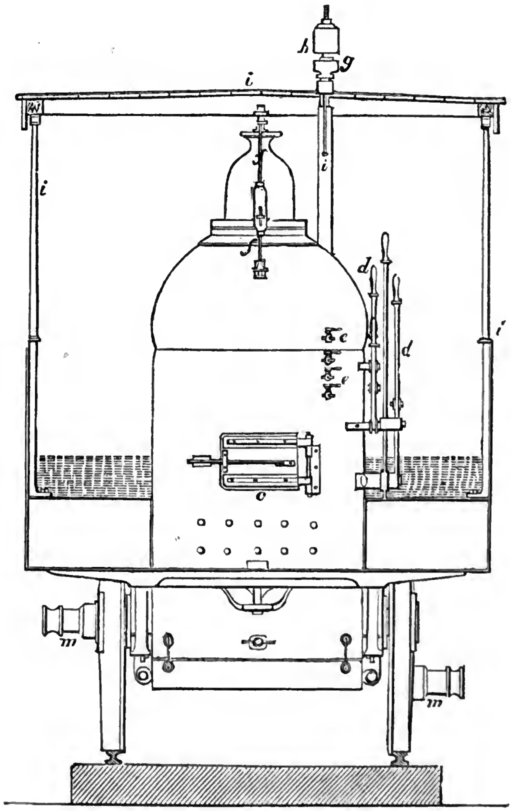


fig. 157.

adopted in all the engines working in the Northern States of America, the climate being too severe in winter to allow the men to be exposed to all weathers, as with us).

In fig. 158 we give an elevation of another form of American locomotive : *a a* the cylinder and valve-casing ; *b* the piston cross-head ; *c* the connecting-rod ; *d d* the connecting-rod coupling the wheels together.

In fig. 159 we give a sketch of a first-class locomotive passenger engine on Crampton's patent principle, as used on the London and Northern and

Western Railway, showing the connection of engine and tender. In fig. 160 a form of engine as used for short journeys is shown; in this species

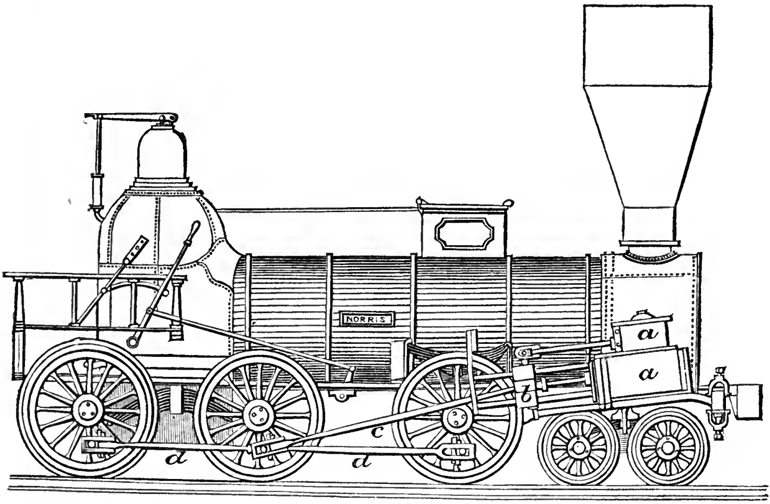


fig. 158.

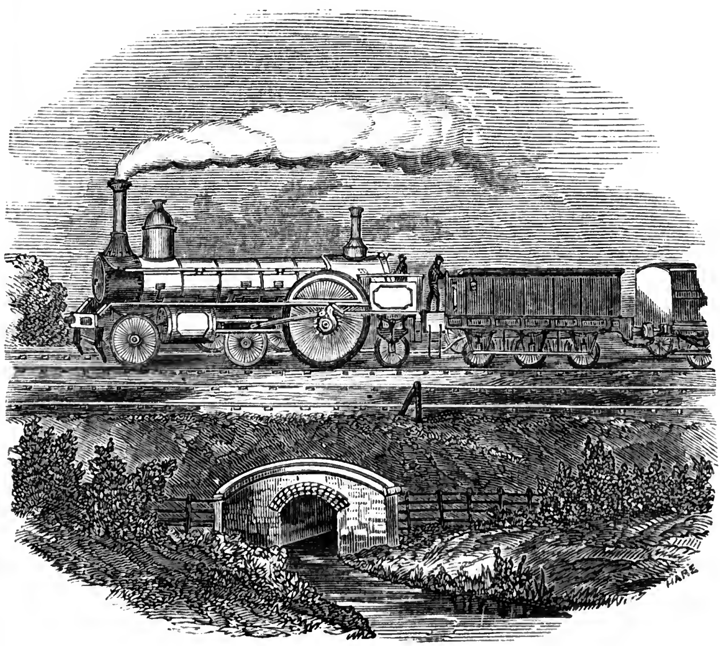


fig. 159.

of locomotive the tender forms part of the engine, and is called the "tank-locomotive."

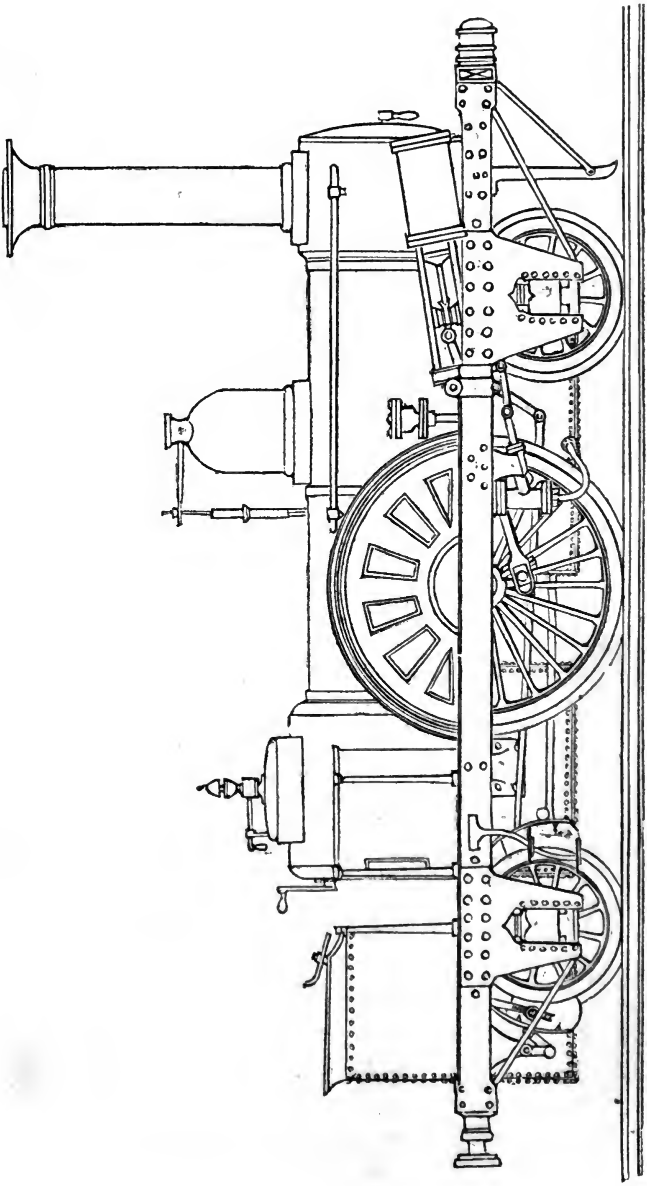


fig. 160.

CHAPTER VI.

STEAM-NAVIGATION AND THE MARINE ENGINE.

UNDER the present division of our treatise we purpose giving a few historical notes as to the introduction of the steam-engine for the purposes of navigation, preliminary to the illustrations and descriptions of the modern "marine engine." From the limited space now at our disposal, we shall be prevented from going so deeply into the historical details as might by some be considered necessary; but we shall nevertheless endeavour to notice the most important of these.

For many years previous to the application of the steam-engine to the propelling of boats, it had been a favourite object with mechanics, the substitution of sundry mechanical contrivances for sails. The most noticeable of these was the revolving wheel with float-boards on its periphery, which acted, on being immersed in the water, so as to move the boat forward: this, modified somewhat in its arrangements and construction, is identical in principle with the "paddle-wheel" of the modern steam-boat. The various contrivances introduced for boat-propulsion were actuated either by manual labour or that of horses, through the intervention of simple mechanical arrangements. The earliest notice we have of an attempt to substitute the power of steam for these methods of working is that of Blasco de Garay, to whose invention we have already alluded in the first chapter. Captain Savery, in the *Miner's Friend*, alluded to the capability of steam as a power for moving steam-boats; but it does not appear that he entered further into the matter than making a mere suggestion. Denis Papin, during his residence in England, is said to have constructed a model by which a steam-piston moving in a cylinder gave motion to the axle of the paddle-wheels; a rack was placed on the piston-rod, working into a pinion fastened on the axle of the revolving paddles. He employed two or three steam-cylinders; and when the piston of the one was ascending, that of the other was working downwards; and as they would give contrary motions, one was detached while the other was in action; and by this means the motion could be made continuous and tolerably regular.

In 1737 Jonathan Hall published "a description and draught of a new-invented machine for carrying vessels or ships out of or into any harbour, port, or river, against wind or tide, or in a calm." In this steam-boat the engine used was an atmospheric one, rotatory motion being obtained by a continuous arrangement of pulleys and cords or bands. We give in fig. 161 a diagram illustrative of the general appearance of this boat. From the imperfect mechanical arrangements, and the defects of the atmospheric as a rotative engine, this attempt at steam-boat propulsion was soon abandoned, if indeed it ever went beyond a mere speculation on paper.

Passing over various unsuccessful attempts made in America by Fitch and Ramsey, in 1785-1793; the Earl of Stanhope in England, in 1795; and of the Chancellor Livingstone and the celebrated Brunel on the Hudson in America, in 1797,—we proceed to notice the first successful steam-engine. We must, however, go back for a few years prior to the last-mentioned date. In 1787, Mr. Patrick Miller, of Dalswinton, a gentleman who devoted much of his time to experiments in the improvement of artil-

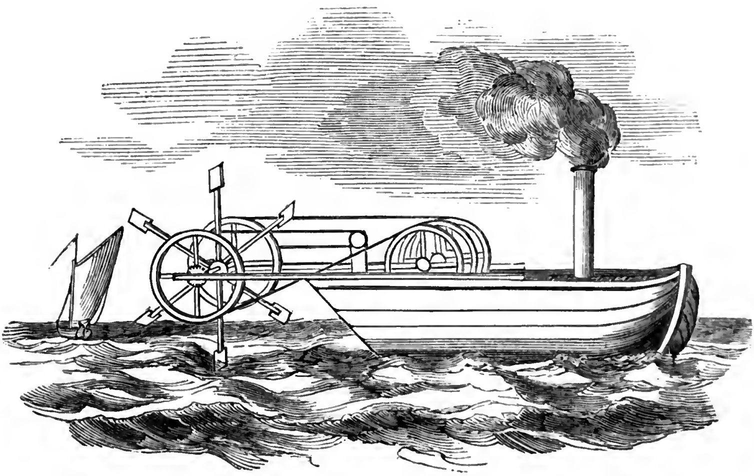


fig. 161.

lery and naval architecture, published a description, with drawings, of a "triple vessel moved with wheels." Convinced that, to give his invention every fair chance, it was necessary to employ some force greater than that of manual labour, he threw out the suggestion of employing the steam-engine for the purpose of moving the wheels; the force of steam, amidst other means proposed, presented itself, however, to his mind "as at once the most potent, the most certain, and the most manageable." "In Miller's family," says his son, in the narrative published in the *Edinburgh Philosophical Journal* in 1824, "there was at this time, as tutor to his youngest children, Mr. James Taylor, who had bestowed much attention on the steam-engine, and who was in the custom of assisting Miller in his experiments on naval architecture and the sailing of boats. One day, in the very heat of a keen and breathless contest in which they were engaged with a boat on the Leith establishment, this individual called out to his patron, 'that they only wanted the assistance of a steam-engine to beat their opponents;' for the power of the wheels did not move the boat faster than five miles an hour. This was not lost on Miller, and it led to many discussions on the subject; and it was under very confident belief in its success that the allusion was made to it in the book already mentioned. In making his first experiments, Miller deemed it advisable in every point of view to begin upon a small scale, yet a scale quite sufficient to determine the problem which it was his object to solve. He had constructed a very handsome double vessel with wheels, to be used as a pleasure-boat on his lake at Dalswinton; and in this little vessel he resolved to try the application of steam." To aid him in the fitting-up of the steam-engine, he secured the services of an engineer to whom he was introduced by Taylor, one whose name will be handed down to posterity as the engineer to whom practical steam-navigation is mainly indebted for its introduction,—William Symington. It was to this latter individual, an engineer of great practical attainments, that the task of fitting-up the steam-engine was intrusted. In the autumn of the same year in which he was employed, the steam-engine, having brass cylinders of four inches diameter, was placed on board the little pleasure-boat. "Nothing," says Mr. Miller in his narrative, "could be more gratifying or complete than the success of this first trial; and while for several weeks it continued to delight Miller and his numerous visitors, it afforded him the fullest assurance of the justness of his own anticipation of the possibility of applying to the propulsion of his vessels the unlimitable power of steam. On the approach of winter, the apparatus was removed from the boat, and placed as a sort of trophy in his library at Dalswinton, and is still preserved by his family, as a monument of the earliest instance of actual navigation by steam in Great Britain. In the succeeding year, a larger boat, sixty feet long, was tried on the Forth and Clyde Canal; the engines and machinery were constructed at the Carron Iron Works, near Falkirk; and in December 1789, "in the presence of a vast number of spectators, the machinery was put in motion." This second trial promised to be every way as prosperous as the first. It happened unluckily, however, that the revolving paddles had not been made of sufficient strength; and when they were brought into full action, several of the float-boards were carried away, and a very vexatious stop was for that day put to the voyage. The damage was repaired, and on the 25th December the steam-boat was again put in motion, and carried along the canal at the rate of seven miles an hour, without any untoward accident; although it appeared evident that the weight of the engine was an over-burden for the vessel (her planking being only three-quarters of an inch thick), and that under such a strain it would have been imprudent to venture to sea. The experiment, however, was again repeated on the two following days; and having thus satisfied himself (Miller) of the practicability of his scheme, he gave orders for unshipping the apparatus, and laying it up in the storehouses of the Carron Works." In consequence, as it appears from the statements in the narrative by his son, Miller was led to abandon further experiments with the view of introducing the steam-boat more extensively, partly from the large expenses which the first trial had cost him, and partly from his attention becoming much directed to agricultural pursuits. In 1801, Symington, patronised by Lord Dundas of Kerse, started a steam-boat on the Forth and Clyde Canal, for the purpose of towing boats. The following is Mr. Symington's own narrative: "Mr. Miller being very much engaged in improving his estate in Dumfriesshire, and I also employed in constructing large machinery for the lead-mines at Wanlockhead, the idea of carrying the experiments at that time any further was entirely given up, till meeting with the late Thomas Lord Dundas of Kerse, who wished that I should construct a steam-boat for dragging vessels on the Forth and Clyde Canal instead of horses.

Agreeably to his lordship's request, a series of experiments, which cost nearly three thousand pounds, were set on foot in 1801, and ending in 1802, upon a larger scale (than those on Dalswinton Lock) and more improved plan, having a steam-cylinder twenty-two inches diameter and four feet stroke, which proved itself very much adapted for the intended purposes. Having previously made various experiments, in March 1802, on the Forth and Clyde Canal, Lord Dundas and several other gentlemen being on board, the steam-packet took in tow two loaded vessels, each of seventy tons burden, and moved with great ease through the canal a distance of nineteen and a half miles in six hours, although the whole time it blew a strong breeze right a-head of us; so much so, that no other vessels could move to windward in the canal that day but those we had in tow, which put beyond the possibility of a doubt the utility of the scheme in canals and rivers, and ultimately in open seas. Though in this state of forwardness, it was opposed by some narrow-minded proprietors of the canal, under a very mistaken idea that the undulation of the water, occasioned by the motion of the wheel, would wash and injure its banks. In consequence, it was with great reluctance laid up in a creek of the canal, exposed for years to public view."

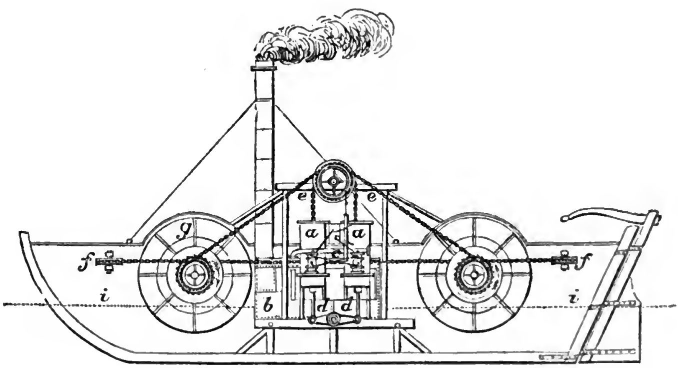


fig. 161a.

In fig. 161ª we give a drawing of Symington's first engine, and in fig. 161ᵇ a drawing of the second and improved design; for these we are indebted to the courtesy of Mr. Wm. Symington, of London, the son of the inventor. The following is the description of the various parts:

In fig. 161ª, *a a* are the cylinders, *b* the boiler, *c* steam-pipe, *d d* air-pump rods, *e e* connecting chains, *f f* direction pulleys, *g g* paddle-wheels, situated and wrought in a trough extending from stem to stern of the boat, and allowing free ingress and egress to the water; *h h* ratchet-wheels, for communicating motion to the paddles; *i i* the water-line.

In fig. 161ᵇ, *a* the cylinder, *b* the boiler, *c* steam-pipe, *d* eduction-pipe, *e* condenser and air-pump, *g* hand-gear and pump-rod, *h* piston and connecting-rod, supported by the friction-wheels; *i* the rod which communicates motion to the air-pump lever; *j* crank; *k* paddle-wheel, situated in a cavity in the centre of the stern of the vessel; *l l* paddle-wheel cavity, open behind and below to the water; *m* steer-wheel; *nn* flotation line. This boat was steered by two rudders connected by iron rods, and wrought in the prow by the steer-wheel.

We come now to notice the exertions of another individual who occu-

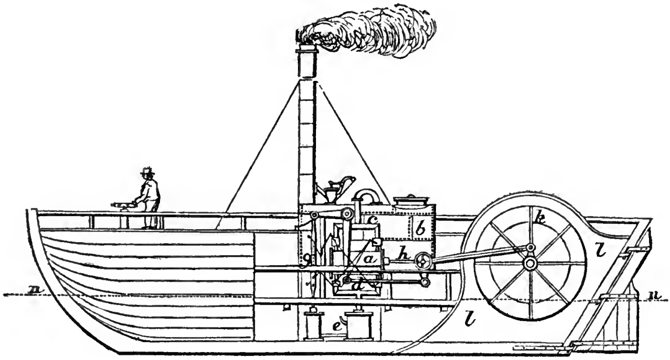


fig. 161 b.

pies an important place in the history of steam-navigation—Robert Fulton, an American. Passing over various matters connected with this individual, with reference to other inventions of his, we proceed at once to state that, on the occasion of his visit to Paris, he became acquainted with Chancellor Livingstone, then minister from the United States to the court of France; who, it may be recollected, has been mentioned as having been engaged in conducting steam-boat experiments at one period in America, but who had not succeeded. He explained to Fulton what had been done, informed him that on his return to America he intended to resume his experiments, and invited Fulton to turn his attention to the subject. This Fulton did, and instituted a variety of experiments with a view to ascertain the best expedients to be adopted. After many trials, he determined to use the paddle-wheel. In 1803, the first boat constructed by Livingstone and Fulton was completed; " the wheels and other mechanism acted according to his (Fulton's) expectations, although her speed was not so great as he calculated upon her machinery producing." So satisfied, however, were they with this preliminary trial, that they wrote to Boulton and Watt, ordering them to make an engine, with modifications adapted for the peculiar purpose for which it was designed; this engine to be sent to New York, to which place Fulton intended immediately to return. Livingstone, through the influence of his friends in America, obtained the privilege of navigating the waters of the State of New York by steam for twenty years, in which privilege Fulton was also included. Before leaving for New York, Fulton visited Scotland, and waited on Symington, who explained to him very fully the whole details of his plan. Symington, in his narrative, says, " Fulton politely made himself known, and candidly told me he was lately from North America, and intended to return thither in a few months; but having heard of our steam-boat operations, he could not think of leaving the country without first waiting upon me, in expectation of seeing the boat, and procuring such information regarding it as I might be pleased to communicate. He at the same time mentioned" (continues Symington) "however advantageous such an invention might be in Great Britain, it would certainly be more so to North America, on account of the many extensive navigable rivers in that country. And as timber of the first quality for building the vessels, and also for fuel to the engines, could be purchased there at a small expense, he was decidedly of opinion it could hardly fail in a few years to become very beneficial to trade in that part of the world; and that his carrying the plan to North America could not turn out otherwise than to my advantage; as, if I were inclined to do it, both the making and superintending of such vessels would naturally fall upon me, provided my engagements with steam-boats at home did not occupy so much of my time as to prevent me from paying any attention to those which might afterwards be constructed abroad. In compliance with his earnest request, I caused the engine-fire to be lighted up, and in a short time thereafter put the steam-boat in motion; and, carrying him four miles on the canal, returned to the place of starting, to the great astonishment of Fulton and several gentlemen who, at our request, came on board. During the above trip, Fulton asked me if I had any objections to his taking notes respecting the steam-boat; to which question I said, 'None.' And after putting several pointed questions respecting the general construction and effect of the machine, which I answered in a most explicit manner, he jotted down particularly every thing then described, with his own remarks upon the boat. But he seems," says Symington, "to have been altogether forgetful of this; as, notwithstanding his fair promises, I never heard any thing more of him till reading in a newspaper an account of his death." Thus provided with practical information from Symington, Fulton proceeded to America in 1806; and in 1807 Fulton had completed his steam-boat, and in the spring of that year it was launched on the Hudson. The steam-engine manufactured by Boulton and Watt had arrived; and, with the assistance of the engineers who had been sent out with it, it was fitted up in the boat; and in August of the same year the first trial was made. On this occasion, Livingstone and Fulton had invited many of their friends to witness the progress of the first steam-boat.

"Nothing," says the historian of the event, "could exceed the surprise and admiration of all who witnessed the experiment. The minds of the most incredulous were changed in a few minutes: before the boat had made the progress of a quarter of a mile, the greatest unbeliever must have been converted. The man who, while he looked on the expensive machine, thanked his stars that he had more wisdom than to waste his money on such idle schemes, changed the expression of his features as the boat moved from the wharf, and gained her speed; his complacent smile gradually stiffened into an expression of wonder. The jeers of the ignorant, who had neither sense nor feeling enough to repress their contemptuous ridicule and rude jokes, were silenced for the moment by a vulgar astonishment, which deprived them of the power of utterance, till the triumph of genius extorted from the incredulous multitude which crowded the shores, shouts and acclamations of congratulation and applause. . . . This famed vessel, which was named the *Clermont*, soon after sailed for Albany (150 miles from New York), and on her first voyage arrived at her destination without any accident."

The speed attained was about five miles an hour. She was ultimately placed as a passenger-boat between the above places, and succeeded so admirably as to place Fulton very speedily in a position of independence. The dimensions of the *Clermont* were, length 133 feet, depth 7 feet, breadth of beam 18 feet. The diameter of cylinder was 2 feet, stroke 4 feet; the diameter of paddle-wheels 15 feet; the float or ducket 4 feet long, and dropped 2 feet into the water. The burden was 160 tons ; the boiler was 20 feet long, 7 deep, and 8 broad.

In the year 1808, a steam-boat called the *Comet* was tried on the river Clyde, in Scotland, by Mr. Henry Bell, a name deserving of honourable mention in the history of steam-navigation, as one who, by his persevering exertions, was a great instrument in bringing steam-vessels into use in this country. The attention of Bell, it appears, was directed to steam-boat propulsion by receiving a letter from Fulton. Whether this letter was written anterior to the starting of the *Clermont* is not known.

"Fulton," says Bell, "had occasion to write me about some plans of machinery in this country, and begged the favour of me to call on Mr. Miller of Dalswinton, and see how he had succeeded in his steam-boat scheme; and if it answered the end, I was to send him a drawing and full description of it, along with my machinery. This led me to have a conversation with Mr. Miller, and he gave me every information I could wish for at the time. I told him where, in my opinion, he had erred, or was misled by his engineer ; and at the same time I told him that I intended to give Fulton my opinion on steam-boats. Two years after I had a letter from Fulton, letting me know that he had constructed a steam-boat from the different drawings of machinery that I had sent out, which was likely to answer the end, but required some improvement upon it."

Bell, as stated by Symington, frequently investigated the steam-boat constructed by the latter, while laid up in the creek of the canal formerly alluded to ; and was led, after receipt of Fulton's letter, "to think of the absurdity of sending his opinion on these matters to other countries, and not putting them in practice himself in his own." From these considerations, he says, "I was roused to set on foot a steam-boat, for which I had made a number of different models before I was satisfied. When I was convinced they would answer the end, I contracted with a ship-builder in Greenock to build me a steam-vessel according to my plans, with a 40-feet keel and a $10\frac{1}{2}$-feet beam, which I fitted up with a small portable engine having the power of three horses, and paddles, and called her the *Comet*, because she was built and finished the same year that a comet appeared in the north-west of Scotland." The *Comet* plied between Glasgow and Greenock, but was by no means a successful speculation for Bell. For the first six months very few, he says, "would venture their precious lives in her; but in the course of the winter of 1812, as she had plied all the year, she began to gain credit, as passengers were carried twenty-four miles as quick as by the coaches, and at a third of the expense, besides being warm and comfortable. But even after all, I was a great loser that year. In the second year I made her a jaunting-boat all over the coasts of England, Ireland, and Scotland, to show the public the advantage of steam-boat navigation over the other mode of sailing; having done what no king, prince, admiral, or general could do—make vessels go against both wind and tide, which had not before been accomplished in this country so as to make them of any use to this country."

A monument is erected on the banks of the Clyde in honour of Bell, as the father of public steam-navigation in this country. Bell having thus led the way, station after station throughout the kingdom was supplied with a steam-boat. At the end of 1823 there had been ninety steam-boats built in Scotland.

The opinion of nautical men during the first few years of the introduction of steam-boats was inimical to the idea that steamers were calculated to make progress against a heavy sea. This question was, however, set at rest, and decided triumphantly in their favour, by the deep-sea voyage undertaken by Dodd, who went to Glasgow for the express purpose of taking a steam-boat from that port up to London. The vessel he navigated was "90 feet long and 14½ feet broad, with a burden of about 75 tons; the engine was calculated to have a power of 14 horses, and the wheels were 9 feet in diameter. She was rigged with a square sail on the chimney mast, a bowsprit sail, and another on the mainmast. The crew consisted of a mate, four seamen of the first order, an engineer, a furnace-man, and a ship's boy. This was the first vessel of the kind that any one had ever dared to venture in on the tempestuous sea that terminates St. George's Channel on doubling Cape Lizard. . . . This interesting voyage, 758 nautical miles, was run in 122 hours."

The bold experiments of Napier, too, tended to hasten the application f steam-boats to deep-sea navigation.

On fairly considering the various claims put forward by different individuals for the honour of having introduced steam-navigation, we clearly think that the honour should be paid to William Symington, as being the first contriver of a *steam-boat* which was carried out into successful practice. The claims both of Henry Bell and Fulton are now, by the generality of authorities, set aside, and the high honour is left to be divided among Miller, Taylor, and Symington. What share Miller had in introducing the invention we have already shown; he played the part—and an important one, doubtless—of the capitalist who found the means to conduct the experiment; but he did nothing more. It is between Taylor and Symington that the matter rests; what claim Taylor had to be considered the inventor we must now endeavour to show. The documents from which our extracts are made have been furnished us by the son of William Symington, already alluded too.

The document chiefly relied upon in the Memoir of Taylor, as establishing his claims to the invention of steam-navigation, was a letter addressed to him by Mr. Symington, in the following terms:

Glasgow, Feb. 9, 1821.

"Sir,—In terms of my former agreement, when making experiments of sailing by the steam-engine, I hereby bind and oblige myself to convey to you by a regular assignation the one-half of the interest and proceeds of the patent taken by me upon that invention, when an opportunity occurs of executing the deed, and when required.

"I am, Sir, your obedient servant,

(Signed) "William Symington."

"To Mr. James Taylor, Cumnock.

"We were not aware of the existence of this letter at the time we penned our former remarks. We think it right, therefore, to take the present opportunity of stating, that it does not alter our view of the case in the least, but, on the contrary, confirms it in the strongest possible manner. Why should Mr. Symington bind himself to assign a share in the patent for the invention to Taylor, if the whole right to it rested with Taylor, which is what Taylor's friends maintain? It could not have been because Symington acquired by any pecuniary means an interest in the invention that the patent for it was taken out in his name, for Symington was notoriously and confessedly a person without money. It must have been the invention of the thing, and that alone, which constituted Symington's title. The monied person in the business, or at least the person who procured from others the money to take out the patent, was Taylor; he also was the person who introduced Symington to the influential patronage of Mr. Miller of Dalswinton; and it seems to have been on these grounds—partly pecuniary considerations and partly gratitude—that Symington covenanted to assign to Taylor one-half of the fruits of his invention. If Taylor had been the principal in the affair, he would have been the assigning party, and Symington the party to receive the assignment. As it is, Symington appears as the principal, and Taylor as a mere auxiliary; which, no doubt, was the relation in which the parties actually stood towards each other.

"The improvement in the steam-engine devised by Mr. Symington was accomplished in 1785-1786; and it was in the spring of 1786 that Mr. Miller, as already mentioned, engaged him to carry on some experiments upon steam-navigation. These were made upon the lake at Dalswinton, Mr. Miller's property, in 1788. It is asserted that Mr. Taylor remained in Edinburgh after Mr. Miller had left, to superintend castings of the parts of the engine intended to be employed in moving the boat. But if this were necessary, why did not Taylor afterwards put the engine together? If he were capable of furnishing the drawings and models by which the various parts were to be constructed, surely there could be no necessity for sending for Mr. Symington from the Lead-hills to put the different pieces properly *in situ*. Mr. Miller would have been little less than mad to employ Symington in these experiments, when he had such a brilliant and inventive genius as Taylor residing under his own roof. If (as has been asserted) Taylor was the author of these experiments, where are the drawings and documents to substantiate his claim? Have they ever been seen by any person? Or, indeed, have they ever existed, except in the imagination of his partisans?

"There is an account of these experiments to be found in the *Scot's Magazine* for 1788, which it has been allowed was drawn up by Taylor himself. He acknowledges, in this statement, that the merit of the expense of trying the experiment was due to Mr. Miller, but that the engine used upon the occasion was the sole invention of Mr. Symington; and throughout the whole account he never introduces his own name, either directly or by implication. The notice alluded to was as follows:

"'On October 14 a boat was put in motion by a steam-engine, upon Mr. Miller's, of Dalswinton, piece of water at that place. That gentleman's improvements in naval affairs are well known to the public. For some time past his attention has been turned to the application of the steam-engine to the purpose of navigation. He has now accomplished, and evidently shown to the world, the practicability of this, by executing it upon a small scale. A vessel, twenty-five feet long and seven broad, was on the above date driven, with two wheels, by a small engine. It answered Mr. Miller's expectations fully, and afforded great pleasure to the spectators. The success of this experiment is no small accession to the public. Its utility in canals and all inland navigation points it out to be of the greatest advantage, not only to this island, but to many other nations of the world. The engine used is Mr. Symington's new patent engine.'—*Scot's Magazine*, Nov. 1788, p. 566.

"In 1789, Taylor is represented as being located at the Carron Iron Works, for the purpose of superintending the castings of an engine of increased size, the cylinders being 18 inches in diameter. But, in opposition to this, we have the affidavit of Mr. Stainton, one of the managers of these works, who states, that

"'He (Taylor) was never considered capable of superintending the work; that he never furnished a single drawing or model by which the work might be forwarded; but that, on the contrary, Mr. Symington was looked up to as being the person to whom all the necessary inquiries for the completion of the engine were to be addressed; and that, so far from considering Taylor a principal, he was rather looked upon as a spy appointed by Miller to watch Symington's conduct, that he did not waste too much of his time upon some experiments he was conducting at the same moment for the Wanlock Head Company.'

"The experiments with the new engine succeeded entirely; but when it had arrived at that point, that by a little more exertion it might have been perfected, Mr. Miller's excitement was over. He had been bitten by an agricultural mania, dismantled the steam-boat, and left steam-navigation to be promoted by other hands.

"In 1801 and 1802, Mr. Symington renewed his experiments, under the patronage of Lord Dundas, that nobleman having purposely gone down from London to engage him. He continued them until 1803, when he completed a steam-tug, which towed two merchant vessels 19½ miles upon the Forth and Clyde Canal, against the wind, in the presence of many spectators. Mr. Symington took out a patent in the usual way for the protection of his invention in 1801; and this fact must dispose of the charge of his having practised any concealment or secrecy with regard to the matter.

"A letter has been published from Mr. Symington to Taylor, in which the former promises to make over half the profits of the invention to the latter. This originated, I am told, in a representation made by Taylor, that he was possessed of considerable influence amongst noblemen and members of parliament, through whose intercession a parliamentary grant might be obtained. But even supposing Mr. Symington was not entitled to the honour of being the first applier of steam to the purposes of navigation, Taylor, from his own showing, and from that of his friends, must have still less claim; for he states that he (Taylor) called upon Mr. Miller, and endeavoured to persuade him to secure the right to the invention by a patent. If it was Miller's invention, Taylor's regretting his own incapability of securing the right by patent is an absurdity. * * * * That neither Mr. P. Miller (the son of the Mr. Miller of Dalswinton) nor Lord Dundas, who employed Symington to construct a boat on the Forth and

Clyde Canal, looked upon Taylor as the party by whom steam-navigation was introduced, the following letters will prove:

Letter from Mr. P. Miller to Mr. W. Symington.

Edinburgh, Feb. 3, 1824.

"Sir,—As I was not at home when you were employed by my father to erect a small steam-engine for him in a pleasure-boat of his, at Dalswinton, with which the first steam experiment now on record was made in the year 1788; nor had I an opportunity of being present at the second experiment, made the subsequent year on the Forth and Clyde Canal, likewise under your management,—may I request you to be so obliging as to inform me if you were acquainted with any practical system of steam-navigation that existed prior to that period, from which you could have derived any assistance in carrying my father's project into effect, or if you considered the speculations you were then engaged in as original in themselves at the time; for I never heard of any of the individuals who were engaged in the matter, that had either ever seen or ever heard of Mr. Jonathan Hull's pamphlet.

"Being credibly informed that a Mr. Henry Bell, of Helensburgh, near Glasgow, has publicly stated that my father's experiments failed, might I also request you to be so obliging as to mention what could have given him a handle for a groundless and unfounded mistake; for at least such did not happen at Dalswinton, as I can show by abundance of living testimony at this very day. I also know that there are many still alive who witnessed the experiment both days after the wheels were repaired, who are ready to bear evidence that every thing the reverse of failure took place on that occasion, and that these two days' experiments were as complete in success as any that have hitherto been made; and I would, at the same time, thank you to say if you know whether this Mr. Bell was ever amongst the spectators upon the occasion.

"I have learnt, however, that some years thereafter he applied to you to see the vessel you constructed for the Canal Company, and that you showed and explained every thing particularly to him, from whence he derived the skill he possesses in this matter; and likewise understand that Mr. Fulton, the American engineer, was also at Carron, and had the benefit of seeing the vessel and receiving instructions from you on the steam system which he so promptly and successfully carried into effect.

"I hope it will be convenient for you, on receipt of this, to give me the information of which I at present request the favour; and be so good as to address to me at the Albyn Club, Princes Street, where I shall be for a few days, previous to my return to Dalswinton.

"I am, sir, your most obedient servant,

(Signed) "PATRICK MILLER.

"To Mr. W. Symington."

From the Right Honourable Thomas Lord Dundas, to Mr. Symington, civil engineer.

"Dear Sir,—I was extremely sorry to hear that you had been at the house while I was from home. I beg to explain the cause of my absence, and the step I had taken to meet the chance of your arrival; and I must first state, that not having heard from you, I hardly thought you were able to accept the appointment I had made. Having accepted an invitation to sleep at Dunmore on Friday, I came over here during that day, and requested my son's tutor to receive you in the event of your coming to breakfast. Mr. Simpson, however, was not aware that you had been to Carsehall, or he would have done all in his power to make up for my absence, and, if possible, would have induced you to remain till my return.

"It was well known to me that you were the first person who propelled boats by steam, and I well recollect the trial boat lying near the drawbridge. The present model is a different one from that possessed by you; but I do not know if Mr. Bell used at first the 'eccentric' now in common use.

"The 'auletic wheel' I do not understand; but I will have the pleasure of calling upon you on Wednesday, when I shall be happy to receive your lecture, how much or how little of it may be within my sphere of comprehension.

"I am, dear sir, your very obedient servant,

(Signed) "THOMAS DUNDAS."

Documents have recently been discovered which substantiate still more fully the claims of Symington. These documents are in the handwriting of John Taylor, the brother of James, the claimant whose rights to the honour we have been examining, and whose name is not so much as once mentioned relative to the matter. We have been thus particular in giving the evidence on this important point. A pension of 50*l.* has, we believe, been granted to the widow of Taylor for his supposed services as introducer of steam-navigation; nothing was given to Symington during his life, and nothing yet to the relatives he has left behind him. We trust that little time will elapse ere the nation has, through the voice of its legislature, showed a nation's gratitude to the memory of the real introducer of steam-navigation—William Symington.

To afford a ready means of judging of the respective claims of the parties interested, the following summary is appended:

In 1786, Mr. Symington exhibited a working model of a steam-carriage in Edinburgh, and suggested steam-navigation.

In 1788, he superintended the construction of a steam-engine of his own invention, and the fitting of it into one of Mr. Miller's pleasure-boats; which boat was successfully propelled that year on Dalswinton Lake by the power of steam.

In 1789, a larger boat, with a more powerful engine of the same kind, was successfully propelled by steam on the Forth and Clyde Canal.

In 1800, he was engaged by Lord Dundas to construct steam-tugs for the Forth and Clyde Canal.

In 1801, the *Charlotte Dundas*, steam-tug, was repeatedly tried on the canal, towed vessels there and up the rivers Forth and Carron, into Grangemouth, and carried Mr. Fulton, the American engineer, eight miles on the canal in an hour and twenty minutes. In the same year he patented his direct-acting steam-engine for propelling vessels.

In 1802 and 1803, the second *Charlotte Dundas*, a larger and more powerful boat, towed vessels on the canal; and on one particular occasion dragged two laden sloops of seventy tons burden each, the *Active* and *Euphemia*, a distance of $19\frac{1}{2}$ miles in six hours, against a strong adverse gale.

His experiments were here ended, through the fear of the managers of the canal that its banks might be injured by the undulation caused by the wheels.

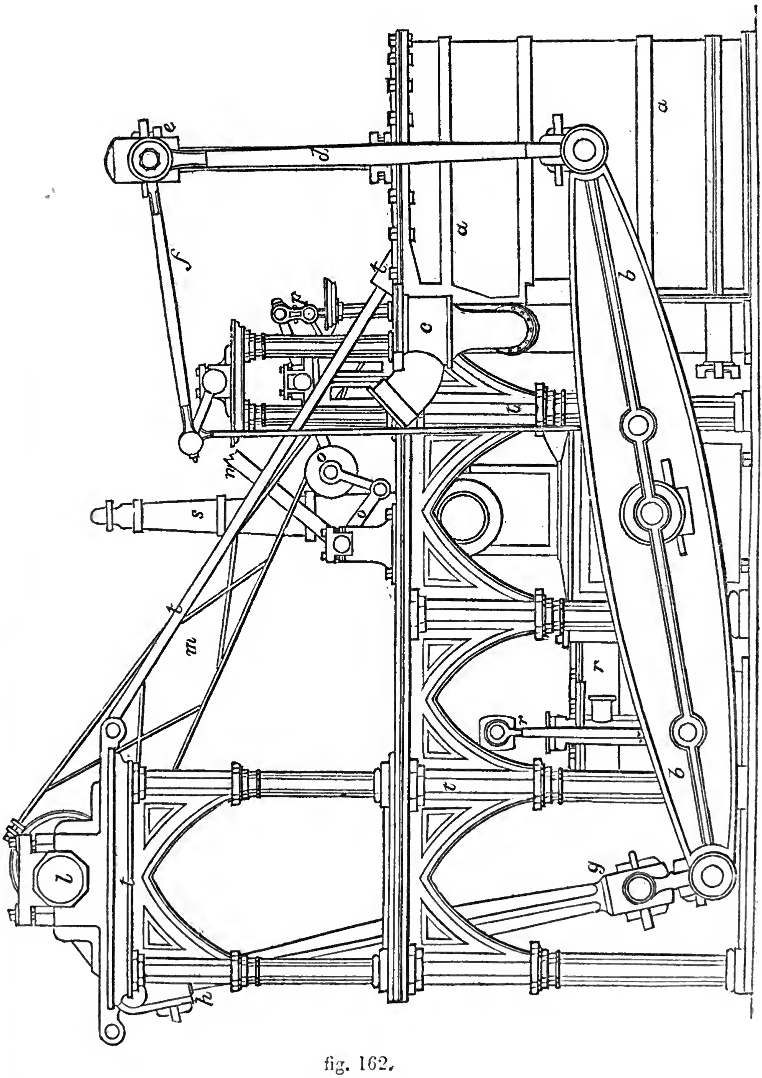


fig. 162.

In 1807, Mr. Fulton first succeeded in propelling a vessel by steam on the Hudson.

In 1811, Mr. Bell's first boat, the *Comet*, was tried, and set to work on the Clyde. Mr. Bell, as well as Mr. Fulton, had been on board of Mr. Symington's boats, and satisfied himself of their efficiency.

Having thus taken a rapid glance at the main points of interest in connection with the history of steam-boat navigation, we proceed to illustrate the various kinds of modern marine engines. These are of two kinds—engines as applicable to the driving of paddle-wheel steamers, and those applicable to "screw" steamers.

The engines adapted for paddle-wheel steamers are of two kinds, "side-lever" and "direct-action." The arrangements of the ordinary side-lever engine will be understood from an inspection of the drawing in fig. 162. As will be observed, this is a modification of the land beam-engine; but as the space overhead in all steam-boats is necessarily limited, the beams are arranged at the lower part of the engine. The cylinder is at *a a*, *b b* the working beam, *c* the steam-pipe, *d d* the side-rod connecting the end of the beam with the cross-head of the piston-rod *e*, *f* the parallel motion; *g* the connecting-rod connecting end of beam with crank *h*, *l* paddle-shaft, *m* eccentric-rod, *n o p* starting handle and valve gearing; *r r* condenser air-pump, worked by the side-lever connected with beam and cross-head of air-pump piston-rod, *s s* air-vessel, *t t* framing.

The drawing in fig. 38 shows the arrangement Mr. M'Naught adopts in his double-cylinder marine engines.

In fig. 163 we give a diagram illustrative of the connection of cylinder, condenser, and air-pump. *a* is the cylinder, *b* the piston-rod, *c* the lower, *d* the upper steam port, *e* the passage leading to the condenser *f*. A division is placed between the condenser and the eduction passage *e*, to prevent the injection-water passing to the lower part *c* of the cylinder. *g* the air-pump, *h i* the air-vessel. We now give descriptions of a few of the details of the engine worth notice. In the air-pump a valve is provided at the bottom plate opening upwards; this is to allow the water to pass from the condenser to the air-pump, but to prevent its return. Another valve is placed at the entrance to the hot-well *h* (fig. 163); this retaining the

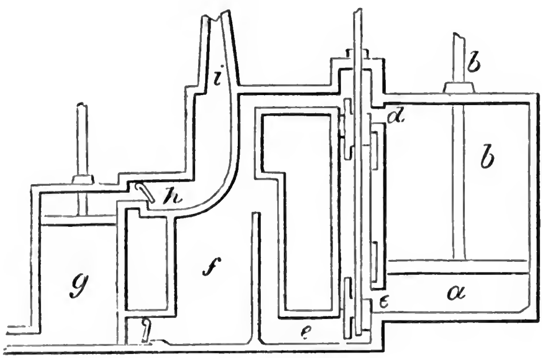


fig. 163.

water in the cone, frees the air-pump bucket from an unnecessary weight of water. The air-cone is now frequently dispensed with. Two orifices are made in the hot-well *h*, fig. 163, one larger than the other; the small one communicates with the force-pump for supplying the boiler, the other with the sea, and is termed the waste-pipe.

Escape-valves are provided to the steam cylinder; the office of these is to allow a passage to the water which collects above and below the piston. The escape-valve at the bottom of cylinder is weighted with a pressure above that of the steam in the boiler; if this precaution were not taken, the steam *a* would blow through them on being admitted to the cylinder. The upper escape-valve is generally placed in the cylinder cover, and is retained by a spring in some instances. In some engines the escape-valves are applied to the ports of the cylinder and kept closed with springs.

The diagram in fig. 164 illustrates the method adopted in side-lever engines in working the slide-valves; *f* is the end of the cross-head of the

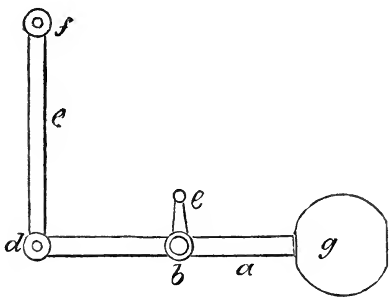


fig. 164.

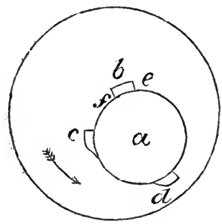


fig. 165.

valve-rod, *e e* side-lever, connected with the end *d* of the rocking-shaft *a* oscillating on the centre *b*, and which is moved alternately up and down by the eccentric lever *c*, to which the eccentric-rod is attached. *g* is the back balance-weight; the office of this weight is to balance the slide-valve in such a position that both of the steam-ports are closed when the engine is at rest. In starting the engine the rocking-shaft is moved by hand through the agency of a lever attached to it. In place of a lever, many engines have wheels placed vertically, like the steering wheels of ships. The best starting gear is that known as Stephenson's link motion, used in locomotives, and which, in Chapter V., we have illustrated and described. This also forms the best reversing gear, as by it the full speed a-head can be instantly changed for full speed a-stern without stopping the engines. In engines where this contrivance is not used, the eccentric has to be thrown out of gear before the engine can be reversed. On the crank-shaft, on which the eccentric is placed, a snug or projection is made, as at *b*, fig. 165; two snugs are also fitted, as at *c d*. Suppose the shaft revolves so as to bring the face *f* of the snug *b* against the snug *c*, the eccentric moves in the direction of the arrow; but if it is desired to change the motion, the shaft *a* revolves in the contrary direction, and the face *e* of the snug *b* comes in contact with the snug *d*.

The comparatively large space occupied by side-lever engines, has directed the attention of many of our engineers to devise arrangements by which space would be economised. This has been attempted, and in some instances with considerable success, by the introduction of the direct-action engine. The varieties of this class are very numerous. To the reader anxious to have a knowledge of these, we must refer to larger works; the *Artisan* treatise gives many illustrations under this head. Our space permits us only to give some simple diagrams illustrative of the most noted of these. The distinguishing feature in this form of engine is the absence of the side beams, rotatory motion being given at once to the paddle-shaft from the piston-rod. In fig. 166 we give a diagram illustrative of the

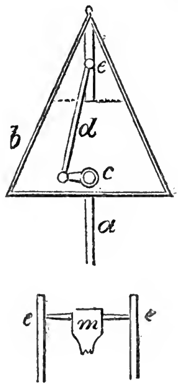


fig. 166.

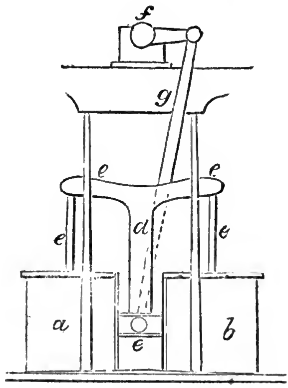


fig. 167.

"steeple-engine," much used in the Clyde. *a* is the piston-rod, carrying a triangular cross-head *b b*; *c* the paddle-shaft, *d* the connecting-rod, attached at one end to the upper extremity of the cross-head *b b*; and the parallelism of the piston-rod is maintained by the guide *e*, in which the cross-head *m* works.

In fig. 167 we illustrate the arrangement of the Siamese or double-

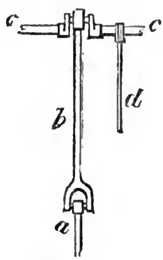


fig. 168.

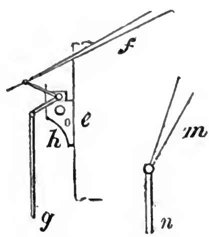


fig. 169.

cylinder engine introduced by Maudsley and Son. *a b* the two cylinders, *e e* the piston-rods connected with the cross-head *e e*, which is continued downwards to *d*, and which slides between the two parallel guides *e*; one end of the connecting-rod is attached to *e*, and the other to the crank *g*, on pedestal *f*. In fig. 168 we give a diagram illustrative of another form of direct-acting engine, which is considered as exceedingly compact; "indeed," says an authority, "no engine can occupy less room than this; for its length is little more than the diameter of the cylinder." Let *a* represent the piston-rod, *b* the connecting-rod, *c c* the paddle-shaft, *d* the air-pump rod worked by an eccentric on the shaft *c c*. The cylinder-valve is worked by the eccentric-rod *f*, fig. 169, from an eccentric on shaft *c c* fig. 168; the rod *f* works the levers *a* and valve-rod *g*; *h* the pedestal fixed to the pillar *e*; *m* is the eccentric-rod working the air-pump rod *n* corresponding to *d*, fig. 168. In direct-action engines, where the connecting-rod is between the piston and the crank, the engine is designated as belonging to the class known as the "Gorgon engine," introduced by Messrs. Seaward, where the connecting-rod is above the crank *a*; they come under the designation of steeple-engines.

A well known form of direct-action engine is that known as the "oscillating." We have already described the action of this; we now give a diagram showing its application to a paddle-wheel steamer (fig. 170).

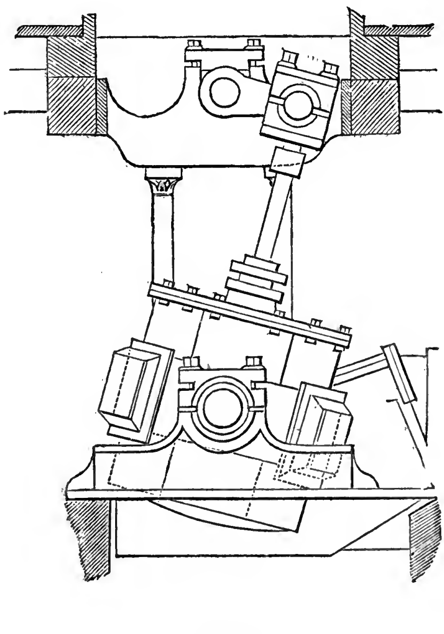


fig. 170.

Where vessels are propelled by the "screw," engines differing in arrangement from those we have already described are adopted. The screw having to make so many more revolutions than paddles in the same space of time, the speed of the screw-shaft is sometimes brought up by cogwheels. In the engines of the *Great Britain* this arrangement is adopted;

a pair of oscillating engines giving motion to a horizontal shaft; in this is fixed the driving wheel, taking into the toothed wheel on the screw-shaft. The inconveniences attendant on this form have, however, prompted in

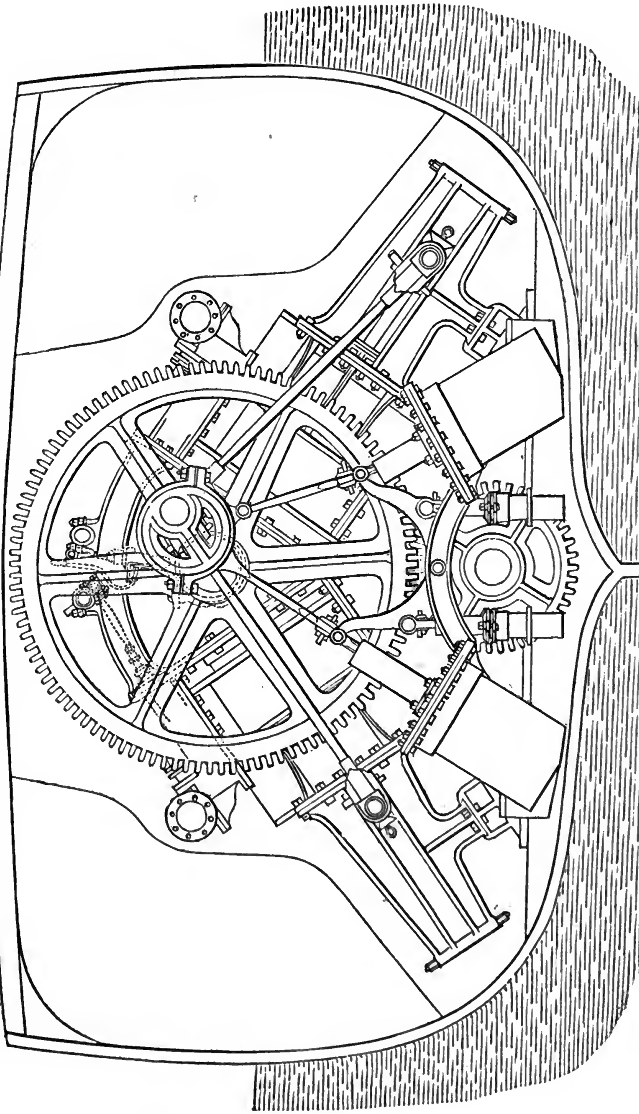


fig. 171.

other instances the use of engines connected directly to the screw-shaft; the difficulty in this case, however, is, that the valves of the air-pump are liable to be knocked speedily to pieces from the high speed at which the engine works. Mr. Bourne proposes to obviate this by replacing the air-pump valves by a species of ordinary slide-valve.

In fig. 171 we give a drawing of a double-geared engine, adapted for screw propulsion by Messrs. Scott and Co. of Greenock. The drawing shows a transverse section of the ship, showing the engines in complete external front elevation. The cylinders are fifty-two inches diameter, and three feet nine inches stroke, placed diagonally athwart the ship, and at right angles to each other; whilst the piston-rods project through the lower covers, to allow of long return connecting-rods. Each cylinder has two piston-rods, for greater steadiness, their outer ends in each case being keyed into a cross-head fitted at each end with slide-blocks, for working in a pair of inclined open guide-frames bolted to the bottom cylinder-cover, and supported beneath by projecting bracket-pieces, recessed and bolted down upon pedestal pieces on the engine sole-plate. From each end of this cross-head, immediately outside the guide-frame, a plain straight connecting-rod of round section passes up, to actuate the main first-motion shaft. The upper ends of these connecting-rods are jointed to side-studs, or crank-pins, fast in two opposite arms of a pair of large spur-wheels, which give motion to the screw-shaft by means of a pair of corresponding spur-pinions, fast on the shaft beneath a single pin in each wheel, answering for the two opposite connecting-rods on the same side of the engine. The main spur-wheels are eleven feet five and a half inches diameter, with one hundred and eight teeth of four-inch pitch, and fourteen inches in breadth on the face. They are keyed on the extremities of a common shaft, which is conveniently placed in the angular space formed by the two ends of the inverted steam-cylinders, being carried in a pair of pedestals cast with angular bracket-pieces to bolt down upon the cylinders.

The wheels are equally compactly placed, one on each side the cylinders and the general mass of machinery, and just filling up the space inside the connecting-rods. The pinions on the screw-shaft are four feet six inches diameter, so that the ratio between the screw and the engine's rate is two and a half to one. By this arrangement each piston is directly coupled to both of the large wheels, and the increased length of the cross-heads which the plan involves is counterbalanced by the effect of the double piston-rods; for by this division of the pressure the cross-strain leverage is proportionately diminished. The system of duplex gearing also insures a good, substantial, and well-balanced connection of the first-motion shaft with the screw-shaft. The air-pumps are both situated on one side of the engines, and are worked from the connecting-rod stud of the spur-wheel on that side, the pump cylinders being bolted at their lower ends by their foot-branches to the sole-plate, whilst their upper ends are connected together by a couple of arched cross-pieces. They are thus well bolted together, and to the main framing, their intermediate connecting brackets answering to carry their stud centres of a pair of bent levers for working the bilge and feed-pumps. The whole of the pumps are constructed on the trunk principle, of which class Mr. Humphries' engines, of the *Dartford,* are so well known as the earliest type. As the throw of the main driving-studs would be too great for the purposes of the air-pumps, it is very ingeniously reduced by means of an eccentric set upon the stud, so as to bring the real working centre nearer to the centre line of the first motion-shaft. One of the connecting-rods for working the pump is formed in one piece, with the eccentric ring, and the other is jointed to the ring on the opposite side; both rods descending to joint eyes on the upper ends of links which are again connected by bottom joints, in the recesses of the plunger-trunks of the pumps. The same intermediate joints of the lower ends of the connecting-rods also afford the means of connection with the upper ends of the bent levers of the bilge and feed-pumps, which levers serve the purpose of radius-bars for the air-pump rods. The links for working the plunger-trunks of the bilge and feed-pumps are jointed nearly at the middle of the bent levers, so as to give the required short stroke, the pumps themselves being set vertically, one on each side the screw-shaft, on the sole-plate. The cylinder-valves are combinations of the four-ported class, so successfully introduced on the Clyde by Mr. Thomas Wingate, and the equilibrium-valve. With this arrangement, the engines are handled with very great facility, and a very free exhaust is obtained. They are actuated by a pair of eccentrics on the main first-motion shaft, rods from which pass upwards to short levers on a pair of parallel rocking-shafts, working in end-bearings overhead. These bearings are carried upon a pair of parallel arched frame-pieces, stretching across between the two valve-chests, so that they thus bind the upper ends of the cylinders. The rocking-shafts are cranked at their centres, and have short connecting-rods jointed on to the crank-pins, and extending right and left to their respective valve-spindles. The steam enters the valve-chests on each side, through the elbow-branches, opening into stop or expansion valve-chests at the lower corners of the valve-casings, and the exhaust steam passes off to the condenser by passages round both sides of the cylinders. The condenser is entirely within the engine, beneath the cylinders; it answers, indeed, as the supporting pedestal for the cylinders, which are bolted down upon it.

Of engines adapted to drive the screw-propeller direct, without the intervention of gearing, recently introduced, the "trunk-engine," by Messrs. Penn, of Greenwich, is most remarkable; it is coming fast into general use. In this form of engine, the direct connection between the piston and crank obtainable by the oscillating engine is obtained without the inconveniences arising from the vibration of the cylinder. To the piston a hollow trunk or tube is attached; this passes through the cylinder-cover; between them a packing is interposed, to prevent any leakage between the trunk and the cover; the trunk is of such length as to project beyond the cylinder-cover when the piston is at the bottom of the cylinder. The trunk is of considerable dimensions; the connecting-rod is connected by a moveable joint to the piston, and its other end to the crank-pin; as the piston moves backwards and forwards, the connecting-rod vibrates within the trunk, and thus the direct action is obtained by very simple means. The trunk is on both sides of the piston, or, in other words, the piston is placed midway in the trunk, the connecting-rod being connected with that side of the piston nearest the crank. In this class of engines the cylinders are horizontal and placed side by side; the air-pumps are also horizontal; the great aim being to have all the machinery as low as possible beneath the water-line, a most important point in vessels of war. Both ends of the trunk pass through stuffing-boxes in the cylinder-cover; by this arrangement the pressure of the steam-side is prevented from preponderating over the other. In fig. 172 we give a diagram illustrative of the arrangement of the trunk-engine. Let *a a* be the piston, *b b* the trunk on the crank side, *c c* that on the opposite side; *d e* the connecting-rod, joined at one end *d* to the piston, and at the other *e* to the crank on the "propeller" shaft; *f* and *g* show the vibration of the connecting-rod in various points of the revolution of the crank. By this arrangement of piston and crank, it will

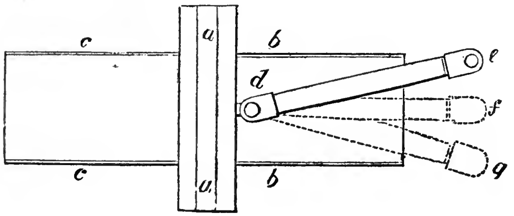


fig. 172.

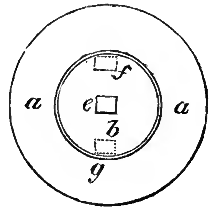


fig. 173.

be observed that the steam does not press on the whole surface of the piston, but only in the annular ring *a a*, between the outside of the trunk *b*, fig. 173, and the interior of the cylinder in which the piston moves.

Governors are usually applied to screw-engines in vessels of light draught, in order to regulate the speed. They are of the usual construction, although many new schemes have been recently introduced; for notices of these we refer the reader to the pages of the *Artisan*, more particularly the numbers for 1853. The necessity for a regulator of the speed of the screw-engine will be obvious, in considering that as the screw is placed at the extremity of the vessel, as it pitches in a heavy sea, the screw would revolve in the air; and as the load would thus be taken from the engine, it would revolve at too great a speed.

We must not omit the mention of an entirely new and very good form of engine adapted for working the screw-propeller, lately designed by Mr. John C. Bothams, engineer, of Salisbury, which differs from the ordinary marine engines in not being a pair of engines of the same description, with

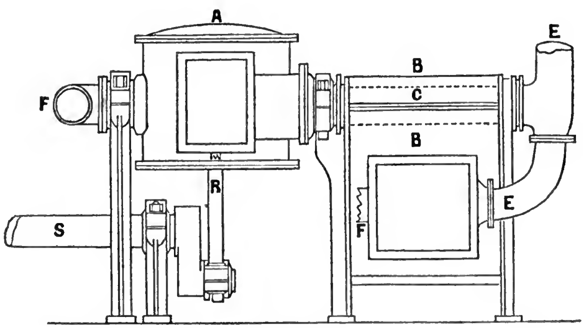


fig. 174.

all the working parts in duplicate, but a combination of two engines of different form: the one A an ordinary oscillating engine, having an oscillating motion given to it by being attached to the piston P of the pendulous engine B, by the hollow shaft C, which conveys steam to the oscillating cylinder A; the centre of gravity of the moving parts, the pendulous piston P, and the oscillating cylinder A being fixed as near as possible the required distance below the point of suspension C, according to the laws of pendulous motion.

The piston-rods R of the oscillating cylinder A have motion in two directions: a perpendicular motion derived from the cylinder A, and a horizontal motion from the pendulous piston P; the result being a circular motion to drive the screw-shaft S by means of a single crank.

Fig. 174 is a side view of the two engines, and fig. 175 a section through the pendulous engine B. The steam enters by the pipe E, and passes out by the pipes F F F to the condenser.

Fig. 176 represents an equilibrium surface condenser, and the pump to

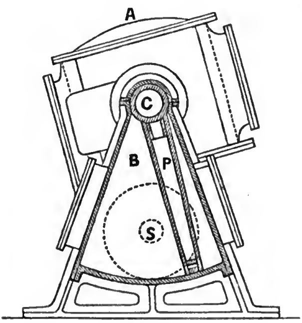


fig. 175.

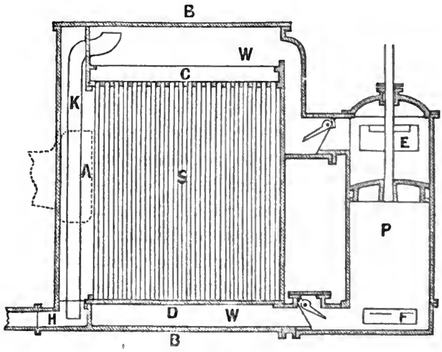


fig. 176.

supply it with cold water: the former consists of a case B B sufficiently strong to resist the pressure of the atmosphere, and is divided into two separate spaces by the plates C D; through the upper plate C a number of thin metal tubes are passed, and are screwed by their lower ends into the plate D; the steam to be condensed is admitted at A into the steam-space S, and flows among or between the tubes, and is condensed by contact with the outer surface of the tubes, which are kept cold by a constant supply of water flowing over their inside surface. P is a pump to supply the condenser with cold water, which enters the pump at E above the piston, is lifted up into the upper part of the condenser W, flows down through the tubes into the lower space W, then is drawn into the lower part of the pump, and by the down-stroke of the piston is forced out at the opening F. No water being admitted to the condenser except when an equal quantity is pumped out at the same time, the tubes are relieved of the pressure of the atmosphere on their inside surface. The condensed steam flowing down the tubes on to the lower plates D, flows into the space H, and is pumped out by the feed-pump into the boiler.

In order to relieve the tubes from all inequality of pressure on their inner and outer surfaces, a pipe K, leading from the upper water-space W, down into the reservoir H, at the bottom of the steam-space S, acts as a trap; the water in H derived from the condensed steam being above the bottom of the pipe K, prevents a communication between the water-space WW and the steam-space S, as long as those spaces are in equilibrium, or nearly so.

The tubes, therefore, being relieved of the atmospheric pressure, are only employed to separate the steam from the salt water used for condensing, and need not be formed of metal of a greater thickness than 1lb. weight per square foot, and can also be of any form, corrugated as in fig. 177, to diminish the number of tubes and joints, the amount of surface being the same.

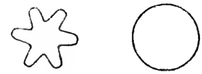


fig. 177.

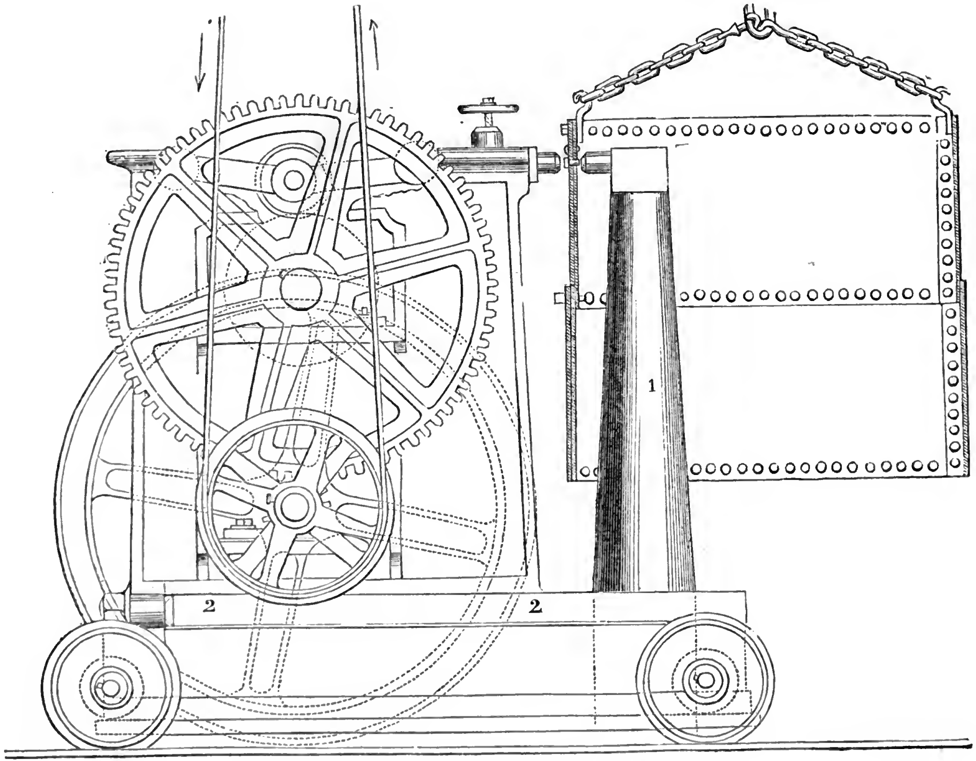
The thinner the metal which can be used, the less the amount of surface required to condense a given quantity of steam. The pressures on the upper and under sides of the piston being always equal, the pump can be worked by a small amount of power, in the case of large marine engines, by the auxiliary engine used to fill the boilers.

The use of brine-pumps, refrigerator, salinometer, &c., is dispensed with, and also the waste of about one-fourth of the whole quantity of feed-water supplied to the boiler, after being raised to the boiling point, whereby a considerable saving of fuel is effected; and it must be borne in mind that for every ton of fuel saved a ton of freightage is gained.

This invention must ultimately prove of great value; and in bringing it to the notice of engineers, we are thereby rendering them good service.

THE END.

LONDON:
PRINTED BY ROBSON, LEVEY, AND FRANKLYN,
Great New Street and Fetter Lane.



FAIRBAIRN'S STEAM RIVETING-MACHINE. (See page 112.)

MECHANICS AND MECHANISM:

BEING

ELEMENTARY ESSAYS AND EXAMPLES

FOR THE USE OF

SCHOOLS, STUDENTS, AND ARTISANS.

EDITED BY

ROBERT SCOTT BURN, M.E., M.S.A.

Editor of the

"ILLUSTRATED LONDON DRAWING-BOOK," AND NUMEROUS SCIENTIFIC WORKS AND ESSAYS.

SECOND EDITION.

LONDON:

NATHANIEL COOKE, MILFORD HOUSE, STRAND.

MDCCCLIV.

LONDON:
PRINTED BY ROBSON, LEVEY, AND FRANKLYN,
Great New Street and Fetter Lane.

INTRODUCTION.

A WORK like the present, treating exclusively on "Mechanics and Mechanism," and forming part of an Educational Series, would, at a period not very remote in our social history, have been looked upon as an innovation, and considered to be upon the whole as useless, as it appeared strange and uncalled for. And this view, singular as it may now appear, would have been founded upon a comparatively correct estimate of the importance of the subject. Mechanism then occupied but a very subordinate position in the ranks of our social powers, and mechanicians were as few in numbers and unimportant in influence as were their works and labours. Not so, however, now; the position of affairs is singularly changed. "Mechanicians and mechanism, the emanations of their genius," as we have elsewhere remarked, "occupy an important position in our social and commercial system. It is now scarcely, if at all, an exaggeration to affirm, that to the improvements recently effected in the various branches of the mechanical arts we owe our present position as a nation. The steam-engine, and the powers it gave us, enabled us to cope successfully with the otherwise overwhelming disadvantages which a long and expensive war entailed upon us. To mechanism we owe the factories from which we send out our cloths to supply the world's markets; to mechanism we owe that giant power which, with equal facility, propels our ships in the ocean-storm, as in the calm waters of our inland rivers. It is mechanism, well arranged and modified, which whirls the traveller along the iron way with an untiring speed which the swiftest race-horse bred by man can never rival; it is mechanism, finely constituted and cunningly devised, which forms the plainly useful as well as the beautifully elegant of our numerous and varied fabrics; in fact and in short, there is scarcely an article we use but what owes its production to one of the many combinations of mechanism. Nothing to the accomplished mechanician comes amiss; constructing the simple mechanism which effects a single purpose with ease, he as freely masters that which is imitative of operations which, apparently, nothing less than human skill could execute or human brains dictate. No matter what the operation to be effected: let it be complex in its details to a degree stultifying to an ordinary mind, no sooner is it required than machinery is devised and set to work; and the operation is effected apparently with as much ease as the forms are made which constitute written language by the pen of the ready writer, or the throwing of the shuttle in the weaver's hand-loom." Seeing, then, the important part played in all our social movements by the mechanic, using the term in its widest acceptation, we think that it is scarcely necessary to dilate as to the expediency of imparting a knowledge of the elements of mechanics and mechanism to the rising generation. A nation which owes so much to the results of these powers should not, in its schemes of education, ignore the necessity of explaining their principles, or adopt a system of instruction in which this important subject is altogether overlooked. As mathematics are said to impart a healthy invigorating tone to the reasoning faculties, so the study of mechanics, in like manner, may be said to teach directly the value of system, and the advantages of "doing the right thing in its right place." We are scarcely prepared to go the length of an eminent engineer, whose opinion was, that if all were taught "mechanics" generally, not with reference to following out of any distinct profession or calling, they would perform their various duties quicker and with greater ease to themselves; and that even females, if possessed of this knowledge, would make better housewives: nevertheless, we conceive there is much truth in the idea, which would become more apparent if generally acted upon. Not further to go into the benefit to be derived from the study of mechanics, we shall proceed to explain briefly the nature of our present treatise, and the method we have adopted in its treatment.

The work is essentially popular, and we may add practical; we have given results and arrangements only, refraining from an exposition of those strictly theoretical rules and mathematical formulæ which serve, in many instances, to confuse rather than to enlighten, to deter rather than induce the pupil to proceed. Not that we deem this theory, and that mathematical formula useless or unnecessary; but we have so frequently been impressed with the benefit to be derived, in the study of *mechanical arrangement*, from separating the purely theoretical from the purely practical, that we have determined to adopt in this work the principle of giving only practical arrangements and their results.

Thus, supposing a pupil desirous of becoming acquainted with the arrangement by which the rectilineal motion of a steam-engine piston-rod is changed into the circular one of the fly-wheel, we proceed to explain, in the first instance, how this change is produced; but we go a step further, and instead of giving a theoretical exercise, or entering into an exposition of the nature of the acting force at various points in the revolution of the crank, or the estimated loss entailed by its use, we suppose the pupil actuated by a still greater degree of curiosity, and desirous of going deeper into the details of this movement. Thus he will at once perceive from our explanation, how pieces of thin iron-wire may produce the desired movement; but this would not explain the method by which *mechanics in actual practice* availed themselves of the principle. We consider the gratification of this curiosity essential, and proceed therefore to explain how a crank is actually made, what is its form, how it is fixed in the shaft, what constitutes a connecting-rod, how it is constructed, how connected with the crank; in short, the arrangement of the various parts and how fitted together, as exemplified in actual working machinery. Again, in describing the nature and uses of a shaft, we first give an explanation of its distinguishing features and how it may be used; then divide it into its component parts, explain their actual construction, the method of making the journals on which they revolve, and the means of reducing the friction of their revolutions. These details we consider preferable, for the purposes of the treatise, to entering into a theoretical disquisition, showing how the shaft should be proportioned to ensure proper strength, without undue outlay of material, &c.

All the explanations we attempt to carry out in such a manner that the pupil, after studying them, could point out the various parts of an actual machine, and say, "this is a pedestal, that a cottar; these brasses are made to embrace this crank-pin by such a means; this is made in such a manner, that so secured; this motion is produced, and that changed, reversed, or altered by these various arrangements." But, not satisfied with these explanations merely, we suppose the pupil anxious to become acquainted with the *preliminary operations or processes* which must be gone through before the various movements can be made available for practical use. We then proceed to explain these processes: how this part is made circular, and what the means employed, thus necessitating an explanation of the turning-lathe; how this aperture is produced, thus involving the explanation of boring tools and machines; how this surface is made smooth, the chisel and planing machine being then described; and so on throughout the whole range of operations of the machine-shop. From this exposition the reader will at once perceive the distinguishing feature of our present treatise. It is not designed to serve as a guide to the practical mechanic, to enable him to proportion the various parts of his machines according to correct theory, or to assist him in drawing up his calculations; but as a means of giving a ready insight into the constructive forms and arrangements of general mechanism, as well as the methods by which the movements are produced, we venture to hope that our treatise will present some claim to be considered as a useful auxiliary in an educational series. The rapidity with which the first large edition was exhausted, may be taken as an evidence that this hope is well founded. We have aimed at using the simplest language, avoiding the use of technicalities as far as the nature of the subject would admit of. We have endeavoured to give a consecutive arrangement to the various departments, giving these, as far as possible, in the order of their general sequence. The illustrations, unsparingly given, will render the text, it is hoped, much more easily understood. For a considerable portion of the first three chapters the reader is indebted to the pen of an able and pleasing writer, Eneas Mackenzie, Esq., author of several popular educational works.

To the reader anxious to go into the study of the action of various machines, as well as the theory of their construction, we cordially recommend the perusal of *The Engineer's and Machinist's Assistant,* published by Messrs. Blackie of Glasgow and London; and the large work of Buchanan on millwork, with two volumes of plates, edited by Sir John Rennie, and published by Weale of London. These, though expensive, will be of eminent service to those of our readers who may be contemplating the following-out of professions in which the theory as well as the practice of mechanics is desiderated. A knowledge of the current inventions of the day, and of the progression of practical mechanics as applied to labour-saving conveniences, may best be derived from an examination of the pages of those valuable mechanical journals, *The Artisan*, *The Practical Mechanic's Journal*, *The Mechanic's Magazine*, and the *Patent Journal;* all of which abound with very interesting and valuable information. To the pages of some of these we have been, in one or two instances, indebted for illustrations of mechanical movements recently introduced; for the great majority of our examples, however, we are indebted either to a practical acquaintance with the subjects, or to sources available through a business connexion.

In concluding, it may be necessary to state, that we have not gone so deeply into the mechanical details of the steam-engine as at a first glance at the following pages might be considered essential, inasmuch as we have fully gone into these details in a special volume (now in course of preparation) on the very interesting subject, entitled, *The Steam-Engine, its History and Mechanism.*

R. S. B.

March 1854.

MECHANICS AND MECHANISM.

CHAPTER I.

THE CENTRE OF GRAVITY.

EVERY atom of matter is equally attracted to the earth. When the atoms form a solid, they cannot separately act, but as it were concentrate the whole weight of the body at a point which, if supported or suspended, will balance, hold in equilibrium, or keep in a state of rest, the entire mass: this point is called the *centre of gravity*, *centre of inertia*, or *centre of parallel forces.*

If a stick be laid across a finger, one particular part will be found where it will balance and remain at rest; that part is the centre of gravity in the stick. The bulk and density on both sides of this point of the stick will be equal; and thus by a sufficient support at this part the attraction of the earth is successfully resisted, for in any other position the stick would fall to the ground. The centre of gravity appears, then, to be the point which seeks the lowest level, and exists in every thing, of whatever shape it may be, in the universe.

By lifting a solid body at this point, the whole is lifted; or by preventing this part being moved, the mass is at rest.

A rod of iron having equal quantities of matter throughout its length will have its centre of gravity exactly in the middle. If a piece of wood or any other substance in the shape of a triangle be hung up from two points so as to swing freely, a string with a plummet attached will exactly cut the triangle in two from each point; and the point where the lines cross each other will be the centre of gravity. By marking the lines with a pencil or piece of chalk, the exact spot can be found. Any irregular-shaped thing, as a painter's palette, fig. 2, freely suspended from different parts, will have the plummet-line crossing at one point, which is the centre of gravity.

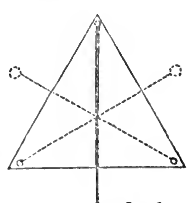


fig. 1.

A line drawn from the centre of gravity direct to the earth is called the *line of direction.* This is only an imaginary line, but one of great importance in the concerns of life; for if a square or angular figure be placed upon the ground, and this line does not fall within its base, it will fall over. This is most clearly illustrated in the case of a

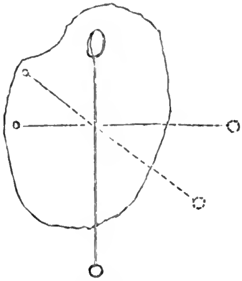


fig. 2.

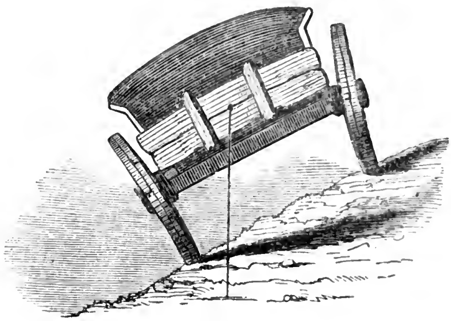


fig. 3.

loaded cart. Suppose a cart (see fig. 3) having lead or iron in it passing along an uneven road, by which one wheel is raised much higher than the other, and the centre of gravity be at the part marked at the back of the cart, then the line of direction falls within the wheel, and the cart will not upset: but if it be so loaded as is done with hops and wool (fig. 4), then the centre of gravity is moved much higher up; and the line of direction falling outside the wheel, which in this case is the base, the cart will turn over. Thus, then, the nearer the centre of gravity is to the base, and the line of direction in its middle, the steadier an object is. This is what gives such permanence to those colossal erections of the ancient Egyptians, the Pyramids.

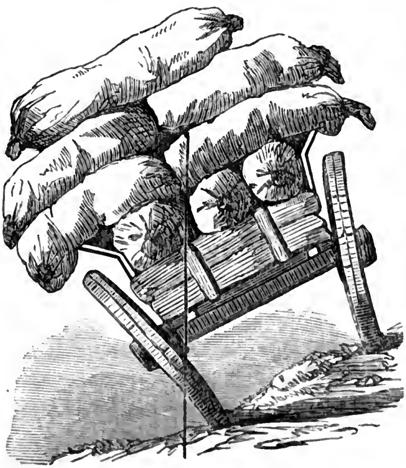


fig. 4.

A ship at sea will upset in a squall, from not having sufficient ballast: so that the centre of gravity must be low down, to counterbalance the weight of masts and rigging; while if the vessel be loaded only close to the keel, it rolls about most unpleasantly. Boys amuse themselves by taking a piece of pith of the alder-tree, and sticking in at one end a brass round-headed tack, when, laying it on its side and removing the finger away, it starts upright. On the same principle, of asserting an upright position, does a loaded ship recover itself from a squall of wind.

The amusing toys for children called Chinese tumblers,—little pink-eyed, cunning-looking Chinamen; or a broad-faced, bluff, laughing Englishman; or a careful, affectionate mother with a babe in her arms,—have broad heavy bases, and when placed on the ground, roll and rock until they have attained a straight position, always starting up when laid on their sides, smiling at their cunning, laughing at the fun, or pleasingly rocking the child to rest.

In a steamboat having the deck laden with passengers, as seen on the Thames at the periods of the fairs at Greenwich, the greatest cause to anticipate an accident lies in some event occurring from which the people might start upon their feet and rush to one side of the vessel; when the centre of gravity being changed, it would capsize, and the pleasure-seeking crowd be launched into the stream, the greater part most likely to meet a watery grave.

Accidents in boats are of continual occurrence, by people, instead of being steady or lying at the bottom of a little bark, rushing to one side on the slightest cause for fear, and thus creating the very mischief they desired to avoid.

In a round ball equally made, the centre of gravity is in the middle; but the base of all round bodies is a mere point. This is what makes them moved with little force, so that even a gust of wind whirls them along a smooth surface.

A round body placed on a slope or inclined plane rolls rapidly down, and a square one slides to the bottom, because the centre of gravity is beyond the base. If a round cylinder of light wood be placed on an inclined plane, and a piece of lead be inserted near the edge and upper part of the roller towards the rise of the inclined plane, then the cylinder may be seen, by its own weight, to roll up the steep.

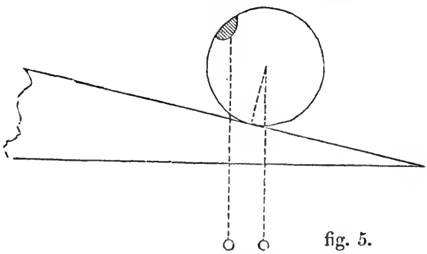


fig. 5.

In fig. 5, it will be seen that the line of direction pointed out by the plummet-line nearest the end of the inclined plane hangs over the base of the cylinder, consequently it would roll downwards; by the insertion of the lead the centre of gravity is moved, and the line of direction is on the other side of the base, which makes the body roll up the slope. It is on this principle that men aid a carriage or cart uphill by stepping on the spokes: their weight moving the gravity of the wheel, astonishingly assists the exertions of the horses.

If two smooth pieces of iron with planed faces, *a b*, be placed close at

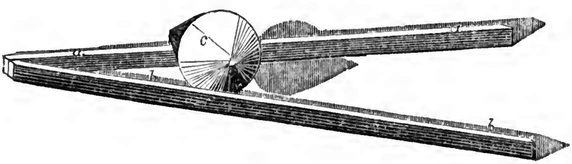


fig. 6.

one end and separated at the other, but raised, and a double cone *c* be put at the narrow end, it will roll along apparently upward. This is from the tapering ends of the cone finding room between the separated pieces of iron, and the heavy middle part, or centre of gravity, really approaching nearer to the earth.

It is a common trick to offer to balance a poker, a pail of water, or a weight, from a piece of wood projecting over a table. It will immediately be perceived, fig. 7, that the weight *w* would fall to the ground if the cord *a*, to which it is attached, were allowed to hang straight; but by placing a piece of wood *b* reaching to the end of the stick, the weight is pushed to one side, and its centre of gravity is underneath the table: thus both the stick and weight are supported by it. The reason of this is, if the stick to which the weight is suspended had to fall, the weight must rise upward towards the table; and being heavier than the stick, this cannot take place, therefore it remains at rest.

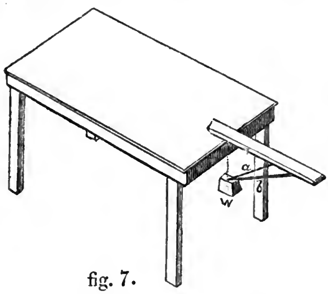


fig. 7.

The mason and the bricklayer, at every addition they make to the height of their work, use the plumb-rule to see that the wall is straight; for if it leaned inward or outward, it would be apt to tumble down: the importance of attention to the centre of gravity is thus seen. The annexed figure (8) represents the mason's level. The under side *a b* is placed on the wall; if the cord by which the weight *d* is suspended from *c* hang so as to correspond with a line on the centre of the upright, the wall on which *a b* rests is level.

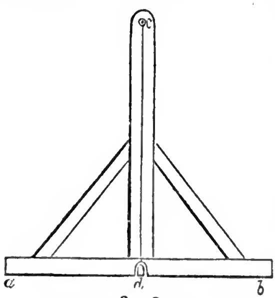


fig. 8.

The celebrated belfry or round tower at Pisa in Italy, encased with marble, is 190 feet high, and leans to one side twelve feet at the top beyond the foundation; but the line of direction is within the base; and therefore, as long as the cement endures, it will safely stand to astonish and frighten the gazing traveller.

At Bologna there is a tower 134 feet high, having an inclination of nine feet from the perpendicular, yet it stands firmly for the same reason that applies to the Pisa tower.

In scale-beams the centre of gravity is made in the same place as the centre of motion, from which arises the utility of the machine, as it will rest according as it may be adjusted in the placing of weights and materials upon each side.

Rope-dancers, that they may balance themselves on a narrow foundation, sometimes use a long pole loaded at each end with lead; this they hold across the rope, and fixing their eyes on some object, perceive when their centre of gravity tends either to one side or the other, which they recover by a movement of the pole, and thus keep the centre of gravity over the base.

Among other devices of itinerants to gain a precarious livelihood is that of dancing on stilts, imitating the unstable and fearful rollings of a drunken man, and hopping about on one long leg or pole: this is all most cleverly performed by a due attention to preserving the centre of gravity.

When a person stands on one leg, the other leg is held up behind to adjust the centre of gravity. This is most beautifully shown in the statue of Mercury, who is poised on the toes of one foot, while the other is elevated behind. The opera-dancers, in their exhibitions of the "poetry of motion," while raised on one foot and the body leaning forward, balance themselves by raising the other in such a manner as to preserve the centre of gravity over that part touching the ground.

On ascending stairs the body is bent forward, that the centre of gravity may progress with the feet.

When seated, the centre of gravity is on the seat; therefore when we rise, the feet are drawn in and the body forward, that the centre of gravity may be in a line with the feet.

When walking, we change the base from one foot to another; this gives a swaying motion to the body: thus people cannot walk well together, when linked by their arms, without keeping in step, that both bodies may have the same motion.

When carrying a burden on the back, we lean forward; if on the chest, we lean backward; if on either shoulder, we lean to the opposite side.

In that useful domestic utensil, a pail, the centre of gravity is near to the centre; and the handle, which is the centre of suspension, being fixed vertically over it, the centre of gravity must ascend; this therefore keeps the contents safely within the vessel. In some measures, such as those used for coals, which are heavy and have to be frequently emptied, the handle is placed lower; thus little power is required to upset it, and empty the contents out quickly (fig. 9).

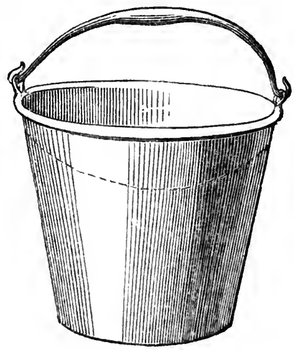


fig. 9.

In some instances the centre of gravity is not in the object itself, as may be illustrated in a ring, where it is in the middle of the space measured from every part of the solid circle.

If we take a circular piece of wood, and near the edge drill a hole and place a piece of wire through it, the wood will steadily hang from this axis; by making the hole exactly in the centre, the point of support will then be the centre of gravity, and the wood may be placed at rest in any position; but if the hole be made below this centrical one, then it is most unstable, and the least motion will cause it to reverse its position, as the centre of gravity will endeavour to get below the point of suspension. Thus, when the point of suspension is far above the centre of gravity, its steadiness offers much resistance to a disturbance from its balance; it will be seen, then, that in constructing fine balances, by making the point of suspension just below the centre of gravity, the balance is delicate and easily moved, which gives value to the instrument.

In many mechanical contrivances, as well as in the truths of science, the position of the centre of gravity is an important fact to ascertain; and it is known as simply as any other question in figures. If a rod of iron be five feet long and equally made, the centre of gravity will be exactly in the middle of the length; but if a weight of one pound be fixed on one end, and a weight of four pounds on the other end, then the centre of gravity will be at one foot distance from the four-pound weight, the other weight and four feet of the rod being required to counterbalance the opposite; thus the length of rod at each side from the point of suspension is in exact opposite proportion to the weights—that is, as one is to four. This is also called the *centre of inertia*, and is the *centre of centrifugal force* as well; for were a twirling body not to have its axis made in that part, one portion of the hole in the wheel would wear out much quicker than another.

Were a small ball attached to a larger one by a chain and fired out of a cannon, the two balls would be seen to fly round and round each other, and the centre of gravity would not be in either ball, but according to their proportion nearer to the large one, and this part in their motion would describe a curve.

The sun and the earth are bound to each other by attraction, and have a centre of gravity. In so speaking, we are not now describing atoms of matter, but masses. Say, then, the earth to be 1, then the sun is 354,936; and the centre of gravity of the sun will be 270 miles from its centre, which is the $\frac{1}{3300}$ part of its diameter.

The earth and the moon, by the attraction of the sun, revolve around it, and are as one mass of matter to that great body. Saying that the earth is a large ball and the moon a small one, they are held together by attraction, as if by a bar of iron; and thus they form a joint system, having a common centre of gravity. The moon is in bulk but the 49th part of the size of the earth, while from its density it is not more than the 70th of its mass; thus the mutual centre of gravity which will mark the line of the motion of the two bodies is a little below the earth's surface; and if the earth were drawn to the sun, this would be the part that would be attracted most strongly, and is the part describing the oval motion around the sun of the earth and moon.

Animals, from the broad base they have to support their weight, are enabled to walk sooner than man. A horse, when moving, first lifts up a hind-leg, leans its body forward, and then lifts up the fore-leg on the same side as the hind-leg it first moved; thus the centre of gravity is advanced: the other hind-leg is next moved, then the fore one on the same side, progressing in this way onward. In trotting he lifts and puts down two feet at once, those diagonally opposite. In galloping he lifts and sets his feet down one by one, though the two fore and hind feet are set down nearly at the same time. Animals with many legs lift the hind one first, and all at one side before moving those on the other side. Thus the centre of gravity is moved in a swaying manner.

CHAPTER II.

SIMPLE MACHINES.

A SIMPLE machine is an instrument by which weights can be raised, the resistance of heavy bodies overcome, and motion communicated to masses of matter. It is by the application of *simple machines*, or *mechanical powers*, that man accomplishes many useful undertakings that, without such contrivances of his ingenuity, would be beyond his natural strength.

Complex machines may be traced to be merely peculiar arrangements of simple mechanical powers.

The natural forces or powers at the command of man for producing motion are few, being principally the strength of men and horses, running water, steam, fire, and wind.

It is the ability to regulate, accumulate, and divide the speed of power, and to connect, oppose, and counterbalance different velocities, that gives the great value of mechanical power to man. Machines do not beget or increase force, they only apply that which has been communicated to them in an advantageous, easy manner.

The power applied must be greater than the resistance, otherwise there would be no motion.

In the volume on *Natural Philosophy*, it is stated that the velocity of a body is measured by the space passed over in a given time.

If we notice the wands of a windmill in rapid motion, the outer parts can hardly be seen, while the parts nearer to the centre of motion can be easily distinguished. Now both parts take the same *time* to perform their journey round; but from the greater space passed over by the ends in the same time, the velocity is proportionally increased (fig. 10).

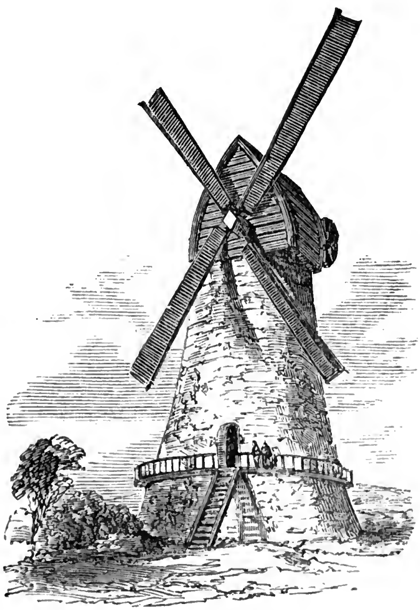


fig. 10.

In some collieries there is

a large wheel used to draw the coals to the surface, and underneath the wheel there are yoked two horses, one outside and underneath the wheel, the other further in; and it will be observed the outer horse has to keep walking at a very brisk pace, while the inner one moves in the most

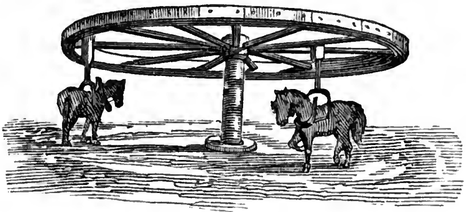


fig. 11.

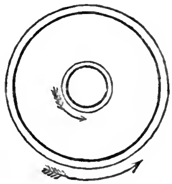


fig. 12.

deliberate manner possible (fig. 11). The relative length of the arrows in the annexed diagram shows the relative speed of the horses (fig. 12).

See, again, those youthful aspirants at our fairs for a ride on a roundabout, who get between the poles to push it along, giving this labour to purchase the luxury. Those near to the happy customers have to run with all their might, while those near to the axis move at almost a walking pace.

There is a contrivance for drawing water used by the market-gardeners near London, that will also serve to illustrate the present subject. We cannot here resist remarking the amusement we lately felt on reading a traveller's grave and minute description of this ancient practice as a piece of clever simple mechanical contrivance which he had discovered on his foreign travel. It is too much the case, that people pass through their own country with their eyes half closed, and only open them wide when a thing is of foreign produce.

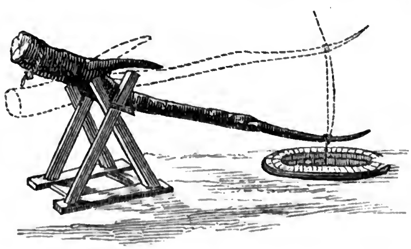


fig. 13.

Here it will be seen, fig. 13, on a man pulling down the end of the pole, that at the same time the other end moves through twice the space, consequently with twice the velocity, while both ends describe in their motion a part of a circle. By having the end of the tree heavy some power is gained.

Time is exchanged for *power;* or, as it is sometimes expressed, "what we gain in power we lose in time." This is termed the law of virtual velocities, or the golden rule of mechanics. Thus if a person could raise fifty pounds to a certain height in one minute, and by the help of machinery he raises 500 lbs. to the same height, it will be found that the time occupied in lifting up the 500 lbs. would be ten minutes: thus the tenfold increased power has to have a tenfold increased time, or the work of ten minutes could have been accomplished in ten different efforts in the same time.

The primary mechanical powers are the *Lever,* the *Pulley,* and the

Inclined Plane. The *Wheel and Axle* are derived from the lever; the *Wedge* and *Screw* from the inclined plane.

THE LEVER.

Of all the mechanical powers the lever is the most simple. It is formed of any strong substance, in the shape of a beam or rod, which rests on a prop or axis called a fulcrum, which is its centre of motion. There are three kinds of levers. The following is an exemplification of the *first* (fig. 14):

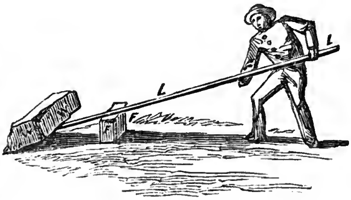


fig. 14.

In this diagram, *l* is the lever, *f* the fulcrum, *w* the weight. By pressing down at the end *l*, the other end of the lever raises *w*, the weight; the centre of motion is at *f*, the fulcrum. In other words, the power or force resting on the prop or fulcrum overcomes the weight or resistance. Thus if the lever be under the centre of gravity of the weight, and the length of the lever from the fulcrum be twice as long as the other part, a man can raise the weight one inch for every two inches he depresses the end of the lever.

Now if the end of the lever be four times the length of the part from the fulcrum to the centre of gravity of the weight, then the power of raising the weight is increased four times; but the space that the *l* end of the lever will pass through is four times greater.

This may be noticed, that as the power of attraction is drawn from the earth at one part where the weight is, it is increased or returned to the earth at the other end; thus is preserved an equilibrium of attraction.

It will thus be perceived, that if a weight of one stone moves through a space of ten feet, we may raise a weight of ten stones through a space of one foot; or a weight of ten stones moving through a space of one foot will make a weight of one stone move through a space of ten feet.

Now if a man can raise the weight at the end of the lever, and then the lever be made twice as long, and a boy of half the man's strength can then raise it, the boy will be sooner worn out by fatigue than the man, because the man in the exertion of his strength only goes through half the space that the boy has to pass through. It is stated, that "the force of the lever increases in proportion as the distance of the power from the fulcrum increases, and diminishes in proportion as the distance of the weight from the fulcrum increases." It was from this general law that Archimedes exclaimed, "Give me a lever long enough, and a prop strong enough, and with my own weight I will move the world." This was true; but from the immense parts of a circle his lever would have to describe, if at the rate of 10,000 feet an hour for about eight hours a day, it would have taken him nearly nine billions of centuries to raise the earth an inch.

If a lever, either formed as a scale-beam or having a fulcrum underneath, have a length from the fulcrum of six inches, and a weight upon it of 100 lbs., and it be desired to know what length of lever would counterbalance this, multiply the weight by the distance from the fulcrum, when the result will be 600; calculate the weight, 100 lbs., as inches, and make the other end of the lever this length, having upon it 6 lbs. weight —for 6 lbs. multiplied by 100 inches is equal to the other result 600, the weight and power balancing.

Should it be desired to know what power will balance a certain weight at the short end of the lever, it is done by multiplying the weight by the length of lever from it to the fulcrum, and then dividing the result by the other length of lever, and the result is the power required: thus if 100 lbs. be on one end of a lever 12 inches from the fulcrum, $100 \times 12 = 1200$; then suppose the long end of the lever be 24 inches, $1200 \div 24 = 50$ lbs., the power required.

A *spade* is a lever, the earth being a fulcrum in the operation of digging. In Ireland they make it a long lever in comparison to that used in England; and thus a man stands upright when digging, with the tails of his great-coat tucked up behind him. The fisher-girls who dig for worms as bait in the sands on our coast also use a long-handled spade; this is to compensate for manual strength.

In moving barrels and very large weights, and principally on board of ships, a *hand-spike* is the lever found best adapted to the purposes required.

Carpenters, masons, and others who have to move bulky masses of matter short distances, adopt the use of a *crowbar*, which is a lever made of iron, having a claw at one end.

A hammer has usually a claw for drawing out nails; now in this the power seems great, for the nail will bear an immense weight attached to it; yet because we move the hand through several inches while the nail moves only a very short way, we can draw it out, and thus the velocity overcomes the resistance.

The *fire-poker* is a lever, having the bar of the grate for a fulcrum.

The simple lever has sometimes two arms; it is then called a double lever. *Scissors* are of this kind, having the rivet as a fulcrum for both. Large scissors called *shears*, used in cutting cloth, pasteboard, tin, copper, and sheets of iron, are double levers.

Nippers, pincers, forceps, snuffers, are all of this description of levers.

The *scale-beam* used in weighing is a simple lever. The arms, *a a*, fig. 15, on each side are made of equal length, and suspended over the centre of gravity. The axis or pivot *b*, which is the point of suspension, is sharpened to a very thin edge, sometimes equal to that of a razor, that the beam may easily turn with as little friction as possible when weights are applied in the scales. Should the arms not be of equal length, then the scales

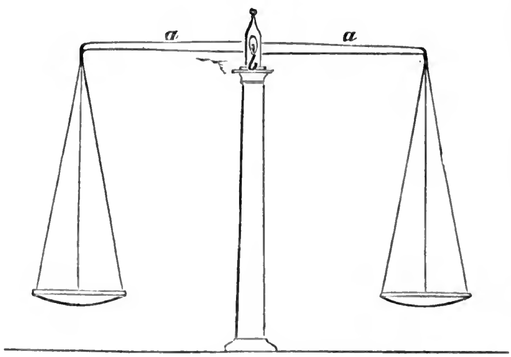


fig. 15.

cannot act justly, although the beam may seem fairly balanced and the weights true; but if one was half an inch longer than another in an arm of eight inches in length, the customer would lose an ounce in every pound. The deceit can be discovered by changing the weight and material to the opposite scales.

In some cases where the beams of scales are not accurate, the articles to be weighed are put in and balanced by shot, sand, or other things; the things of which it is desired to know the weight are then removed, and weights put in their place, thus the true and exact weight is known. By this mode almost any elastic substance may answer the purpose of a weighing-beam. Suppose a piece of steel, or a walking-stick that will bend, were held over a place, and a substance attached to its end; then when so attached, mark exactly the place the stick or steel bent to when the substance was on it; remove the thing to be weighed, and attach weights until the steel or stick bends again to the mark, and then the weight of the material is truly found.

The Chinese and Romans use instead of the weighing-beam an instrument called a *steel-yard*, fig. 16, which is a lever with arms of unequal length. The lever is suspended from a hook *a*, which is the fulcrum or pivot, and from which the steel-yard must truly balance; this is its centre of gravity. Thus one pound weight will weigh any number of pounds in the scale that the yard is long enough to perform. In the diagram, the one-pound weight at *c* is weighing eight pounds in the scale at *b*, for the space over which it is placed on the long arm of the lever is eight times that where the scale hangs from on the short arm. By dividing the spaces in the long arm into halves, quarters, and sixteenths, then half-pounds, quarters, and ounces can be weighed. In applying the rule for calculation previously given to the steel-yard, it will be found as stated: thus the short arm is 1, and the weight or resistance in the scale is 8, then 8 multiplied by 1 is equal to 8; the length of the long lever from the fulcrum is 8, and the weight 1; 8 multiplied by 1 is equal to 8, thus both are in equilibrium.

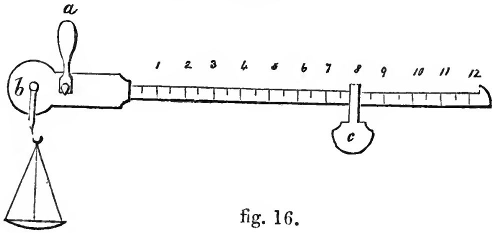


fig. 16.

We may here notice the Danish balance, which is a modification of the steel-yard, fig. 16ᵃ. In this construction the weight *a* is permanently at one end, the article to be weighed suspended from a hook at the other end; while the handle for supporting the balance, and which forms the fulcrum, is placed at a point somewhere between these. As may be noticed, the gradations are not at equal distances as in the steel-yard. This is owing to the fact that the centre of gravity of the beam is constantly changing. Thus suppose the centre of gravity is at *b*, and the fulcrum placed there, the beam will be perfectly balanced; but if a weight, or an article to be weighed, is placed at *c*, the centre of gravity will be

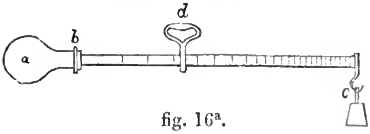


fig. 16ᵃ.

shifted nearer to the weight, say to *d*; the fulcrum then must be moved to the same point. At each change, then, of the weight of the article at *c*, the centre of gravity being moved and also the fulcrum, there is a difference made in the length of the respective levers; moreover, the weight of the portion of the lever from *d* to *b* is transferred from one side to the other. The best way to graduate this balance is to place certain definite weights on the hook *c*, and mark the place where the beam is balanced.

An equally-made spring is sometimes used as a measure of weight, from its compactness; the letter-balances, now so common, are a familiar example.

The annexed diagram, fig. 17, represents a spring balance: a cylindrical case, *b b*, of iron has one end filled up by a tightly-screwed cover, to which the hook or ring *a* is fastened, by which the balance is suspended. The spring coils spirally round the spindle *c c*, which is securely fastened to a circular plate *e e*, which moves in the inside of the case *b b* somewhat like a piston. The lower end of the spindle *c c* has a hook, to which the dish *d* is suspended; or instead of the dish, the article to be weighed may pass over the hook. On the hook being pulled downwards, the balance being suspended by *a*, the spindle also pulls the piston *e e*, and consequently depresses the spring in proportion to the force employed. The spindle is divided into graduated spaces near the extremity of the case at *f*; according as these are seen out of the case, so is the weight of the article indicated.

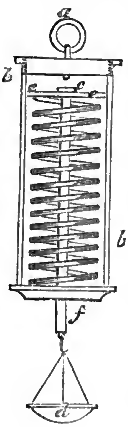


fig. 17.

The elastic force of a spring, not being affected by terrestrial gravitation, is that which is used to ascertain the amount of the earth's attraction in various places.

The spring has a weight attached to it, and is made to swing clear of the bottom of the machine; weights are then added until the weight just grazes the bottom of the stand. The machine is then carefully packed away, and removed to the place where required, and the difference of the weights there necessary is the difference of the gravity. This is a most delicate instrument, and from its truthfulness of action in all latitudes, shows the difference of weight or heaviness in all parts of the earth's surface.

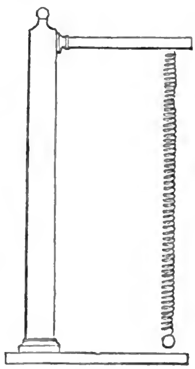


fig. 18.

The second kind of lever is that where the weight and the power are on the same side of the fulcrum: the power is furthest from the fulcrum.


fig. 19.

Thus, if a mason, fig. 19, desires to move forward a large piece of stone, instead of bearing down upon the lever to raise it up a little, he sticks his crowbar into the ground, and pushing upward, moves the stone little by little onward, the ground being the fulcrum.

A wheel-barrow affords another example: in using it, a point in the wheel of the barrow pressing on the ground is the fulcrum; the load is the weight, and the handles held by the man the power; as the person shortens or lengthens his hold on the handles, so does he move the centre of gravity to the wheel or himself.

If two men carry a load slung from a pole resting on their shoulders, and the load be in the middle between them, they have an equal share of the weight; but in proportion as it is more towards one than the other, so is the extra amount of weight to the one nearest to it. The men are the fulcra in this case; they act in that capacity the one to another, while both are the moving power. Should the pole be eight feet long, and the weight 200lbs., each man will bear 100lbs. weight. Suppose that a man and a boy are set to carry this weight, and the man, from the boy's inability to carry his equal share, out of humanity places the weight four times as far from the boy,—that is, about 6 ft. 4 in. distance, and only 1 ft. 8 in. from himself,—then the boy will only have about 50 lbs. weight, while the man will have 150 lbs. to bear.

A hand-barrow is on the same principle; and one man may bear less or more as the load happens to be placed, or as the handles may be held to increase or lengthen the lever.

In yoking horses to a loaded wagon or coach having cross-bars, care is taken that the bar is hooked to the centre of the load. Sometimes a small, weak animal is placed to assist one larger and stronger; in that case the cross-bar is not placed equally, but more past the centre for the bigger animal.

The common operation of opening a door is an illustration of this lever; the hinges are the fulcra or centres of motion, the door the resistance or weight, and the hand the moving power. The finger is painfully nipped when caught near the hinge, from that part being near the fulcrum, acted upon by a lever passing through a larger space. In opening a box the same is noticed (fig. 20). Every one has experienced that on opening a

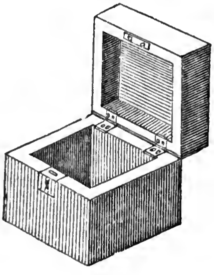


fig. 20.

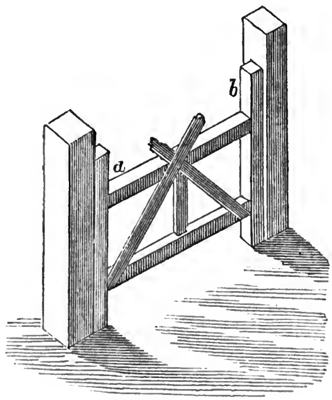


fig. 21.

door or gate when near to the hinge *b*, fig. 21, the force required is considerable, having little space to pass through; whereas near to the latch *a* the task is easy, though the space is increased.

The oar of a boat is also a lever of this kind; the water being the fulcrum, the person who rows the power, and the boat the resistance or weight. This lever is most powerfully employed in the coal-barges on the rivers in the north of England. These vessels retain the old Saxon name of *keels*, which is the term that distinguished the ships containing Horsa and Hengist and their enterprising followers on first coming to this country. They are in the form of half a walnut-shell, huge and unwieldy, and contain upwards of twenty-one tons of coals. The keel is propelled with one immense oar, wielded by three men remarkable for their muscular powers; they pull with all their might, adding the entire weight of their bodies, as they do not sit, but move backward with the motion of the oar: thus this heavy clumsy barge has but the yielding water for a fulcrum, and yet is skilfully managed even among the waves of the ocean.

The *masts of a ship* act as levers, having the cargo or ballast and the vessel as the resistance, the bottom of the vessel as the fulcrum, and the sails holding the wind as the moving power. Thus we see in well-equipped smuggling-vessels and gentlemen's yachts, where the masts seem enormously high for the size of the vessel, that they lean over when in full sail, by pressure on the levers, in a fearful manner.

Nut-crackers, lemon-squeezers, &c. are also illustrations of this kind of lever. The two legs are joined by a hinge, which is the fulcrum; the article placed between is the resistance; and the hand is the power.

The *rudders* of boats, ships, &c. are levers acting on the same principle.

Many are the industrial purposes to which this form of the lever is applied by chemists, grocers, chaff-cutters, coopers, patten-makers, &c. &c. The wooden soles of the shoe called a *clog*, at one time almost universally worn by boys and countrymen, was formed by this cutting lever. In snowy or wet weather, or where persons' avocations compel them to work amid wet or stand on cold stones, this ancient shoe is invaluable in the preservation of health, being warm and dry. In the college at Manchester we have seen this cutting lever, fig. 22, used in cutting bread; and so excellently was the work performed, that all the fragile delicacy of a "Vauxhall slice" was gained with a rapidity and regularity that would have caused envy in the bosom of the lessees of that place, so notorious for its transparent dainties.

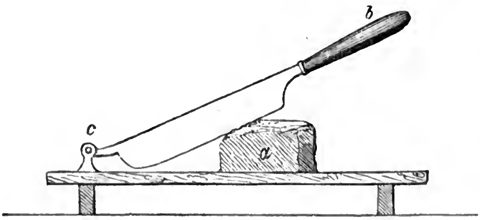


fig. 22.

This lever is a common appliance in the country for bending down haystacks partially cut, and other loose light bodies that might be carried away by the wind; and it is even retained in some places for pressing cheese when in course of manufacture. A pole is stuck into a wall as a fulcrum, the resistance is the object to be pressed or held in its place, and at the other end are hung weights as the power.

The *third* description of lever is that in which the fulcrum is at one end, the weight at the other, and the power placed between them. At one time this was called the *losing lever*, because the power had to be greater than the weight. The advantage of it is now discovered and appreciated, consisting, as it does, in a small power causing the extreme point of a long arm to move over a great space; and is one of those wonderful adaptations of the Divine Being in the construction of the appropriate mechanism of animals and man (fig. 23).

fig. 23.

The domestic implements *fire-tongs* have two long levers with a small motion near the pivot, near which the power is applied: thus they open widely to grasp a large coal or cinder, and have a weak power at the ends, but powerful near the fulcrum.

The mechanical power of the muscles of man, acting on the bones as levers, is one of a surprising nature in the combination of power, velocity, and beauty of construction. The arm, fig. 24, will be a sufficient illustration. The elbow is the fulcrum, the muscles the moving power, and the weight raised the resistance. Thus if the weight raised be 50 lbs., and the elbow passes through a space of 20 inches, the muscles springing from the shoulder will contract 1 inch, and the force be equal to 1000 lbs. The muscles being near the joints or fulcra, give a high degree of velocity to the other end of the lever, generating great momentum. In the human body sometimes the fulcrum is between the power and resistance, as the elbow between the muscles of the shoulder and humerus, and the hand with the weight; in other places the resistance is intermediate, and the fulcrum at the end, as the toes on the floor and the hinge of the lower jaw; and in parts the fulcrum is at the end and the power intermediate, as the weight of the arm has its fulcrum in the shoulder-bone, and the power is in the muscle covering and proceeding from the shoulder.

fig. 24.

The muscles of large emigrating birds must also be most powerful, sustaining the weight of their bodies while they travel unrested for days amid the tempests of the heavens.

Compound Levers are arrangements of simple levers by which less space is required, thus: Suppose, fig. 25, three pieces of iron 12 inches long, having their fulcra placed 3 inches from the ends of each, let us see what 1 stone (14 lbs.) moving power placed at the end of the first will balance at the end of the last: 9 inches to the fulcrum

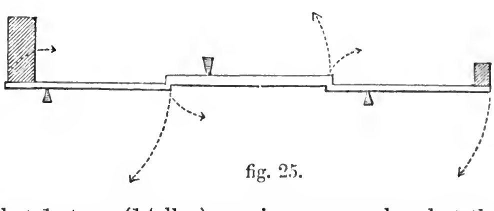


fig. 25.

of the first lever multiplied by 1 stone is equal to 9, then the 3 inches at the other side of the fulcrum divided into 9 gives 3 stone as the balance at its end. 3 stone, then, is the power at the commencement of the second lever, which must be multiplied by its 9 inches, giving as a result 27; this divided by the 3 inches at the other side of its fulcrum makes 9 stone as the power at the beginning of the third lever, which multiplied by its 9 inches results in 81, which divided by the three inches at the end, the total weight of the block at the other end is found to be 27 stone.

It is by this kind of combination that at railway-stations luggage is weighed; and at entrances to towns where tolls are paid according to weight, carts and wagons are drawn on to tables and their heaviness known. By lengthening the arms on one side of the fulcrum and shortening them on the other, the force is greatly increased.

Bent Levers.—The levers we have considered are supposed to act at right angles, and the power may be the less the farther it is from the fulcrum. Bent levers are often used for their aptitude to peculiar circumstances, and act obliquely, consequently with less effect.

A bent-lever balance will show the principle (fig. 26). Now, the end of the long arm where the scale is attached does not act upon the entire length of lever, that is to the weight, but only as far as the fulcrum at the top of the

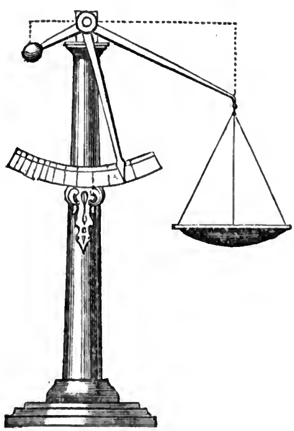


fig. 26.

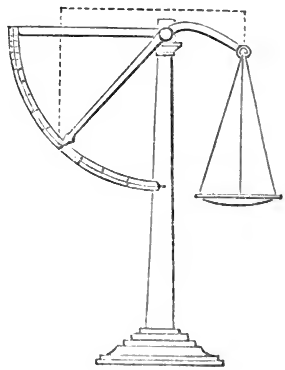


fig. 26ª.

stand, while that portion with the weight upon it acts as if it were not longer than the fulcrum; therefore a weight of two pounds on the short arm will balance a weight of one in the scale. Thus as the long and short arm move out of the imaginary dotted line, so is the influence of weight.

Fig. 26ª is another form of the bent-lever balance. The fulcra of levers, as those in balance-beams, are of a triangular shape, as in fig. 25. The fulcra of levers, however, as used in machinery, are cylindrical, supported in the interior of a cylindrical aperture made in the material in which the lever works. To reduce the friction, brasses are inserted, in which the lever works. The fulcra thus constructed become available not only where an oscillating or vibrating action is given to the lever, but where the motion is circular, the fulcrum in this case becoming the axis of rotation, as in

THE WHEEL AND AXLE.

This simple machine consists of a wheel W fixed upon an axle A. Suppose it took 1 foot of rope to go round the axle and 4 feet to go round the wheel, then the proportion would be as 1 to 4, and a weight of 1 lb. at the wheel would support a weight of 4 lbs. at the axle. If the rope be wound round the axle in a different direction to that on the wheel, and an increase of weight be attached to the rope at W, then it would unwind and the weight descend, while the rope on the axle would wind up and lift the weight fastened to it. Thus one power is made to act against another, as pointed out in the lever.

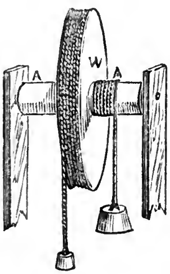


fig. 27.

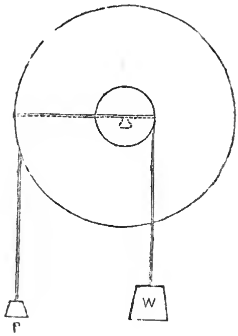


fig. 28.

The wheel and axle are called a perpetual lever. In the diagram (fig. 28) it will be seen how the term may properly be applied. The power P is the weight hanging from the wheel, the fulcrum is the centre of the axle, and the weight to be raised that hanging from the axle. Now, if the distance from the edge of the wheel to the centre of the axle be 8 inches, and from the centre to the edge of the axle be 1 inch, and 1 lb. be the power hanging from the wheel, it will balance 8 lbs. hanging from the axle. A slight addition of power, then, would raise up the 8 lb. weight; but for every inch the weight rises, the power would descend through 8 inches of space. The dotted line shews that a handle inserted would act the same as a wheel. As must be evident, a lever would only raise the weight through a small space, while the wheel and axle will act as long as the length of the rope will allow.

The larger the wheel and the smaller the axle, the more powerful is the machine, but the greater time is taken in raising the weight.

In the *gin* used at collieries of small depth, in threshing-machines, sand and plaster mills, and various other useful occupations of commercial industry, the principle is of infinite service.

In the common method of drawing water from a well, the handle is made to describe a large circle, and thus performs the part of the wheel described, while the axle receives the rope with the weight. When the well is very deep, and the rope overlaps several times on the axle, then the operator finds, as the bucket approaches the top, that more and more power has to be applied: the cause of this is, that the rope winding upon itself increases the circle on the axle, while the handle describes the same motion through space; and as a larger axle requires more power, the weight feels augmenting.

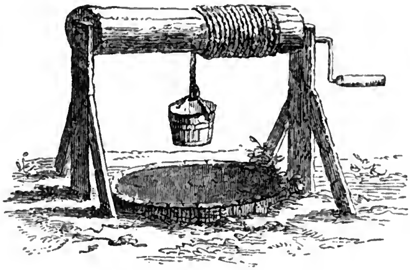


fig. 29.

That punishment accorded to petty offenders, *the treadmill,* is a large wheel having the outer parts arranged so that the condemned turn it round by lifting their feet as if stepping up stairs, which, by the weight of their bodies, pass from under them: the axle of the wheel is connected with apparatus for grinding sand or other things. Cranes at one time were worked on this plan, but the men were inside the wheel instead of outside: the clumsy contrivance has given way to other more compact inventions. Some bird, mice, and squirrel cages are formed in the same manner.

The *windlass* used on board of ships for raising the heavy anchors, and

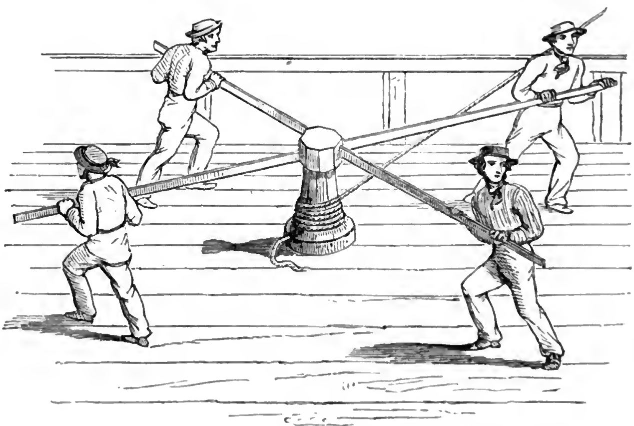


fig. 30.

the *capstan,* are wheels and axles, the latter being upright. The head or drum has holes in it, in which are placed levers, or, as called, capstan-bars, against which the men push. They may be likened to the spokes of a wheel, but made movable; this causes the size of the wheel to be considerably enlarged, describing a large circle. If a capstan-bar be six times as long as from the edge to the centre of the part on which the rope is coiled, and six men are at six bars, they will raise thirty-six times as much weight as one man could do by his unassisted strength. Capstans are used to open and shut dock and canal gates, drawbridges, &c.

The handle applied to a coffee-mill, a draw-well, a crane, or a grindstone, may properly be called a *winch*. In fact, wherever a circle is described by the hand, it is of little consequence whether there be one or more spokes or handles, the principle is the same.

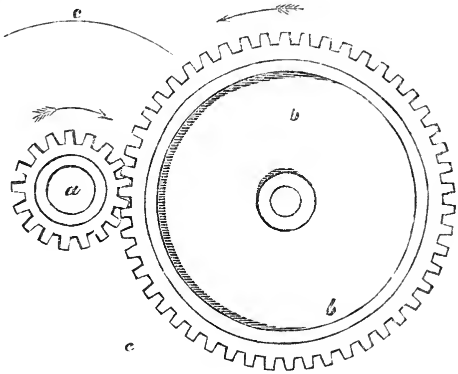


fig. 31.

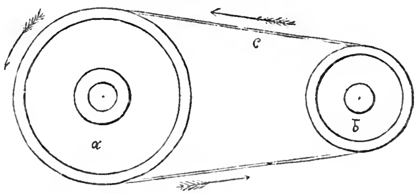


fig. 32.

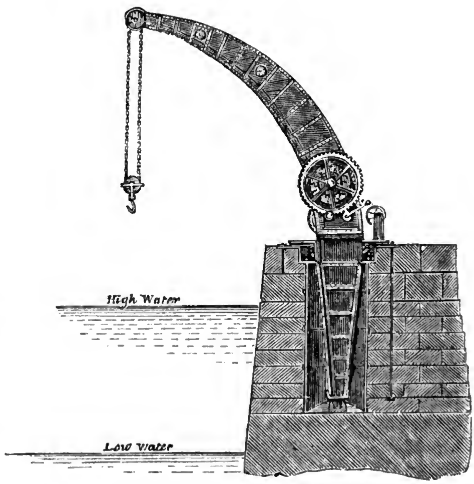


fig. 33.

The Pinion.—If two large wheels be notched or teethed so as to fit into each other, they revolve in the same time, and a weight would be raised by the axle of one as soon as the other. Where different velocities are required, and machines are to be of compact formation, then a combination of wheels is made by introducing what is called a pinion.

In fig. 31 let *b* represent a wheel, and *a* the axle of another. It will be seen that the teeth placed round the edge of the one wheel work in the teeth placed round the axle of the other; thus then, as the wheel with the teeth at its edge is much larger than the axle with the other teeth, it must consequently go round much slower than the axle or pinion-wheel. The teeth on the axle are termed leaves.

The mode of calculating the power gained is to divide the number of teeth in the wheel by the number of leaves in the pinion; thus if the latter has 12 and the former 144, then $144 \div 12 = 12$, the power gained; which may be either velocity or intensity between weights or forces.

In lathes, spinning-wheels, printing-machines, &c., wheels without teeth are made to act upon each other by means of cords, straps, or bands; this adds nothing to the power, but is useful in the regulation of a quick or slow motion. Thus in fig. 32 the wheel *a* drives *b* by the belt *c*.

By increasing the number of wheels working into each other, or by proportioning the wheels to the axles, any degree of power may be acquired. On this principle the cranes (fig. 33) in common use are made, by which a man can raise many tons. The pulley over which the rope or chain is passed at the highest part is to change the direction of the draught; and the weight may be raised to the height required by a person standing on the same level with it. As it swings on a pivot, the packages are moved, when hoisted up, to the parts required, within reach of the crane.

THE PULLEY.

This simple machine is a small grooved wheel, called a *sheave*, made of hard wood, with a rope passing over it, fixed in a scooped-out *block* of wood, moving round a pin passing through its centre. Sometimes they are made of brass, iron, and china-clay.

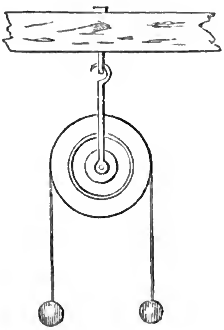


fig. 34.

fig. 35.

A *fixed* pulley, fig. 34, with two equal weights at the ends of the rope passing over it, gives no mechanical advantage, for the weights balance; and when moved, they rise or fall through an equal space in the same time. The service to which it is applied is merely to change the direction of the power, and enables a man to stand on one spot and raise a weight which he might otherwise have to carry up a ladder (fig. 35). Another use is that of enabling several men to join their strength at one time in raising a considerable weight.

The pulley forms one of the most valuable assistants to the toiling and hardy sailor, and by its means fewer men are required to do the necessary work of the ship. It is hung about all parts of the rigging, and is ever a ready helpmate; by its means, amid calms or storms, the weather-exposed mariners can stand on the decks of their vessels and hoist the booms, spars, and sails of the loftiest vessel that the ocean bears on its bosom.

A man, by placing himself in a loop of a rope passed over a fixed pulley, fig. 36, may by his own strength raise himself up or lower himself down as he pleases. This is sometimes practised by workmen when a slight repair has to be done to the front of large mansions: for safety, one end of the rope is fastened round the body; if movable blocks be added, the ascent and descent are very easy. The reason of this being accomplished with a fixed pulley is, because the man throws more than half his weight by his strength on one side of the pulley, which causes that side to descend, while the other part with the loop in which he sits rises.

fig. 36.

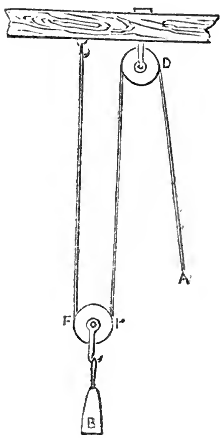


fig. 37.

A *movable* pulley F, fig. 37, is sometimes fixed to the weight B, which has to be lifted, and rises and falls with it; the rope passes under it, having the pulley hanging upon it. It is plain that the weight must be equally borne by both sides of the rope, the one end fixed in the hook, and the other held by a man at A: as to its passing over the fixed pulley at D, that is only of use as a convenience in giving direction to the rope. Then between the hook and the man there must be action and reaction, which being equal and contrary (see Treatise on *Natural Philosophy* in this Series), the weight becomes divided. If the weight were 8 stone, the man has only to bear 4; still he must draw up 2 feet of rope, that is, 1 on each side of the pulley, to raise the weight 1 foot: hence it is very evident that in doing so he lifts 4 stone 2 feet; that is, though the weight has passed through only 1 foot, yet he has pulled the rope 2 feet. But then the weight he pulled at during the time was only 4 stone; without the pulley he would have had 8 stone to raise 1 foot; thus the weight was one-half, but the space he pulled through double to the movement of the weight.

To increase the advantages of the pulley, several are combined together. In fig. 38 there are two fixed pulleys and two movable ones; thus the rope, it will be observed, passes four times over them, and the resistance capable of being overcome is as 4 to 1: that is, if a power of 100 lbs. was applied, it would be equal to a weight of 400 lbs. to be raised. Each fold of the rope bears a fourth of the weight, the last being the power applied; that over the top fixed pulley is of no more use than to aid the person pulling the rope in giving it a proper direction.

Thus, then, an increase of pulleys decreases the weight, and allows a smaller power to overcome a larger; still it is always at a loss of time and space.

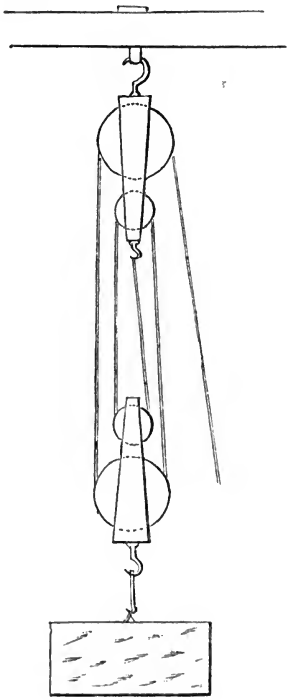


fig. 38.

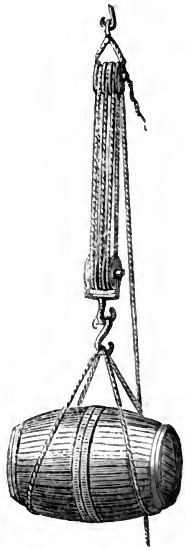


fig. 39.

The ropes used about a pulley are called tackle, and the pulleys blocks; therefore, when a sailor or workman collects together all necessary for the application of this machine, he speaks of the *block and tackle.*

The placing a number of pulleys together in many cases would occupy too much space, besides other inconveniences. To avoid this, and at the same time reap advantage, it is common to have several pulleys in one block on the same pin, fig. 39; thus there are sometimes two, three, four, or more sheaves placed side by side, having a strong pin as an axis driven through the whole: by this means the power can move the resistance two, three, or fourfold, as in the rules already given. In a three-sheaved movable block 100 pounds would balance 600 pounds, and so forth.

Sometimes a wheel and axle is employed to wind up the rope attached to a block and tackle; this combines the power of the lever with that of the pulley.

THE INCLINED PLANE.

This is another of the primary mechanical powers, and is of use to man in many of his daily occupations of raising or lowering weights short distances, as it gives to a small power facility in overcoming a larger.

If a cask be on a flat surface or plane, it will be at rest on any part of it where it may be laid; but had a man to lift it on to a cart, fig. 40, he would have to apply a power equal to its weight to prevent its falling upon the ground. Were he, however, to place a plank up to the bottom of the cart, he then makes an inclined plane, and he would only have a

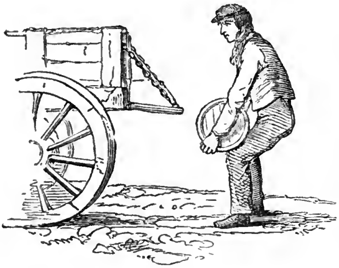


fig. 40.

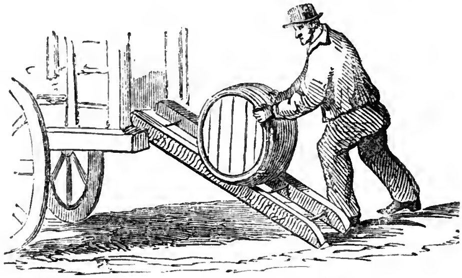


fig. 41.

part of the weight of the cask then to support, fig. 41. Or had the man to load the cart with casks, he might have to lift them from the ground perhaps four feet; but by placing a plank eight feet long, and forming an inclined plane, he can roll them up with one-half the power he would have to exert when lifting them, yet he would be double the time, as the space would be twice that of the height. An inclined plane, then, is seen to be a slope, and according to its height will the time be of a body in rolling down it; thus, if it be 16 feet high at one end, and its length 32 feet, a cannon-ball or cylinder will, by the force of gravity, fall through the 16 feet in 1 second, but to roll down the incline it would take 2 seconds; if it were 64 feet high, and the inclined plane 3 times 64, or 192 feet long, then a ball would fall through the space or height in two seconds, but would take 3 times 2, or 6 seconds, to roll down the incline.

Thus this mechanical power is in proportion as the length of the plane exceeds its height; and if a cask weighing 3 cwt. had to be rolled into a cart or part of a warehouse 4 feet high, and a plank 12 feet long was used, then a power of 1 cwt. would balance it, because the inclined plane is three times the perpendicular height. A slight power over the hundredweight would move the cask onward.

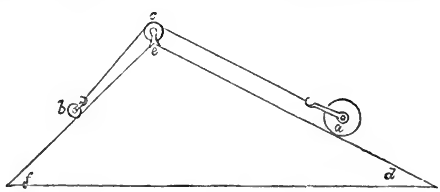


fig. 42.

If an inclined plane, *de*, fig. 42, be 4 feet long, and have on it a weight *a* of 12 pounds, to which a cord is fastened, passing over a pulley *c* to an inclined plane *ef*, 2 feet long, both having the same height, then a weight, *b*, of 6 lbs. on the short incline will balance the other, *a*, of 12 lbs.

If a loaded cart, omnibus, or coach, on a plane at the bottom of a hill, had a plummet-line hung from the top, it would fall straight to the ground; but as the vehicle moved up the hill, the steeper it became the more the plummet would fall towards the back of the conveyance, and the heavier the load would become to the horse, increasing the difficulty to the animal in dragging it up the hill.

If the rise be 1 foot in 20 on a road, the horse has to lift the 1-20th of the load, as well as to overcome the friction and gravity; because in 20 feet the load has to be raised up a height of 1 foot, and the weight to be overcome at any part of the 20 feet is the 20th of what it would be if raised that height at once, being gradually lifted, as it were, the 20th part at a time over the 20 feet. The greater or less the slope, the greater or less power is required to overcome the resistance. It is this reason that causes drivers, on ascending Holborn and other steep hills, to wind from side to side, by which the incline is made less.

On railways a locomotive engine can draw a train and 700 persons 22 miles an hour up an incline of 3 inches in every 8 feet; but were the incline 1 foot in 12 feet of length, then the engine could not move forward.

In the coal districts the inclined plane is of common occurrence on the railways. It is a curious sight to see twenty loaded wagons set off from the top of a hill, rushing down towards a river, without any thing but a rope attached to the last one; this rope is attached to a small wheel or drum, and while the loaded wagons descend by their weight and velocity, empty ones, on a parallel line, are drawn upwards. As this is frequently a considerable distance, and as there are often curves in the road, the wagons seem moving uncontrolled downhill, and running unpropelled uphill. But it is usual to make the railroads, or tram-ways as they are called, belonging to collieries on an incline; for by so doing, one horse can with ease move an immense weight of coal away from the mine to the place of sale.

In building houses an inclined plane is often used for the easy transit of wheelbarrows; and it is believed that the ancients, in erecting their immense works of art, used inclines formed of mounds of earth.

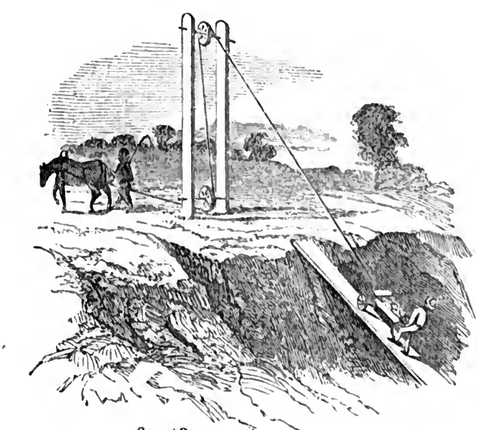


fig. 43.

A curious illustration of the inclined plane and pulley was shown at the excavations of the Southampton and Sunderland Docks. A steep incline of planks, fig. 43, was laid down to the deep hole below, and a man hooking a rope on to a full barrow, which rope, passing over and under fixed pulleys, was attached to a horse, the animal received a stroke of a whip, walked sharply on, and the barrow, with the man taking long quick steps, leaning far out of balance, were as quickly at the top as if the horse had walked up the incline.

The inclined plane is beautifully illustrated in that exciting and pleasing sight, the launch of a ship. Whether the destiny of the splendid triumph of man's handicraft be war or commerce, still it strikes with awe, wonder, and gratification, to see it move majestically down the sloped ways, breast all opposition, and then settle buoyantly and calmly on the surface of the waters.

To the drayman, in unloading ponderous hogsheads, the inclined plane is of great use; and again, when he drags the empty butts from the cellar, he places down a plank or two, puts a hook into the bung-hole at the end, fixes a rope to one of his horses, which he drives on, and up pops the barrel.

The stairs of a dwelling-house are an inclined plane in principle, having steps to allow of a footing. This forcibly struck us once on seeing a highlandman who had never been in any other habitation than a cabin. He mounted the stairs well enough; but when about to return, after looking at them for a moment, he sat down, and descended as we would a steep declivity having foot-holds cut in it.

When roads are made to the tops of high hills, they are either wound round and round, or made so broad as to allow of tacking from side to side.

Chisels, adzes, and other tools which are sloped only on one side, are in principle inclined planes.

The *Columbian printing-press*, which is one of great simplicity of construction and power, acts entirely on the inclined plane and lever.

THE WEDGE.

The wedge, fig. 44, is in the form of two inclined planes, *abc* and *dbc*, joined at their bases. It is used to rend wood, rocks, &c., also to raise heavy weights short distances, and compress substances closer together. More power is gained by striking the head of the wedge with a hammer, either small or large, than by pressure, as the momentum of the blow seems to shake the particles of matter and cause them to separate. A thin wedge requires less power to move it forward than a thick one, less resistance being offered, as in the case of an inclined plane. The power of the wedge cannot be correctly estimated, as the force, number of blows, and incline have all to be taken into account. In splitting wood, fig. 45, the sides of the opening act as levers, and thus rend the parts in advance of the point of the wedge.

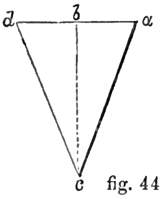


fig. 44.


fig. 45.

The wedge is useful in dockyards, where large vessels are raised by its agency.

The heads of hammers are fastened on by wedges driven in at the part of the handles near the heads.

Nails, knives, awls, needles, swords, razors, hatchets, chisels, and other similar instruments are, in their operations, on the principle of wedges. A saw is a series of wedges, which act by drawing them along and pressing them on the object to be cut. When the edge of a razor is examined by a microscope, it is seen to be a saw in formation, which by being drawn along the beard, enters the hair and thus cuts it off. A scythe acts in the same manner on grass. The saw-nature of fine edges may be illustrated by pressing the thumb against a sharp penknife; the skin is not cut, but the slightest movement of the edge across the skin immediately cuts it.

THE SCREW.

The screw is placed under the head of simple machines, but cannot be used without the application of a lever or some other contrivance, when it becomes a compound engine of great power, either in pressing bodies closer together or in raising great weights.

A screw is in principle a projecting inclined plane, *b b* fig. 46, winding round a cylinder, *a a;* for were it unwreathed, it would form an inclined plane, the length of which would be to its height as the circle of the

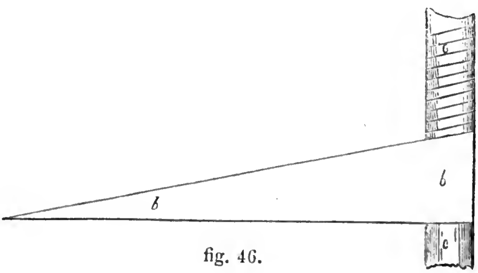


fig. 46.

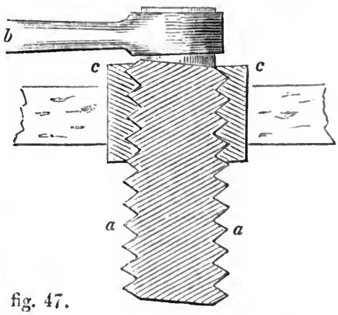


fig. 47.

cylinder is to the distance of one incline or thread, as they are called, from the other. This spiral thread or screw, *a a* fig. 47, works in another which is cut in the inner surface of a hollow cylinder, *c c*, called a nut or box, and sometimes a female screw. This portion is generally fixed. The one is formed exactly to fit the other. A lever, *b*, is placed in the head or other part of the screw, and every turn carries it forward upon the nut or box, or draws it up it to the extent of two turns of the thread. If the circle of the screw be 3 inches, and the distance of the threads half an inch, then the power gained will be as 6 to 1, as seen in the inclined plane; the height raised will be half an inch, but the whole circle of the cylinder, 3 inches or 6 half-inches, has been passed over by the power, while the weight has only moved half an inch. Thus it is as 1 to 6 of power gained. But as the distance of the threads of the screw is lessened, so is the power increased. Suppose the distance of the threads to be a quarter of an inch apart, and this to be turned by a lever 36 inches long, then the circle described by the lever will be about 216 inches, which multiplied by the quarter-inch of the screw gives 864 for the power gained, being 864 times as great as the distance between the spirals; therefore a power of 1 lb. at the lever would balance 864 lbs. acting against the screw, and the velocity of the power will be to the velocity of the weight as 864 to 1. Saying a man's pull or pressure to be equal to 120 lbs., and four men employed at the lever, then the pressure would be 864 multiplied by 120 four times over, equal to 414,720 lbs.

Formerly in the paper-mills, where it was requisite to have an enormous pressure, the lever was frequently 16 or 20 feet long, worked by eight or ten men assisted with a winch and pulleys.

A corkscrew is a screw without a central spindle or cylinder.

The screw is applied in pressing books, letters, fig. 48, &c.; packing light substances, as cotton, flax, and blankets, by which they are made to occupy a comparatively small space; also in wine-making to squeeze the grape, in cheese-making, and by the smith, carpenter, turner, and other artisans.

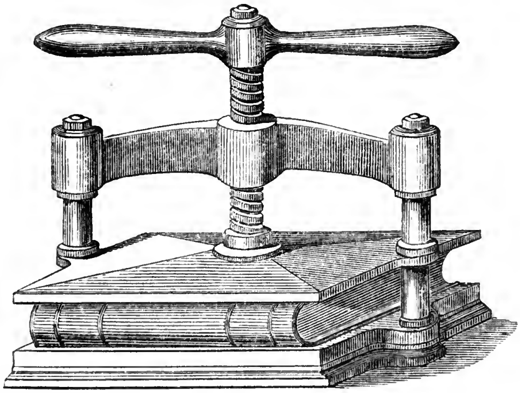


fig. 48.

It has also been the power by which the hand printing-press has been made, by which the curtain of ignorance has been lifted, and the light of knowledge diffused over the whole world. To effect this operation with rapidity, the thread of the screw is made very wide and others placed between, so that there are three screws, the great incline of the plane giving velocity, and the number of screws power. Thus in a moment, by a pull at the press-bar or lever, a pressure of a ton is given on the paper and type.

The screw is the means by which coin is formed and rendered legal by the impression upon it, letters copied, and dies imprinted on letter-paper and envelopes. The beautiful embossed boards, displaying great artistic taste in design and execution, so much used in the elegant ornaments conceived by ladies in the adornment of the drawing-room, are impressed by a large and much-inclined screw, similar to that of the printing-press, having a huge horizontal wheel as a lever power, swiftly turned by the strength of several men.

The screw also regulates many of the instruments of the mathematician, astronomer, operative-chemist, and engineer, and is an invaluable assistant to the maker of delicate instruments, as by certain turns he can adjust his tools so as to mark a hundred thousand lines in an inch, the exactitude of which is all-important in the pursuit of scientific truths.

When the screw is applied to a toothed wheel, instead of a pinion, it is called a *perpetual* or *endless* screw, as it constantly moves in one direction, and keeps the wheel moving round.

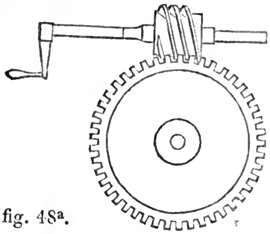


fig. 48ª.

If the winch, fig. 48ª, be 20 inches long and the screw 2 inches in diameter, here is evidently a power of 20 gained; then if the wheel have 30 teeth and the screw at each revolution throws off one tooth, this is a power of 30 gained, which multiplied by 20, the other power, gives a power of 600. Again, say that the cylinder is only half the diameter of the wheel, that is an additional power of 2 to 1, by which multiply the former power, and the result is 1200 as the power gained by this machine.

We have in conclusion to notice the "differential screw." From our previous remarks it will have been noticed that there are two ways of increasing the power obtained by the use of a screw, either by lengthening the lever or increasing the number of threads in a given space, that is by making the threads very fine. There are obviously limits to these: in the first place, by increasing the length of the lever the machine in which the screw is used would become very unwieldy; in the second place, the threads become weaker as they are finer. The differential screw invented by Mr. Hunter obviates these inconveniences; its principle is simply the employment of two screws, the threads of which are different in pitch. The principle is analogous to that of the Chinese windlass, the barrel of which has two diameters, one giving off as the other takes on rope; for the pressing surface is urged forward by the screw having the thread of greater pitch, whilst that with the smaller pitch draws it back to an extent corresponding to such pitch. Thus during each revolution of the screw, instead of advancing the action through a space equal to the pitch of either of the threads, it is really moved a distance equal only to the difference between

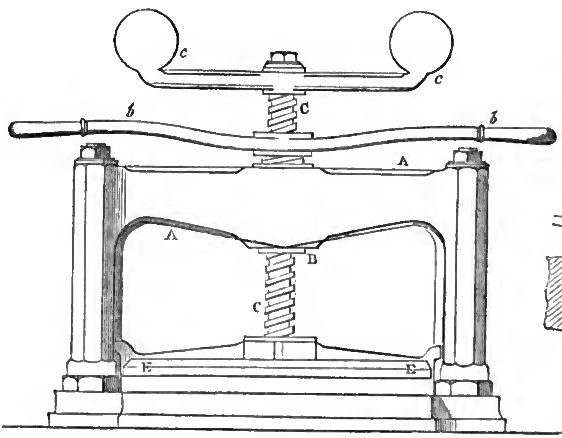


fig. 49ª.

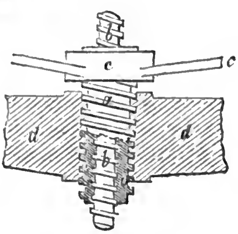


fig. 49ᵇ.

the two pitches, and the mechanical power is therefore equal to that obtained from a single screw having a pitch equal to this difference. In this way power is obtainable to any extent within the practical limits of the difference between the pitches. This screw has recently been applied to a copying-press, of which we give an elevation in fig 49ᵃ, and a section in fig. 49ᵇ. The detail in fig. 49ᵇ will explain the operation of the differential screw movement. In the cross-bar AA (fig. 49ᵃ), a screw-nut is fitted; this is worked by the double-handled lever *b b*; the upper lever *c c* works a screw C, which passes through the nut. The plate E E bears upon the object to be pressed by turning the lever *c c* ; when the article is thus adjusted, the lever-handle *b b* is brought into play; the turning of this gives a differential movement to the screw C C, which is prevented from revolving by its friction on the top of the plate E E, against which it bears. In fig 49ᶜ we show the application of this principle to the book-binder's press, for which it is peculiarly applicable.

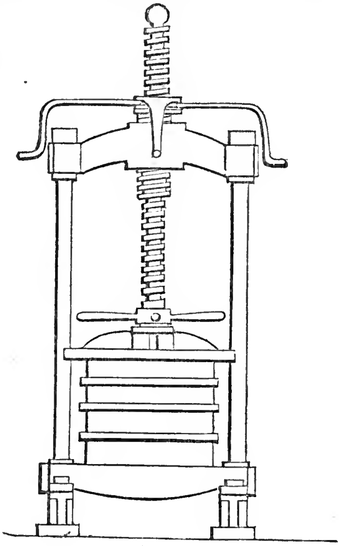


fig. 49ᶜ.

CHAPTER III.

REMARKS ON MECHANICAL POWERS.

Before describing and illustrating the application of the simple mechanical powers, the principles of which we have now discussed, to the varied forms of machinery, whether these be directed by the power of man himself, or by those willing natural agents which his intellect has appropriated or controlled to work his bidding, we shall give a few remarks explanatory of certain principles which it is essential for the reader to understand before endeavouring to become acquainted with the nature and construction of machines in which these principles are exemplified.

From the preceding pages it will be seen that the principles of the mechanical powers are resolved into two,—the lever, embracing the wheel and axle and pulley; and the inclined plane, to which belong the wedge and screw,—although the manner in which they operate differ greatly from each other.

It will also have been evident that what is gained in power is lost in time. If a man by a fixed pulley raises a certain weight to a particular height in three minutes, he may with three movable pulleys raise six times the weight with the same ease, but then he would be eighteen minutes in doing so; thus the work would be effected in the same time, whether the additional mechanical powers are used or not. But should the weight be in one piece, as a beam of wood, then one man by the additional pulleys effects what would otherwise require several men to accomplish. A carpenter with a lever may be fifteen minutes in moving a piece of timber a certain distance, whereas fifteen men would do the same work in one minute. It then appears that no labour is saved, but that mechanical powers allow a small power to labour a long time, and produce an effect equal to a concentration of power requisite to accomplish the desired effect.

No machine will enable a person to raise two pounds with the same velocity as the power that raises one pound, although a machine may allow the two pounds to be raised with half that velocity, or a hundred pounds with a hundredth part; still no greater quantity of motion is produced when the hundred pounds is moved than when the one pound is moved, as the heavier body moves slower in proportion.

In truth, labour is lost by machines, from the increase of friction adding to the amount of bodily exertion which has to be used, more than would be required if machines were done without. The value of machines consists in having the power of the concentrated labour of many men at command when perhaps it might be inconvenient to procure workmen or pay for their short engagement. Therefore one man labours the time of several men, and does a piece of work in twenty minutes which twenty men would do in one minute.

Machines give a convenient direction to the moving power, and allow of the application of its action at a distance from the resistance. By them also the intensity of the moving power can be so equalised as to produce effects which otherwise could not be obtained.

By the control man gains from changing the direction of motion or force, he is able, by solid connecting parts, to arrange the wonderful, beautiful, and complex machines which vie in the formation of fabrics with the delicate nicety of the human hands. Man arrests the winds and stops the waters, that he may turn them to his own advantage. By steam he moves ponderous and intricate machinery which weaves his garments, drains his land, defies wind and tides, threshes his corn, cuts iron as if it were paper, saws huge trees into veneers, bores his cannon, teams out miles in length of paper, and prints thousands per hour of the records of the world's progress, and then despatches it over the land with a velocity only excelled by that of the swiftest wind.

FRICTION.

So far we have given the comparative velocities of the power and resistance as they exist in *theory;* but in all mechanical powers when put in operation, a deduction has to be made from the advantage gained for friction, which is a resistance to the free motion of a body.

Friction arises either from a cohesion of the substances touching each other, or from the roughness of the surfaces, although such parts appear to be smooth. When polished surfaces have been submitted to the powers of a microscope, they have been seen to have inequalities; and the little imperceptible hills fit into the hollows of the opposite surface, out of which it requires some force to lift or slide them, perhaps to break them off.

Friction is increased by the weight of one body pressing on another, and also in proportion to the velocity with which a moving body has motion.

The manner of measuring friction is by placing the substance, iron, wood, stone, &c., on an inclined plane; the utmost the incline can be raised without the body sliding is called the angle of repose, then according to this angle is the resistance of friction.

An experiment was tried of moving a flat piece of cast-iron, having a surface of 44 square inches, and weighing 24 lbs., on another piece, when it was found that a force of 51 ounces was requisite to slide it; the weight being doubled, 48 lbs., the force then required was 104 ounces,—proving that friction is nearly proportionate to pressure.

From the angle of repose it is known when a screw will hold in a press without starting back when screwed down tightly; also from the shape of mountains whether they be formed of stone, sand, gravel, earth, &c.

It is the friction of the ground and the shoe that gives man a firm footing; when we step on a hole for admitting coals, covered by an iron plate, and the iron is smooth (thus giving little friction), we often receive severe falls. Glass and ice having little friction, cause a person when walking upon them to move with extreme caution.

Rivers flow smoothly and gently from the friction presented by their banks and channels.

It is stated by Mr. Babbage, that a rough block of stone weighing 1080 lbs. required a force of 758 lbs. to move it along the surface of its own bed; placed on a wooden sledge on a wooden floor, a force of 606 lbs. to drag it along; when the floor and bottom of the sledge were rubbed with tallow, 182 lbs. force moved it; and when on wooden rollers three inches in diameter, a force of 28 lbs. was sufficient.

Friction is reduced by polishing the surfaces; by applying oil, grease, and black-lead to fill up the little holes; and by making two different substances to be in contact, as the brass boxes in wheels, clocks, and engines, and the diamond in watches.

The smaller the diameter of the axle of a wheel, the less the friction.

According to the velocity, weight, and diameter of the axle is the friction of the wheel and axle.

Pulleys have very great friction, as have also wedges and screws: the latter have the most when the threads are sharp; but the endless screw has the greatest friction of any.

In going down a steep hill the drivers of heavy vehicles pass a chain through a part of the wheel, which is to create friction between the wheel and the surface it is passing over.

If by calculation a combination of pulleys gives a power of 120 to 1, in order to overcome the friction and give motion, the power must not be considered more than 80 to 1.

In the finest surfaces that can be made it is found that an eighth of the moving power is lost from friction.

To lessen the friction of wheels, there are sometimes used at the axle a number of small wheels, or friction-rollers as they are called, that the axle of the carriage may rest upon them, and cause them to turn round their own centres when the wheel is in motion (fig. 50).

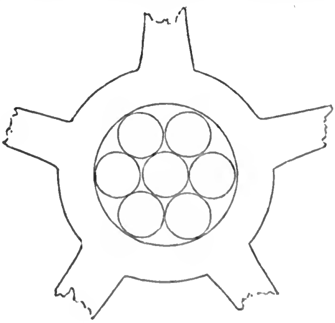


fig. 50.

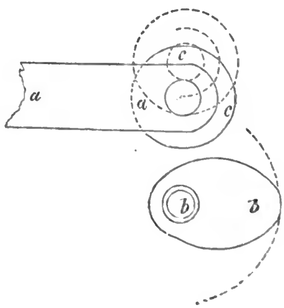


fig. 51.

Rollers or small wheels to reduce the friction are frequently used in mechanical contrivances. Thus suppose a cam *b b*, fig. 51, by its revolution moves the lever *a a* up and down, a wheel *c c* is fixed at the end of the lever against which the cam works. The end view of this is given in fig 51[a]. Small friction-rollers are placed at the lower parts of the legs of tables, &c.; these are generally called "castors," and serve, by reducing the friction, to enable a heavy piece of furniture to be moved along a rough

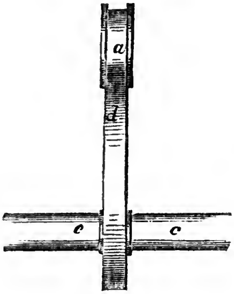


fig. 51ᵃ.

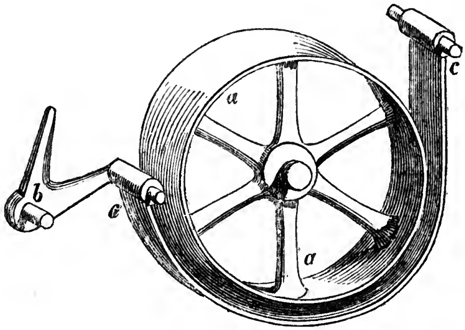


fig. 51ᵇ.

carpet with considerable ease. In the power-loom, the pulley, *a a*, fig. 51ᵇ, is stopped when required by the friction-belt, *c c c*, being tightened on the periphery of the drum by the lever *b*.

Friction-rollers are generally used at heavy gates, whether they slide sideways or open in the ordinary manner; in the doors of presses for papers, books, and other articles, when not opening on hinges; at the tops of windmills, which turn at every change of the wind; in observatories, where the motions of the heavenly bodies are followed; and in swing-bridges, dock-gates, &c.

The resistance of *air* and *water* may be said to be a friction which moving bodies have to overcome; but this, as in other cases, is reducible to a certain rule, for *the resistance is proportional to the square of the velocity*. Thus, if a steam-vessel went at the rate of 12 miles an hour, and another sailed at the rate of 6 miles, the resistance to the one going 12 miles would be 4 times that of the one proceeding 6 miles; for the square of 12 is 144, and the square of 6 is 36, then 144 divided by 36 gives 4; thus the resistance to the one is 4 times greater than to the other. Consequently when velocity is increased, the moving power must be increased, not only to gain speed, but to overcome the increased resistance.

Naval architects have long studied and experimentalised so as to give such form to their vessels that resistance might be decreased; but many think that no shape will ever supersede that given by nature to the fowls whose living is derived from the waters, as displayed in the conformation of their breasts, or in the almost universal form of the head of fish, that have swiftly to move in their natural atmosphere of water: a sharpened nose on these animals may be likened to the cut-water of a ship.

The atmospheric resistance to a railway-engine moving at 32 miles an hour is calculated at 353 pounds.

A cannon-ball meets with great resistance in passing through the air, but its great velocity causes it to vary considerably from the rule given above; while it is also supposed that when moving upwards of 1000 feet per second, a vacuum is created in its path which is productive of further hindrance to its progress.

Thus, then, by friction the foot holds the ground, poises the body, and allows its leverage to have a fulcrum, whereby we step forward with easy and safe locomotion. It is by friction that we can grasp any thing; the hand of man is full of ridges, its softness yields to slight pressure, and thus its powers of opposition are increased. The savage warrior and more modern prize combatants greased their bodies, that friction might be less available to their opponents, and the chances of victory augmented to themselves. The want of it on the skin of an eel has been experienced by most persons, and the reduction of it by shaving and soaping the tail of a pig has afforded amusement to thousands. It is the friction of flax that gives its great utility when spun, and of the rope that enables the sailor to grasp it in his arduous duties, and that binds it on the windlass with the weight of the anchor in opposition; by it, too, stone holds to stone in forming the arch that spans our noblest rivers, and affords us solid and capacious habitations, while almost all the means of comfort or utility in our houses are held in their places by this power; it is the binding chain that must be torn asunder before motion can be given. The nail and screw have their usefulness from their power of friction. It is that which again restores rest to a moving body, when fresh force of motion is not added, as exemplified in the hoop and top of the boy, and the ball whirled upon ice. The brake by which the engine-man arrests the velocity of his trains is a powerful application of this property of matter. Friction is one of the necessary conditions of earthly mechanism; it ceases in application to the heavenly bodies, and allows of that intermediate state between perpetual motion and eternal rest.

WHEELED CARRIAGES.

The substitution of wheeled conveyances for that primitive mode of locomotion, sledges, derives its value from the great reduction of friction.

A sledge touches every part of the surface it passes over, while a wheel measuring 16 feet in circumference, in once turning round, goes the length of its measurement, and is not dragged, but only changes the surface touching the ground, and the friction is at the axle and nave: thus, then, if the axle measures 6 inches in circumference, it turns in a smooth greased box 6 inches, while the carriage is moved 16 feet, making a reduction in the friction of 1 to 32.

A sledge is the best means of travelling on snow, because a broader basis is required than a wheel, which would sink into the soft substance: for this reason the Laplander fastens large pieces of flat wood to his feet. On ice there is too little friction to hold the small portion of a wheel that touches the surface; hence the sledge is found to be most fitting for such travelling. Our earliest projectors of railways, reasoning from the non-resistance of friction on ice, thought the smooth wheels of their carriages would not turn round on the smooth rails of their iron roads, and therefore placed cogs on the wheels and racks on the rails, that they might turn; this was soon discovered by practice to be an error in theory.

A wheel meets with obstruction at the point touching the ground, and is retarded thereby; while the momentum and moving power propel the free upper part forward, and thus a circular motion of the wheel results. Large wheels act as powerful levers; they do not sink so deep in the ground, and more readily overcome the inequalities of the road: this is the reason why those carriages for the conveyance of baulks of heavy timber are of such large dimensions.

The fore-wheels of wagons and carriages are made lower than the hind-wheels, as by their being so, less room is required in turning, and on ascending a hill they are less liable to rise in front and turn over; nevertheless, if they were not so, the carriage would go easier.

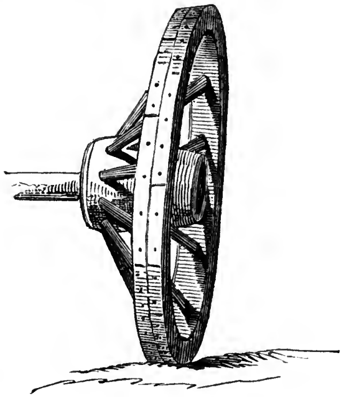


fig. 52.

From the inequalities of a road, a dish-formed wheel, fig. 52, is found to be preferable to that where the spokes are inserted straight, as when one wheel is in a rut and the other higher, the spokes are perpendicular to the rut, and therefore can better support the weight of the load which is then thrown upon them, while the other wheel being relieved of much weight does not require such strength. The wheels of railway-carriages always being on a level, are never made in the dish form, but have their spokes straight.

THE PRINCIPAL MOVING POWERS.

These are the strength of man and animals, wind, water, steam, weights, springs, and magnetism.

Man.—The ordinary strength of a man is estimated at the one-fifth of that of a horse; that is, the strength of five men is equal to that of one good horse, and can accomplish as much work.

Man can exert the greatest strength in pulling upwards from about the height of his knees, and the least when he pushes from him horizontally about his own height.

In dragging a barge along a river, having a rope over his shoulder, a man does not perform more than the twenty-seventh of the strength of a horse.

In turning a winch a man's power varies at different points of pulling up and pushing from him; but if he is able to work a day drawing up a weight of thirty pounds, by fixing a winch in an opposite direction and placing another man at it, the two will with equal ease raise seventy pounds, because at the weakest point of one man the other is strongest, and by this equalisation the advantage of ten pounds is gained.

In carrying weights upon the shoulders the strength of man exceeds that of a horse; as a dock-labourer will carry 200 lbs. at the rate of three miles an hour, and a coalheaver a sack containing 250 lbs. from his wagon to the coal-cellar. With a weight of 300 lbs. on elastic poles slung from the shoulders, as the old chairmen, two men will walk at the rate of four miles an hour.

A *horse* can draw 200 lbs. over a pulley, eight hours a day, $2\frac{1}{2}$ miles an hour. If the weight be 240 lbs. he can only work six hours a day, and slower. In turning a mill a horse exerts its strength to the best advantage in a circle of forty feet; if reduced one-half, he has two-fifths less power.

A horse has the least power in ascending a hill; three men will accomplish much more than a horse in such a case.

The greatest power of a horse is in drawing in a straight line, a position in which man loses strength, one horse being equal to twenty-seven men.

WIND.—Air in motion is wind, and breathes with a soft zephyr force of little more than $1\frac{1}{2}$ feet per second, but in the hurricane rages with destruction in its course at about 147 feet in the same period of time. Roughly, we may say, that a wind moving at about $12\frac{1}{2}$ feet per second will strike a surface of a square foot with a force equal to two ounces. Man spreads out a large surface, arrests it in its progress, and thus conveys, by this invisible power, his restless spirit and commercial genius to every cranny on the "lips of the sea." By it also he produces a rotary motion in his mills, and grinds his corn for food, his flint for earthenware, or drains his quarries and mines of water.

WATER.—The running stream or river, the natural waterfall or roaring cataract, man seizes and makes subservient to his uses; they afford a uniformity of motion beyond that of the wind, and consequently are in proportion more valuable as a moving power. Water falling from a height of two feet, with a velocity of eleven feet per second, will turn a wheel so as to give motion to a 4 ft. 6 in. diameter mill-stone at a rate of 120 revolutions in a minute, the wheel moving with a third part of the velocity of the water.

STEAM.—This is one of the most powerful of the moving agents, as it is capable of the greatest intensity. A cubic inch of water forming into a cubic foot, or 1728 inches of steam, possesses an elastic force of 15 lbs. on the square inch at a temperature of 212°; at 250°, 30 lbs.; at 270°, 45 lbs., and at 290°, 66 lbs. A cubic inch of water converted into steam gives a mechanical force capable of raising one ton one foot high. A cubic foot of water made into steam per hour is equal to the power of one horse, that is, 33,000 lbs. raised one foot per minute. With such power, controlled by man's inventive genius, the many wonders that daily present themselves are achieved.

WEIGHTS.—Weight, or gravity, is another power which is uniform in action. Weights are applied as the motive power of clocks and other machines. Requiring to be wound up, they are only taken into use where the motion is slow.

SPRINGS. A spring requires time to bend it, as a bow, when a force is concentrated that can in a moment be released to give a rapid blow. Like weights, springs have to be wound up after being expended, and thus are adapted to slow action. A spring is not uniform in its action, having the greatest power when most bent; this peculiarity, where regularity is wanted, as in a watch, requires contrivances to rectify it; this is effected by what is called a fusee. The part on which the chain is wound by means of a key or winch gradually lessens from the bottom to the top; by a spiral line when the watch is first wound up the fusee is covered to the top by the chain, and the newly-wound-up spring in the other barrel being strongest at that time, unwinds it from a short lever, which the top of the fusee represents; gradually, as the spring loses its power, the lever becomes longer, and thus an equal motion is preserved.

MAGNETISM.—If a bar of soft iron, in the form of a horse-shoe, or rather that of a common door staple, be wrapped round with copper wire, and a current of electricity passed through the wire, the iron becomes a most powerful magnet, called an electro-magnet, and may be constructed so as to bear the weight of many tons. With this power, by making some magnets movable and others fixed, an attraction and repulsion has been created with such intensity, as to act as a great moving power, giving motion to large engines. It is plain that the force may be almost illimitable, but the expense seems to prevent the general adoption of this giant moving power.

Power is accumulative; that is, it may be collected in some machine, and then expended either gradually or by one effort, but to no greater an extent than has been accumulated. A man may find he has not power to push a stake into the ground; he therefore takes a mallet or hammer, and swinging it round, collects so much power and momentum with which he hits the stake, and so causes it to enter the ground. The hammer may have passed through thirty feet of space, and the power sends the stake a few inches into the earth; thus this forms a machine for a weak power to overcome a great resistance by a succession of efforts.

A man in leaping accumulates power by running a short distance first, and he expends it in one effort.

A sling is first moved gently, then more rapidly round and round, to collect power before the stone is allowed to fly.

A swing at a fair, filled with people, requires force to set it going; but it collects power and momentum, until it mounts so high as to become dangerous.

A *fly-wheel* is another reservoir of power, and is mostly used to equalise motion, as there is a continual pressure on the stronger part of its force to overcome the weaker, illustrated in a previous page by two men turning a winch. A fly-wheel does not increase the power of a machine, but distributes it regularly during its movement. The first putting it in motion is a loss; but still motion may be accumulated in it, by a continuance of power, sufficient to produce effects in raising weights and overcoming resistances.

The wheel used in the screw-press for coining and embossing, previously noticed, is of this nature; as is also that in which a piece of flat silver is placed, and by a quick motion a perfect spoon is made. Some screw-presses are moved by having a horizontal lever of a bar of iron fixed at the axis, and at each end a heavy ball of iron; by drawing these balls back, then giving to them a quick forward motion, the power accumulated and the momentum is great, and the velocity considerable.

The grindstone and wheel of a lathe become a fly-wheel, or reservoir of motion, when once set fairly in action.

STRENGTH AND SIZE.

A limit seems to be set to the size of animals, man, and the works of man, as it is found that strength depends on the bulk, shape, position, and cohesion of materials. A compact useful-sized cart, if increased to four times the size, the strength of the materials must be increased sixteen times, and the weight consequently is increased sixty-four times; and if we proceed enlarging, the machine would ultimately break down under its own weight. It is a principle in mechanics, that weight increases in a greater ratio than strength, and therefore places a limit which demands the attention of all practical scientific men.

To some houses, more especially those formed to be let out into offices, having a common staircase, the stairs are formed of stone. If these stairs, which are inserted at one end into the wall of the building, were made to project too far, they would break of their own weight. A stone of a moderate size will be found to bear more than one double the length and double the thickness projecting twice as far out from the wall; for the larger one at the point of insertion, or fulcrum, in bearing the weight has to support, by the cohesion of its materials, twice as many particles beyond it, and each particle being pulled at by gravity, the length of the lever is increased, which renders it weaker than the smaller one. The centre of gravity in the large stair being much further from the point of support than in the small one, the weight is accumulated there. When mechanics calculate such an example as the present one, fig. 53, they proportion in solids the cubes of their sides, to find the contents of matter in each; therefore in those two stairs there will be eight times as much in the larger as in the smaller one. The forces assisting to keep the bulks whole, therefore, are four to one in favour of the large stair: that is, it is four times less liable to break; but the stress upon the end of the large stair being eight times as much as on the smaller one from its weight, and twice from the centre of gravity being at double the distance ($8 \times 2 = 16$), makes the liability to break from bulk and position sixteen times greater; then divide this disadvantage by its advantage ($16 \div 4 = 4$), it proves that there is a proportion of four to one in favour of the small stair.

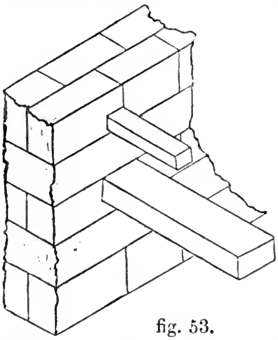


fig. 53.

Following out this example, it shows that in all levers the strongest part must be where the strain is greatest; and in all machines, that the weight different parts have to bear must be taken well into account in proportioning them.

From this principle a limit is set to the size of the human frame, buildings, and machinery. It is this also gives size and form to mountains, trees, and animals. The oak that braves the tempests of centuries increases in bulk, but not in height. The massive megatherium, of immense structure, had bones proportionate to its bulk, but sloth-like crawled along the surface of the ground, leaving its path a cleared space, thus proving beneficial to other animals, and by existing on roots thinned the forest, giving air and space to the remaining vegetation. The ponderous whale is borne by the surrounding water so as not to feel incumbrance from its size, and moves about with ease and velocity. Where the preservation of life often depends on agility, we find the slender and elegantly-formed stag; but where there is great bone, there is strength to defend the right of life, as in the elephant, rhinoceros, and hippopotamus. We are somewhat grieved that philosophy robs the fables of the heathen of their celebrated Goliath deities, and produces unbelief in the exciting romantic deeds of the hero Jack the Giant-killer. We are compelled to think the latter warrior "made the giants ere he killed them."

STRENGTH OF BODIES.

Solids will bear an immense amount of pressure before the shape of them can be changed permanently. In a cube of one inch in size, the following solids have been found to require a pressure equal to that placed opposite each to effect an alteration in their shape :

	lbs.		lbs.
Elm	3240	Tin	2880
Ash	3540	Zinc	5700
White Fir . . .	3630	Brass	6700
Oak	3960	Cast Iron . . .	15,300
Red Fir	4290	Malleable Iron .	17,800
Lead	1500		

The manner in which experiments can be tried as to the resistance of metals in a flat shape to that of a tubular is very simple. Two solid pieces of iron are placed at a little distance from each other, and joined together at the bottom by a hinge; on the ledge, half way up, a flat piece of the metal is placed, and then weights applied at the top, until the strength is proved; the tube, as seen in the diagram, is next put between the solids, and weights placed until tested.

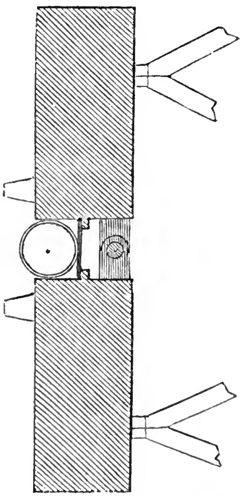


fig. 54.

Wood is found to afford the greatest resistance when placed in an upright position, and that it is strongest when of a short length.

In our mines, where there are immense numbers of supports required to hold up the superincumbent mass of the roof in the excavations, short props are invariably used. The reason of the superiority of a short piece of timber to a long piece used as a support is, that the force acting upon it does so equally on the whole, and has little mechanical advantage. In the short piece every atom resists, and therefore the impenetrability of matter has to be overcome; whereas in a long piece the leverage is greater, and it is more apt to bend, the slightest yielding in a great number of atoms making a considerable total. If a long piece bend in the centre, then it may be considered that the pressing weight acts as a lever against the strength from the mark in the centre to the outside bend, while the lever of the short piece is its entire length and thickness (fig. 55). By applying any stay or projection which will strengthen the part likely to bend, firmness is added to the support.

When a piece of timber is bent by pressure, the atoms in the inside

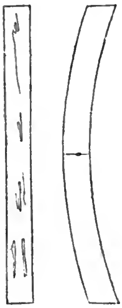


fig. 55.

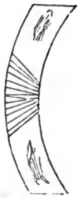


fig. 56.

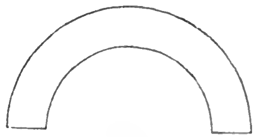


fig. 57.

curve are pressed together, while those at the outside are separated and stretched out, as represented by the radial lines, fig. 56; the middle portion is neutral, and might be removed without lessening the strength of the timber. It is on this principle that hollow pillars are made. A solid piece of iron formed into a tube has greater strength, as a mechanical support, from having a longer lever, by the substance standing further from the centre. In fact, hollow tubes combine lightness, saving of material, and strength, far beyond the material as a solid body. Tredgold states that when the inner half diameter of the hollow cylinder is to the outer as seven to ten, it will possess double the strength of a solid cylinder of the same weight.

A fluted column, from offering a greater resistance to a bending force, is found to be stronger than one perfectly smooth.

From this combination of advantages, the Divine contriver has made the bones of man and animals hollow, being strong and hard externally, and light and honeycombed internally, while the bone of the upper arm in man has ridges, which add to the strength.

The quills of birds are another beautiful illustration of a careful use of material with strength and elasticity; had they been formed the same size as they now are, but solid, they would have been unfitted to soar in the aerial atmosphere, tread lightly on the ground with their slender limbs, or swim upon the surface of the waters.

The hollow stalk of corn rears its slender form two or three feet with its valuable cereal head bending gracefully to the stormy wind.

The common mint has an angular stem, ribbed with fibres and filled with pith.

The willow and elder-tree are slim and light of construction; and the bamboo and sugar-cane have manifold usefulness from their construction.

On the same principle that a large column is more liable to break than a small one, and that forces increase more to break bodies than those which keep them entire, the child is in less danger from accidents than a man.

When a beam is supported at both ends it is twice as strong as one half its length supported only at one end. Still if a beam be too long, supported at each end, it will from its own weight break in the centre, or weakest part.

A beam or a plank supported at its ends will bend down in the middle, fig. 58, when the atoms in the upper side will be pressed together, those

fig. 58.

on the under be pulled out, and those in the middle, called the *neutral axis*, undergoing no change, might be taken without much diminishing the strength. From each end to the centre might be called levers, and from the centre to the upper part the resisting force, having very little assistance from the under half. When much bent the fibres underneath are so stretched that a penknife passed across will make them fly asunder, and the plank or beam snap in two.

In forming the roofs of large buildings the beams are made to lean against each other, as a letter **A** : by this arrangement the pressure is applied to the grain of the wood endwise, and consequently supports a greater weight; cross strains are made as much as possible to convey their weights into beams, having a longitudinal position, and the skill in doing this renders the buildings more stable; in truth, a well-constructed roof may be considered as a bone hollowed out, where substance would not add to strength.

A plank bears a greater weight when resting on its edge than on its side. In the flimsy shells now erected called houses, hardly strong enough to resist a gale of wind, and leaning against each other for support, this is taken advantage of; for instead of good firm joists, a piece of wood not thicker than a good plank is put in; but as they would be apt to curl and thus start out of the wall, they are held in their position by cross binding pieces in the centre. And this is the improvement of the age in house-building!

If we take the bent plank in fig. 58 and turn it upwards, we form an arch. This form given to a fixed body is capable of enduring an immense transverse pressure, because force compresses the atoms both of the under and upper side, which prevents their separation; and as every atom thus bears its share of the strain, it becomes equal to an upright support.

Man in forming bridges may have derived the hint from nature, as there exist several fine natural arches. The grandest in size is that in Virginia, United States, being 270 feet high, 90 feet span, 60 feet broad in the centre, and 40 feet thick. On this gigantic scale does nature work.

The arch acts with pushing force against the piers of the bridge; and in domes, which are on the same principle as simple arches, the piers not generally being thought sufficient to resist the horizontal thrust which exists, other means are taken, as having girders inside crossing over. At St. Paul's, London, two powerful chains pass around the exterior, resting in the stone-work.

The strength of the arch is exemplified in the safety of materials packed in a cask to that of a square box; in a watch-glass, bottles, and many of the common utensils in domestic use.

Nature adopts it as the most safe protector of incipient life in the eggs of birds. In the vegetable kingdom the vital principle is wonderfully preserved in an arched case. The elegant rounded finish to that master-piece of creation, man, where sensations and action have their termini—the brain—is carefully and powerfully protected by the beautiful, light, graceful arch which forms the skull of the human form.

In concluding the subject of Mechanics, we may observe that the whole rests on very simple laws.

A mass of matter when in motion may be compared to another mass, either with respect to the size and weight of each other or the swiftness with which they move. The greater the mass, the greater will be the force required either to give it motion or restore it to rest; while the swifter its motion, the greater will be its force. The momentum is calculated by multiplying its weight by its velocity of motion. When bodies act in contrary directions, as when weights are acted upon by a lever, wheel and axle, pulley, &c., the ascent multiplied by its weight, and the descent multiplied by its weight, if equal, balance each other; because, as both actions take place during the same period of time, their velocities are as to the space passed through, and the preponderance of weight in one body is equal to the greater velocity of the other; and thus extra velocity and space balance the lesser velocity and space, but greater weight.

This, then, shows a great fact in all mechanical contrivances, and places the power of accurate computation within the reach of an earnest investigator; for by knowing how much swifter the power moves than the weight, or how much more space is passed over by the moving power than the power moved in the same period of time, the exact increase of assistance gained by the machine is known. But we entertain a hope that the familiar examples we have given throughout the chapter, illustrative of this important and pleasing branch of science, will have fixed on the mind, without much effort, the principles by which it is universally governed. The laws of mechanism are beautiful from their very simplicity.

CHAPTER IV.

PARTS OF MACHINES IN WHICH THE SIMPLE MECHANICAL POWERS ARE EXEMPLIFIED.

In almost every machine, however simple, the lever is seen applied; its modifications are very numerous. In the apparatus for opening and shutting valves in steam-engines, and other prime movers, the lever is the principal part. Thus in fig. 60, where *a b c* is a lever-handle of the form generally used, suppose the end *a* is firmly fixed to a rod capable of revolving, by moving the end *c*, it will describe part of the circle shown by the dotted lines; while at the same time the rod to which the end *a* is fixed will revolve. For the convenience of handling the lever, a projecting handle or lever *d*, fig. 61, is placed at the end, *c* fig. 60. The diagram in

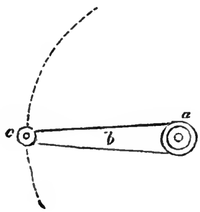


fig. 60.

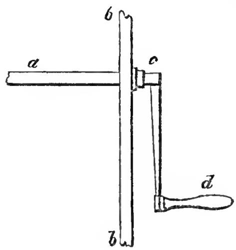


fig. 61.

fig. 61 illustrates the method adopted in starting and stopping the engines of a locomotive: *b b* is part of the boiler through which the rod *a a* passes to the valve to which it is connected; a lever, *c*, is moved by the handle *d* and being connected at *c* with the rod *a*, it causes this to revolve and moves the valve, of which in its proper place we shall give a description. In fig. 61[a] we show another method of giving motion to valve-rods by means of levers; this modification is in use in locomotives. Suppose *f* to represent the end of a valve-rod connected with the lever *e*, the valve being placed at the front of the engine, while the engineer

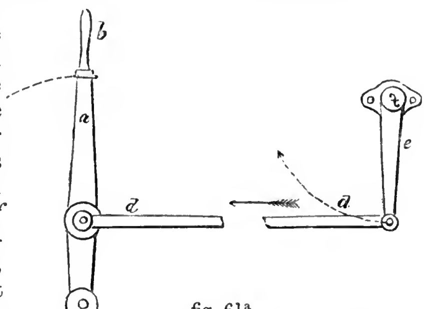


fig. 61[a].

stands at a distance from it, as towards *a*, near the fire-box; a rod, *d d*, is connected with the end of the lever *e*, and is fastened by a movable joint to a part of a lever *a*, the centre of motion of which is at *c;* the engineer, by pulling the handle, *b*, in the direction of the arrow, will cause the lever, *d d*, to move as in the diagram, and *vice versa*. In some cases a small wheel, *a a*, fig. 62, is attached to the rod, *b*, to be moved; a handle, *c*, is fixed on one of the arms at any desired distance from the centre; a leverage is obtained equal to the space between the centre of the wheel and the point at which the handle is fixed. This method is frequently adopted in slide lathes, the wheel being fixed at the end of the screw which moves the central spindle; in some cases (fig. 62ᵃ) the handle, *c*, is dispensed with, the arms of the wheel itself being used to turn it round. This adaptation may also be seen applied to the brakes used in locomotives and railway-carriages.

The application of the lever is also observable as a principal feature in

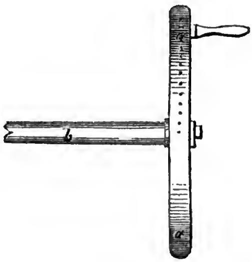


fig. 62.

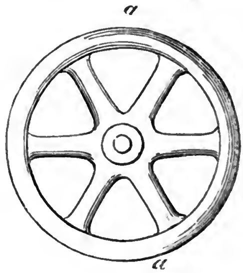


fig. 62ᵃ.

the steam-engine; thus in fig. 63, which illustrates the beam with its usual appendages, termed the "parallel motion," the lever plays an important

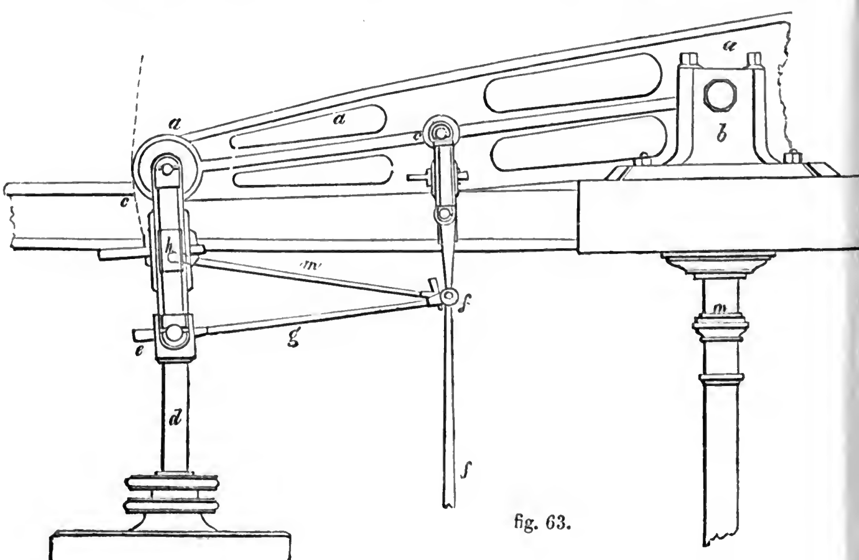


fig. 63.

part. The great beam, *a a*, is a lever, the centre of vibration of which is at *b*; the links, *c c*, are also levers, the centres of which are at the ends of the lever *g*, and at the points where they are attached to the beam; the centres of the lever *mg* are at *h* and *f*. The result of this combination may be here generally stated; although the end, *ac*, of the beam describes a part of a circle at each vibration, yet the piston-rod, *d*, traverses up and down in a straight line. In the proper place we will fully investigate the *rationale* of this elegant adaptation of one of the simple mechanical powers. In the "governor," another important appendage of the steam-engine, the lever is the principal feature; in an advanced portion of this treatise we will explain the principle of its action. In the safety-valve of the steam-

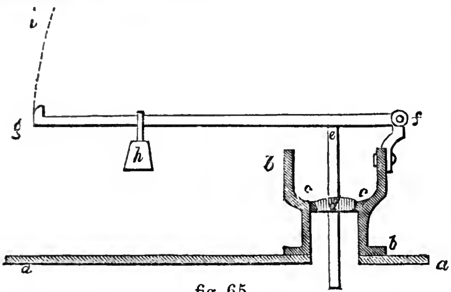


fig. 65.

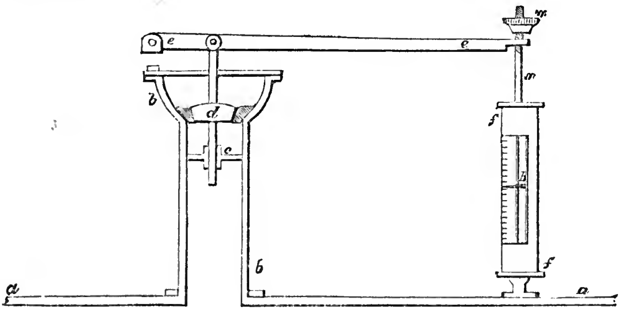


fig. 66.

engine boiler, fig. 65, and in that of the locomotive, fig. 66, the lever is also noticeable as the main feature. In fig. 65, the steam pressing upon *d* causes the spindle *e* to move the lever *g* in the direction of the dotted line *i*; the centre of the lever is at *f*, and the weight at *h*. In both these kinds of valves the levers are of the third order. In the self-acting feed apparatus attached to boilers of steam-engines, the lever is also employed; thus in fig. 67, the water *b b*, rising or falling in the boiler *a a*, acts upon the float *c* and the spindle *d*, which is attached to it, and also to the end of a lever

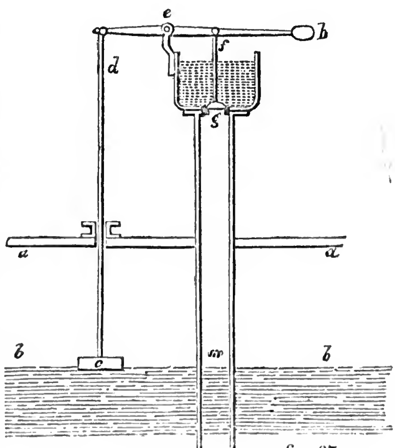


fig. 67.

which vibrates in the centre *e;* this, again, acts on the valve *g* by the rod *f.*

In the diagram, fig. 68, we give an arrangement of levers which act very powerfully; they are used in the Stanhope printing-press. The short lever *a b* is attached to the head of the screw which acts on the platten, which presses down the paper on the inked types. This short lever is connected by the rod *c c* with the bent lever *f e d;* the power applied at *d* having to move through a much greater space than the screw at *b*, considerable power is obtained by this combination. In fig. 69, the arrange-

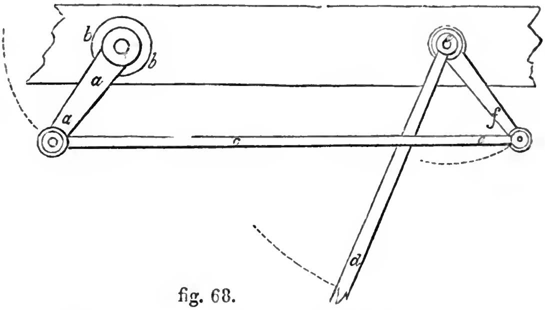


fig. 68.

ment of levers in the well-known "copying press" is shown: the plate *f* is first pressed in close contact with the article subjected to pressure by means of the lever *d e e* acting on the screw *c;* thereafter the lever *k i* is

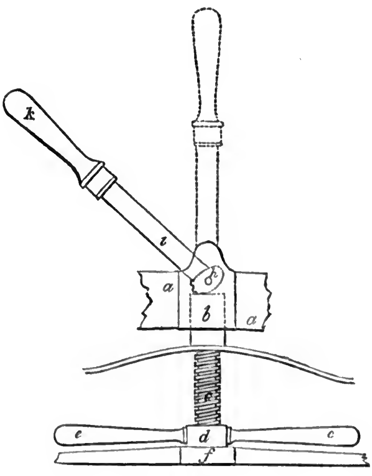


fig. 69.

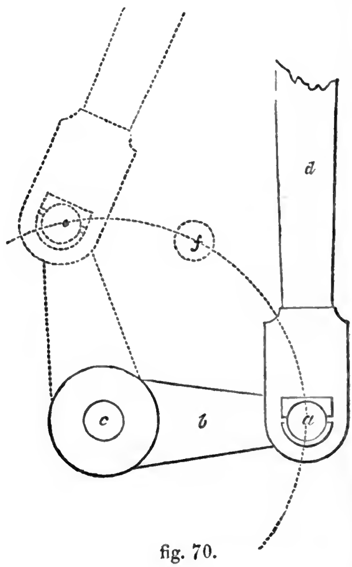


fig. 70.

brought into action, which acting on the screw by means of the cam *h*, depresses the plate *f* with great pressure.

A crank is a simple lever; thus if the end *c* of the lever *c b a*, fig. 70, be fixed to the end of a shaft to which it is desirable to impart rotatory motion, and a "connecting-rod," *d*, be attached by a movable joint to the other end *a*, by causing the rod *d* to move up and down, or in other words to have a reciprocating motion, the end *a* will revolve in a circle, as shown by the dotted lines and figures: a fly-wheel is required where the motion is to be continuous and without jars or jolts; the reason of this being required is explained at p. 37. The contrivance known as the "bell-crank" is a modification of the single crank. The crank-arm *a b*, fig. 71, being at right-angles to that of *a c*, the connecting-rod *e* being moved in a horizontal reciprocating direction will cause that at *d* to have a vertical motion, or *vice versâ;* the ends, *b c*, of the cranks will only describe portions of circles, proportioned to the length of stroke of the connecting-rods. The form of crank used for steam-engines of con-

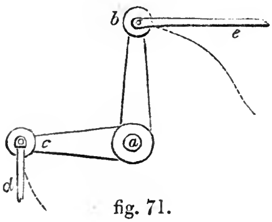
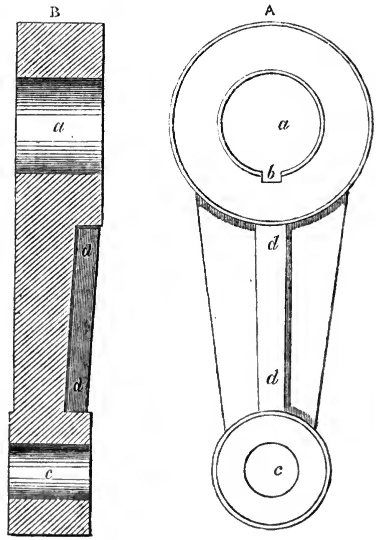


fig. 71.



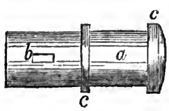


fig. 71b.

71a.

siderable power is shown in fig. 71a, of which A is a front view, and B a section. The crank is passed over the end of the shaft which it is designed to turn at the eye *a*, and secured by a key, as will be hereafter described. The crank-pin, to which the end of the connecting-rod is attached, is passed through *c*, and fastened by means of a key or cottar; *d d* is a rib or projection, which gives strength without incurring much weight. The crank-pin is figured in fig. 71b; *b* is the part fastened in the eye *c*, the connecting-rod brasses (hereafter described) embrace the part *a*. Fig. 71c shows a method adopted in marine engines of attaching the connecting-rod, *a*, to the end of the beam, *b;* while in fig. 71d the method of attaching the other end of the rod to the crank is shown. In fig. 71e the mode of attaching the connecting-rod of a large beam steam-engine to the end of the beam is illustrated: *a* is the end of the beam, *b b* the pin or journal, *c c c* the connecting-rod. The bent rod observable in

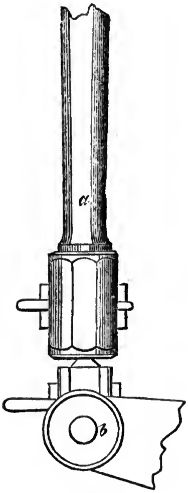


fig. 71^{c}.

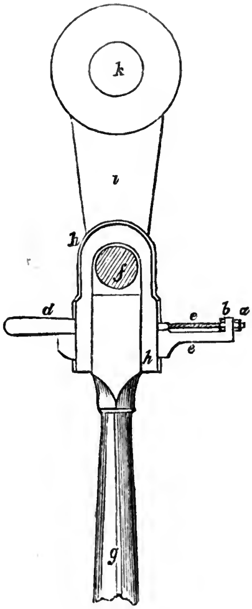


fig. 71^{d}.

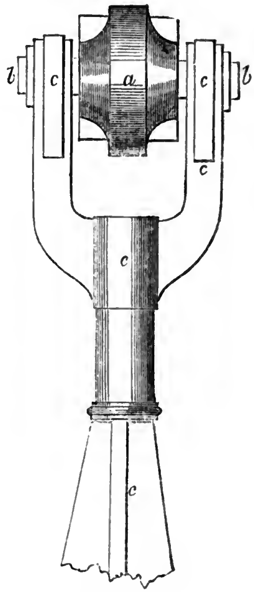


fig. 71^{e}.

the knife-grinder's machine is also a crank ; the operative, by alternately raising and depressing his foot on the jointed foot-board *a a*, fig. 72, imparts a

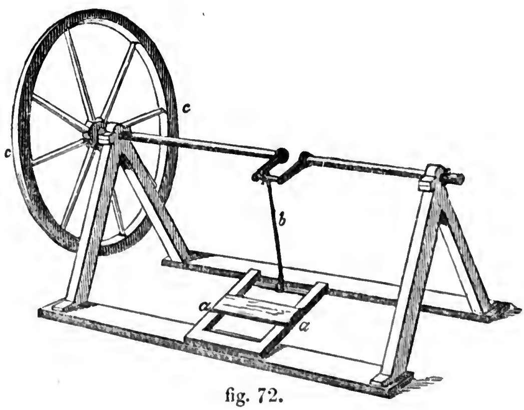


fig. 72.

reciprocating motion to the rod *b*, which turns the axle and fly-wheel *c c*. In the "potter's wheel" the crank is also used to drive his machine ; by turning the crank-handle *a a*, fig. 73, motion is imparted to the fly-wheel *b b*, from which motion is communicated to the machine by the strap or belt *c c*. The bent handle used in turning grinding-stones, coffee-mills, &c. is a crank.

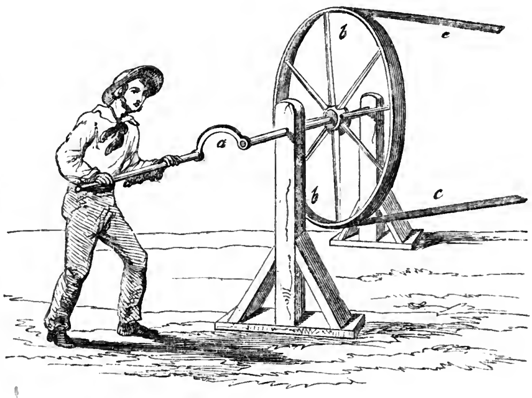


fig. 73.

The instrument used by mechanics for shifting moving nuts upon bolts, and called a "key" or "monkey," is a lever. A common form is shown in fig. 73ª: a recess, *a*, is made at one end, by which the nut, *b*, is grasped; the power is applied at *c*, which performs part of a circle, of which the centre of the nut *b* is the centre; the nut revolves on the bolt, and is tightened or loosened at pleasure. Keys are sometimes made in the form of a bent lever, as *e g f*; recesses of different sizes being made at the ends, in order to grasp nuts of various dimensions.

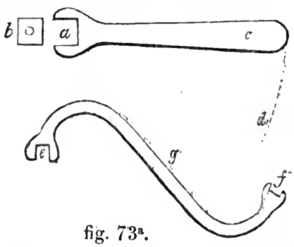


fig. 73ª.

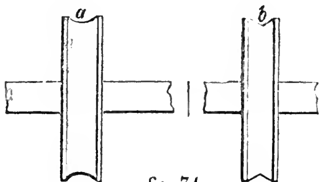


fig. 74.

In the various departments of practical machinery, the adaptation of the wheel to many purposes is very noticeable. We have already given exemplifications of this mechanical power in figs. 27 to 31. They are used in numerous ways to transmit power from point to point, to change the direction of motion and its relative velocities. Pulleys or drums, as used for this purpose, are merely wheels and axles; in fact, the axle or fulcrum is always an inherent part of every wheel or pulley, without which it could not be used. Pulleys used in machines are of different forms; those in blocks used on board ship, or in cranes on land, for lifting heavy weights, have either angular grooves cut in their periphery, as *b*, fig 74, or concave, as *a*. In factories they are generally made, as in fig. 75, with a comparatively thin rim, *a a*, attached to the centre *c* by the arms *b b*; an aperture is made in this, through which the shaft, *c c*, is passed, as already noted (see fig. 62). Motion is communicated by means of leather straps or belts from one wheel or pulley to another. If the outside of the pulley was made quite flat, that is parallel with the shaft or axle, the belt would have a continual tendency to slip off the surface; to prevent this, advantage is taken of a curious property observed in these contrivances, which causes the belt always to remain on that part of the periphery which is highest; hence in all well-constructed pulleys the outside rim is turned so as to be convex, as $d\,d$, fig. 75. In cases where the strain is severe, the belts are apt to slip on the surface of the wheels. Where this embarrassment is merely temporary, from increase in the work to be performed, or from other causes, engineers generally obviate it by strewing the inside of the belt with pounded resin; this is taken up by the wheel surface, and considerable friction is induced, which enables the belt to take the necessary "grip." But in cases where the power is too great to be transmitted by belts, other contrivances are adopted. The first of these we shall notice is the linked-chain motion, as being closely allied in principle to the belt. If we could suppose little protuberances or projections to be made on the periphery of an ordinary pulley, and similarly disposed apertures to be made in the belt, then as the wheel revolved the projections would be caught by the apertures, and slip would be prevented: theoretically this plan is available; in practice, however, its defects are obvious. Fig. 76 shows one of the methods adopted in practice by which the idea is carried out: the projections *b b b* in the links *a a a* are made to fit in the indentations *d d d* of the wheel *c c*; as the links are jointed in many places, enough of flexibility is imparted to the chain to enable it to pass easily round the wheel *c c*, of which only a part is shown in the diagram.

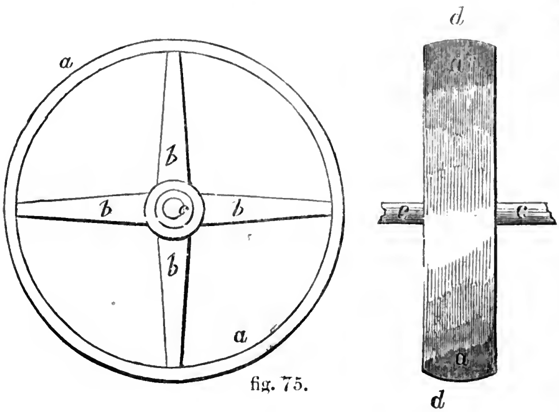


fig. 75.

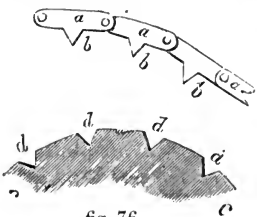


fig. 76.

In place of belts, and the rather cumbrous contrivances of linked gearing-chains, now described, motion is transmitted from one point to another by means of toothed wheels. Where the driving wheel is large, it is called the "wheel" *par excellence*; the driven wheel being smaller is termed the "pinion." Thus in fig. 31, *a* is the pinion, and *b b* the driving wheel. Wheels thus working revolve in contrary directions; by the interposition of a third wheel *a* the last revolves in the same direction as the first.

In future illustrations in this treatise we shall have occasion to illustrate various adaptations of toothed wheels to different machines. To reduce the friction as much as possible between the rubbing surfaces, the form of the teeth has been always an important consideration amongst engineers; much attention has, consequently, been given to the subject by learned men, the most practical of whom may be said to be Professor Willis. In this branch of engineering he has contributed much of value. Where the teeth or projections of the wheel are formed as part of the wheel, that is when both are cast in one piece, they are designated as "teeth," the projections of the pinions being in like manner termed "leaves." When the teeth are made of wood, and inserted in holes made in the periphery of the wheel, they are termed "cogs." In some cases, instead of a pinion, a modification termed a "trundle" is used; some engineers (among others Smeaton) prefer it to a pinion, as it is considered by them to wear more equally. On this point, however, difference of opinion prevails. In fig. 77 we have shown the form of a trundle; it consists of round spindles of wood or metal, *c c*, their ends firmly inserted in flat pieces, *a b*. In some cases small wheels or rollers are made to move one another without the intervention of belts or teeth. This is effected by one of two methods,—either by making them slightly fluted in their exterior surfaces, or by covering them with leather; in either case they work in contact, and the friction produced suffices to cause them to revolve, motion being first imparted to one by some prime mover. This principle is met with in most of the "machines of preparation" in cotton-spinning factories. In some machines motion is to be transmitted from one point to another, while at the same time the shafts or axes are not parallel, but at right angles to one another. This necessitates the employment of a different form of toothed wheel; this is called the "bevil" or "mitre" wheel. The rolling surfaces, as will be observed in fig. 78, are parts of cones; thus *b b* fixed on shaft *a a* gives motion to *c c*, fixed on shaft *d d*, at right angles to *a a*. In fig. 79 the form of these wheels as generally used is shown.

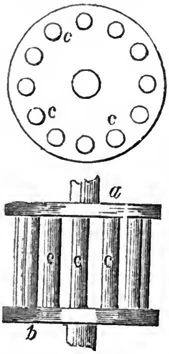


fig. 77.

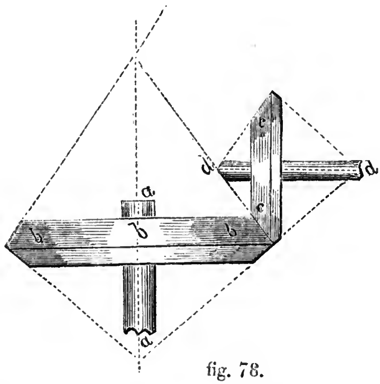


fig. 78.

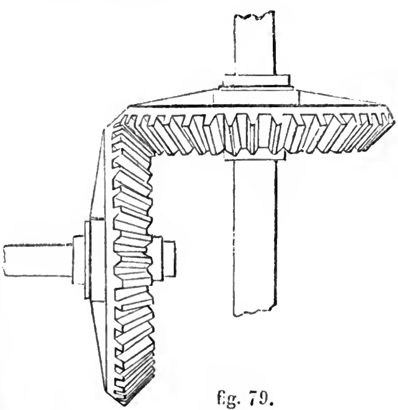


fig. 79.

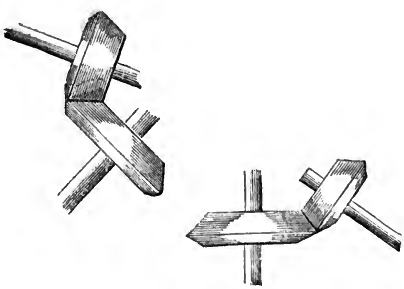


fig. 80.

As may be seen in figs. 80, 81, bevil wheels are useful in transmitting motion in various directions. The "trundle," in conjunction with the "face wheel," as it is termed, has been frequently used in corn-mills for changing the direction of motion by toothed wheels: this is illustrated in fig. 83. Another and a familiar method is that known as the "crown-wheel," much used in the cheaper kind of watches, called "verge" or vertical: it is shown in fig. 82.

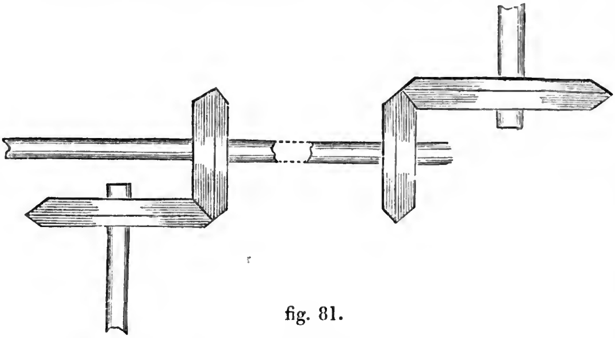


fig. 81.

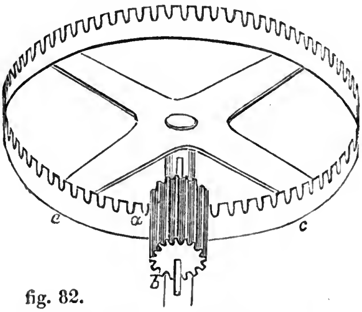


fig. 82.

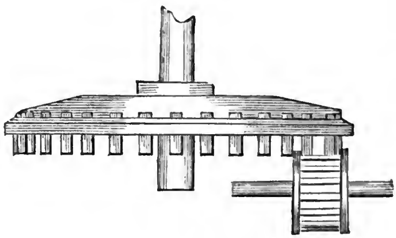


fig. 83.

A modification of the wedge frequently met with in machinery is what is termed a "key" or "cottar." It is shown in fig. 84 at *d d*; *a a* is another form: by striking at one end, the "gibs" *b c* are tightened; that is, *c* is forced down, while *b* is forced up, and *vice versâ*. In fig. 85 its use in tightening up the brasses of a connecting-rod is shown; *c c*, *d d*, *e e*, are forms of wedges, *d c* being the keys or

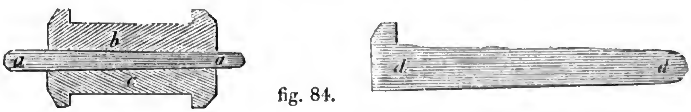


fig. 84.

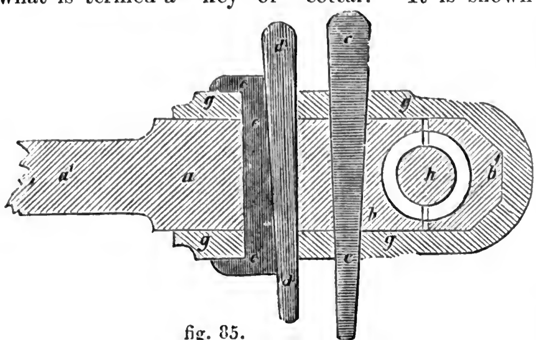


fig. 85.

cottars, and *e e* the gib: this arrangement will be explained more fully hereafter. "Cambs," used for giving alternate motion to parts of machinery, are modifications of the wedge. In fig. 86 is shown a modification: *b b* is

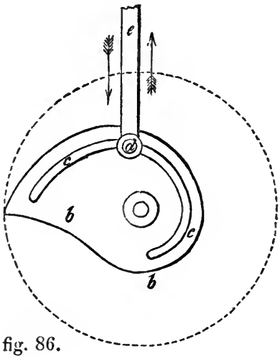


fig. 86.

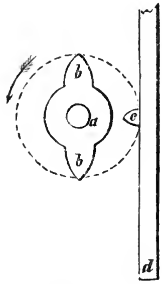


fig. 87.

the camb, having a groove *c c* made in it; in this groove a pin *d* works, attached to the rod *e*. In some cases cambs are termed "wipers," as in fig. 87: *b b* are the wedge-shaped wipers projecting from the wheel or shaft *a*; these strike alternately on the wiper *c*, projecting from the rod *d*. Another modification is shown in fig. 88, where *b b* are the "wipers" on the surface of the shaft *a*. In fig. 89 a view of a washing-machine is given, in which the "beaters" *b b* are made to rise and fall by the revolution of "lifters" placed on the axis of the driving-wheel.

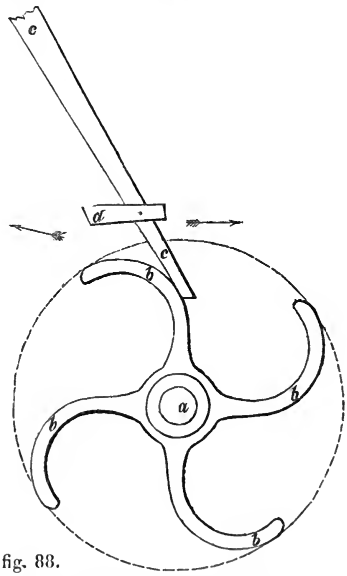


fig. 88.

The "ratchet-wheel" may be called a modification of the wedge. Wedge-shaped teeth, *b b*, are cut in the periphery of the wheel *a*, fig. 90, the object being to prevent it from turning in any but one direction; for this purpose a "catch" or "detent," *c*, is fastened to a beam, or part of a frame over the wheel. Suppose the wheel to be moving in the direction of the arrow, the end of the detent freely allows each tooth to pass it: but on the wheel beginning to move in a contrary direction, it catches in the bottom and side of the tooth, and prevents it moving. This movement is used in cranes and windlasses, where it is essential to prevent the rope unwinding; it is also used by the mechanic in boring holes in metal, as will be described hereafter.

The screw is much used in machinery in fastening and tightening

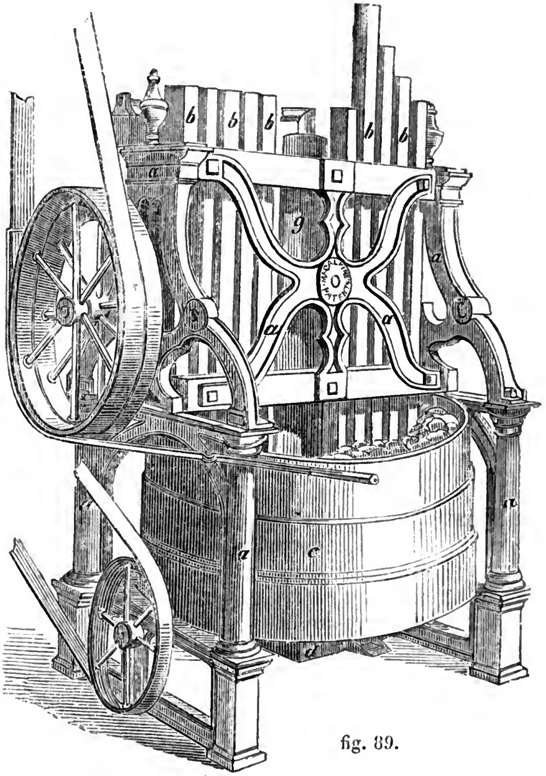


fig. 89.

various parts. In fig. 91, *a b c* shows the general form of "bolts" used in machines: the screw is cut at the end *c*; a head is formed at *a*; the part *b c* is passed through a hole made in the parts to be joined together, as *e e*, *f f*; by tightening the nut *d* the parts are fastened together and firmly secured: nuts are sometimes made square, sometimes hexagonal

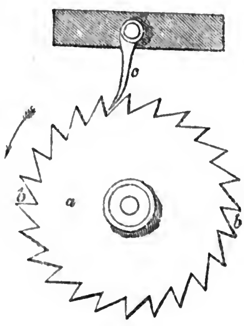


fig. 90.

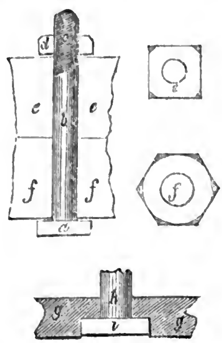


fig. 91.

and octagonal, as *e, f.* A shifting "key," in which the screw is made available, is shown in fig. 92. In fig. 73ᵃ two forms of keys for moving nuts are shown; in these, certain sizes of nuts only can be taken or grasped; but the form in fig. 92, which is technically called a "monkey," is available for varying sizes of nuts. The fixed jaw *a* is riveted to the stock *b*, one end of which has a screw cut on its surface; this works into a corresponding internal screw cut in the shoulder of the handle at *e*;

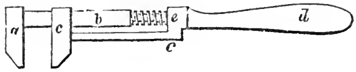


fig. 92.

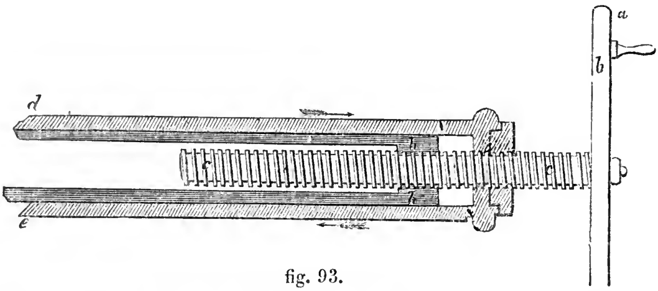


fig. 93.

this plays between a grooved part on the arm *e* of the sliding bar *c*, attached to the jaw *c*, which moves along the stock *b*; by turning round the handle *d*, the sliding-bar and jaw *c* is made to move either to or from the fixed jaw *a*; by this means the distance between them can be proportioned so as to enable any size of nut to be grasped between them. The internal screw is used in turning-lathes; this is exemplified in the section of part of the "head" given in fig. 93. The spindle of the lathe-head works in an accurately-bored aperture made in the head, as at *d d*; one end, *h h*, of the spindle is made with an internal screw, which fits the male screw *c c*; by turning the wheel *b b* fixed at the end of *c*, by the handle *a*, the spindle is either projected further from the hollow head or drawn within it.

CHAPTER V.

CONSTRUCTION AND ARRANGEMENT OF ESSENTIAL PARTS OF MACHINES.

In communicating motion from one point to another, and for supporting the assemblage of wheels, pulleys, and the various modifications of mechanical powers which may be adopted for this purpose, contrivances known as "shafts" are used. When of considerable diameter, this is the term by which they are known; when of comparatively small dimensions, they are called "spindles." Shafts are of two kinds, "horizontal" and "vertical:" the former being used when motion is to be communicated from one end of a room to the other, or similar positions; "vertical," where it is to be taken from a low to a high position, as from the engine on the ground-floor of a factory to the various floors above.

Shafts, up till a very recent period, were generally made of wood. Excepting in very rare instances, and those chiefly in rural districts, this material is now seldom used, cast and malleable iron being alone employed. The former is generally adopted in the case of heavy shafts, while the latter is almost always employed for shafts of comparatively minor diameters. Shafts are composed of two portions—the "body" and the "gudgeons," or "journals." The latter term denominates the parts on which the shafts revolve, and in small iron shafts are formed by merely making a certain portion circular and smooth by being carefully turned in a lathe. Thus, in fig. 94, *c c* is the body of the shaft, while *b b* are the "journals."

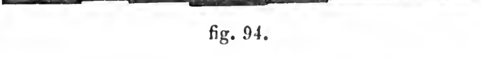


fig. 94.

When shafts are made of wood, oak in a solid mass is used, or they are BUILT of lengths of fir. Sometimes they are made octagonal, or have the corners roughly taken off; more generally they are left square. As it is evident that the journals must be of some better or more durable material than that which forms the body of the shaft, cast iron is usually adopted for this position; hence arises a necessity for having an efficient method of fastening the journals, thus necessarily separate, to the body of the shaft, in such a manner that they shall, as nearly as possible, approximate to the condition of a shaft perfectly solid and stable throughout its length. We here figure one of the methods adopted to attain this desideratum. Thus, suppose *a a* (fig. 95) to be part of a wooden octagonal

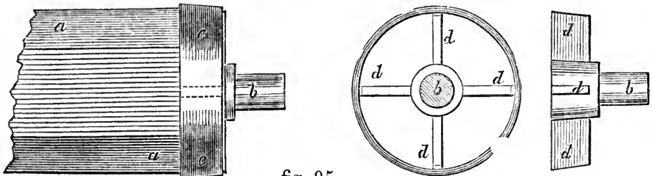


fig. 95.

shaft, mortices or apertures are made in the end of the shaft of a certain depth, and of shape and width corresponding to the "cross-tails" *d d* cast round the journal *b*; these arms are let into the mortices on the end of the shaft and driven home; a hoop of metal, *c c*, is put over the end of the shaft in a heated state, then carefully wedged up; on cooling, the hoop closely binds the end of the shaft and the ends of the cross-tails *d d*.

When large shafts are used, as in water-wheels, where the motion is slow, they are made of cast-iron and *hollow*. In this case the journals are sometimes inserted, as shown in the sketch, fig. 96: *b b* is a project-

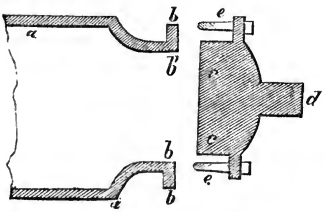


fig. 96.

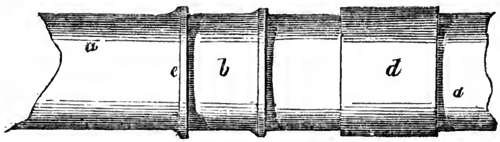


fig. 97.

ing flange, cast round the end of the shaft *a a*; the interior of this is carefully bored, to receive the part *c c* of the journal *d*, which is turned of the same diameter as *b b'*; the parts are held together by the bolts *e e*, passing through the projecting flanges, and secured by nuts.

The method of fixing wheels, pulleys, &c. on shafts is simple. In every shaft there is provision made for this. In fig. 97, the part *d* is that on which the wheel is to be fixed: it is called the "boss," and is of larger diameter than the body *a*; *b* is the journal, terminated by two projections, commonly called "ruffs" or "collars." As the "eye" or centre of a wheel to be fixed on a circular shaft is generally bored out, it is necessary that there should be some means adopted to prevent the wheel from turning round or shifting on the shaft. This is effected by cutting, in the first place, a longitudinal "slot," or groove, along the inside of the eye of the wheel or pulley, as in fig. 98 at *b*; this may be done at only one side, or

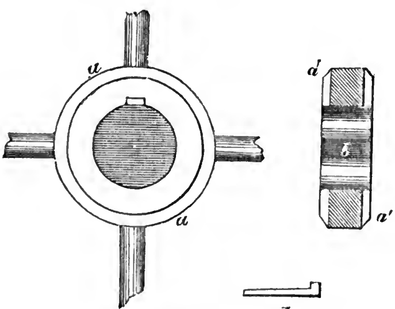


fig. 98.

at both ends of the diameter; in some cases four are made: the parts cut out are termed "key-seats." Part of the boss of the shaft is next made flat by means of appropriate tools; the wheel is put on the boss with the slot opposite this flat part; a key, as *d*, is then inserted in the slot and driven home; acting as a wedge, the wheel is prevented from slipping round the shaft. In some cylindrical shafts, ribs or projections are cast, as in figs. 99 and 100, *b b*: fig. 99 is a section of fig. 100.

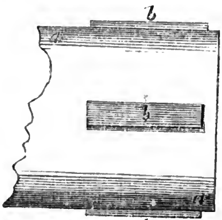


fig 99.

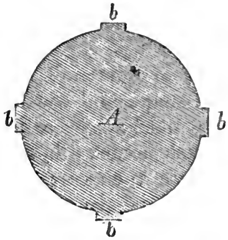


fig. 100.

Where shafts are made square, as in fig. 101, the eye of the wheel being made square, by cutting key-seats in it, it may be fixed easily on any

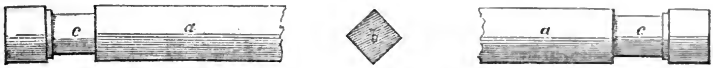


fig. 101.

part: *c c* are the journals, *a a* the body of the shaft, *b* a section through the body. As a general rule, the journals of shafts should be of the same diameter: enough should be merely taken off to form them, leaving depth enough to keep the journals in the brasses.

This brings us to the next important feature in this department of machinery, namely, the "bearings" by which shafts are supported and in which they revolve. They are generally known as "plummer" or "plummet blocks," or "pedestals." They consist of two parts: the "sole," *a′ a′*, or part which is bolted down to the standard or frame *e e* (fig. 102),

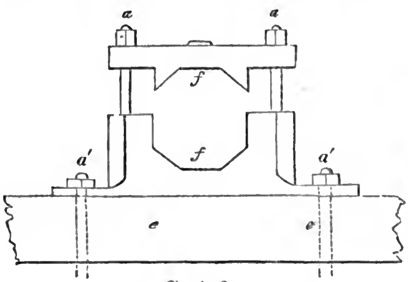


fig. 102.

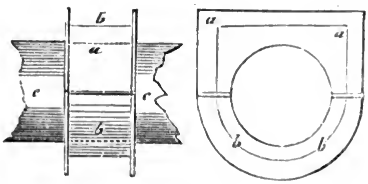


fig. 103.

by the bolts *d d*; and the "cover," *a*, which is secured to the sole by bolts passing through it, as in the sketch. The journal of the shaft revolves in a space, *f f*, left in the centre of the block. In order to prevent as much as possible loss of power by friction, the shaft journal is made to revolve within "brasses" or "pillows," made of brass, or a mixture of copper and zinc. In fig. 103 a front and side view of a brass generally used is given. The part *b* is that which is placed in the sole of the block; *a* that placed in the cover. They have both projecting flanges, which embrace the sides of the block; *c c* is the journal. In some cases the brasses are made octagonal in form, as in fig. 104, where *b b* are the upper and lower brasses, and *d* the journal. It is evident that as the sides of the brass will embrace those of the block, as *f*, fig. 102, the brasses will be prevented from turning round. Another method of keeping the brasses in their place is shown in fig. 105, where a projecting snug or rib *b* is made beneath the brass *a a;* this fits into a slot, *d*, made in the cover or sole of the pedestal, part of which is shown in the figure. This plan is generally used where the brass is made circular; this allows the space in the block to be accurately bored out to the size required.

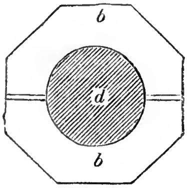


fig 104.

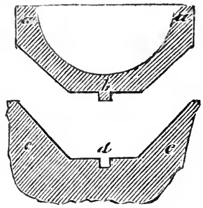


fig. 105.

The method by which the brasses of connecting-rods, &c. are made to embrace the journals may be described here. Suppose *m*, fig. 106, to be the journal or crank-pin, *b b* the lower half of the brass, *d d* the upper half; a strap, *a a*, of which the usual form is as in fig. 85, is made with one end circular, which embraces the lower brass, *b b;* a space, *a a*, fig. 107, is cut out on each side; the butt, *e*, of the connecting-rod, which is more fully shown in fig. 85, is of breadth sufficient to pass easily down between the sides of the strap; a space is also cut through this, as at *m*, fig. 108, at such a distance from its extremity, that when placed within the strap at its proper place, the space through it and those in the strap coincide. The end of the brass being kept in its place by the projecting

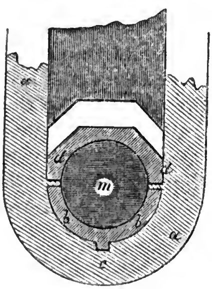


fig. 106.


fig. 107.

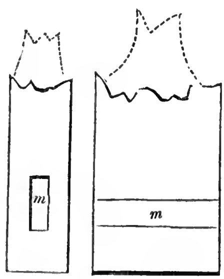


fig. 108.

rib, *c*, fig. 106, it is very frequently made with projecting flanges, as in fig. 103; in this case the breadth of the strap, *a a*, is so that it can pass easily between the flanges. The manner in which these parts are kept together is as follows: the brasses are made to embrace the journal; the strap is then passed over these, so that the inner curve presses against the outer curve of the lowest brass; the butt of the connecting-rod is then passed between the sides of the strap; keys are then passed through the space, or slot, and driven home. When the brasses begin to wear, and the journal works loose between them, by tightening the keys the brasses are brought close together; to admit of this, they are originally fitted so as to leave a space between them, as in the sketch. In fig. 85, to which we again refer, we have shown a method of fitting the brasses, connecting-rod, and strap of a locomotive engine: *h* is the journal, *b′ b* the brasses; a strap, *gggg*, is passed round these, embracing the lowest, *b′*; the connecting-rod, *a′a*, is secured to the strap by the cottar *dd* and gib *ee*; when the brasses become loose, the wedge or key, *cc*, is driven in, and presses upon the upper brass *b*. When the key and gib, *dd*, *ee*, are in their proper places, they are secured by small force-screws. In fig. 109 we show another form of connecting-rod butt, strap, and brasses: *m* the end of the journal, *ee′* the brasses, *ff* the strap, *b* the butt of the connecting-rod *a*; by driving home the key, *dd*, the gib, *cc*, is tightened; this lowers the strap, and tightens up the end on the brass *e′*. In fig. 71[d] another method is given: this is sometimes used in locomotives, but chiefly in large marine and land engines. *ik* is the crank, *f* the crank-pin, *g* the connecting-rod, *hh* the strap; the key *d* is furnished at its extremity with a screw, *e*, which passes through the end of the gib *c*; while the nut *a* is tightened, *b* is loosened; the pressure thus

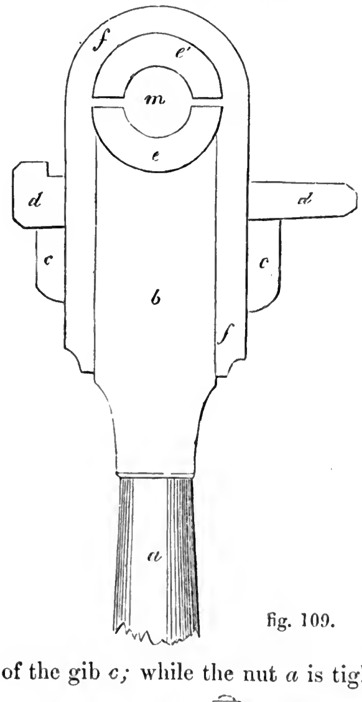


fig. 109.

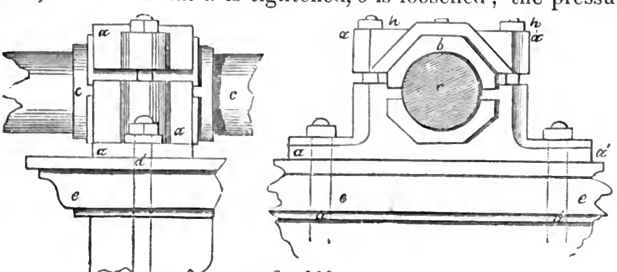


fig. 110.

transmitted to the gib, *c*, tightens up the strap in the brasses embracing the journal, *f*. In fig. 110 we give a front and side view of a plummer-block, showing the connexion of all its parts: *e e* is the standard or frame, to which the sole *a' a'* is bolted by the bolts and nuts *d d*; the cover, *a a*, is bolted to the sole by the bolts *h h*; *b b* the brasses or pillows. As these wear, they are brought in closer contact with the journal by tightening the bolts *h h*; *c* the shaft. Another form, showing a method adopted of making the bearing in a steam-boat engine, is given in fig. 111: *a a* is part of the side-framing, *b* the shaft, *c* the cover, *d d* the bolts for securing this.

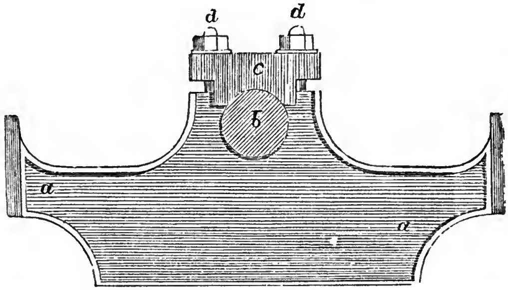


fig. 111.

The bearings for vertical shafts are formed by having the brass generally hollowed out, somewhat like a cup, placed in a footstep, *b*, fig. 112, which is secured to a footbridge of cast-iron, *e e*, adjusted in the plate placed on the block of stone *a a*. The end of the shaft, *d*, is formed so as to work easily in the cup-shaped brass.

In order to adjust plummer-blocks upon the stands to which they are fixed, it is usual to adopt a foundation-plate, on which two projecting snugs are cast; the sole of the block goes into the space between them, and wedges or keys are driven up at the ends; thus any lateral adjustment can be made by driving the keys correspondingly. When the height of the block is to be altered, pieces of wood or thick mill-board are placed between the sole and foundation-plate.

When shafts are to be carried a short distance beneath a ceiling, a different form of bearing is used; one generally adopted is shown in fig. 112ᵃ.

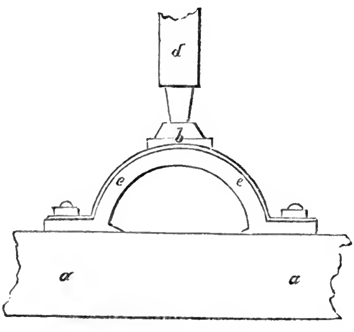


fig. 112.

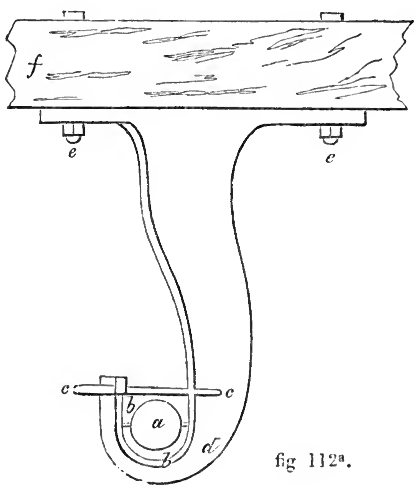


fig 112ᵃ.

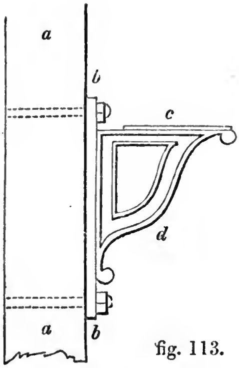


fig. 113.

It is denominated a "gallows," or pendent bracket: *f* is the beam or joist to which the gallows is suspended; the plate of the gallows, *d*, is fixed to the beam by the bolts *ee*; *a* is the revolving shaft, *bb* the brasses, *cc* the key by which the brasses are brought in close contact with the journal as the former wear away. Where shafts are carried along the front of a wall, the bearings are what are termed brackets, as in fig. 113, where *aa* is the wall, *d* the bracket projecting from it, sufficiently to allow wheels, pulleys, &c. to revolve freely, without coming in contact therewith. A wall-plate, as *b*, is used to serve as a foundation on which to adjust the bracket; it is bolted firmly to the wall, and the bracket adjusted thereto by bolts and keys.

In cases where only one end of a shaft is supported by a separate frame, as in some kinds of simple high-pressure steam-engines, the other extremity works in a bearing placed in an aperture made in the wall opposite to which the framing is placed; the aperture in the wall is provided with a cast-iron box, of depth equal to the breadth of the shelve, which serves as a foundation-plate on which to adjust the block. Thus, in fig. 114, *aa* is the wall, *bb* the wall-box, *c* the plummet-block, *d* the shaft, the other end of which revolves in a bearing placed on the top of the framing of the steam-engine, or otherwise placed as the case may be. In some cases where the shaft has to be continued to the other side of the wall, for communicating motion to machines there placed, the wall-box is simply a frame or box contained within four sides, and provided with a shelve as above stated; in place of a separate shelve, the bottom side of the box is made to serve as the plate on which to adjust the bearing, as in fig. 114.

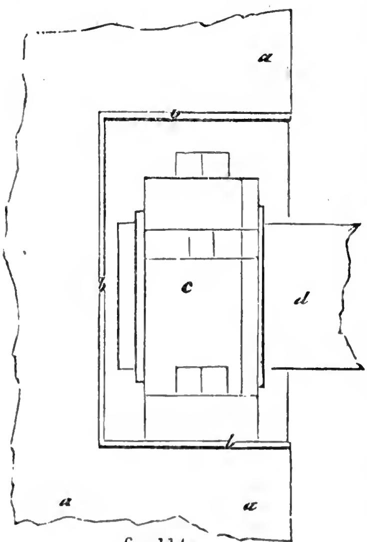


fig. 114.

Where shafts are required of too great a length to admit of their being cast or made in one piece, contrivances are resorted to by which two or more lengths are joined together. These are known as "couplings."

Couplings are of two kinds or classes; those having two bearings, and those having one: by this time the pupil will understand the term bearing, meaning thereby the plummer-blocks or pedestals on which the journals of the shafts revolve. Theoretically, the construction of couplings is a matter of extreme simplicity; on the supposition that the shafts remain always as fitted up at first, it is an easy matter to adopt means by which shafts can be coupled together effectually. But in practice the difficulty is increased from the wearing of the journals, brasses, sinking and altering of foundations, and from other causes; many adverse circumstances are called into play, which make it a matter of practical difficulty to find a form of coupling which will answer to the expectations of theory. Hence the number of variations of couplings: to notice a few of these will suffice for our purpose.

The "square coupling" is shown in figs. 115 and 116, the latter being a transverse section through the centre of the coupling; the ends *a' a'* of the shafts *a a* are made square, and put together end to end; they are then embraced by a "coupling-box," *b b*, placed diagonally on the shaft; the inside of the box is fitted to the exact size of the squares of the shafts; it is also provided with flanges, through which bolts are passed, and secured by nuts, *c c*. In some instances the coupling-box is made in one piece, and

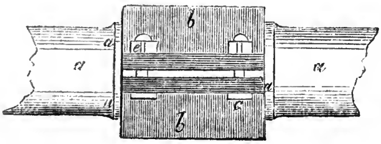


fig. 115.

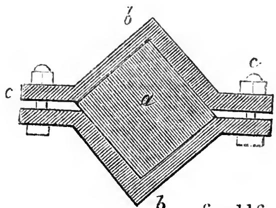


fig. 116.

the square parts of the shafts are together rather longer than the length of the box; this enables the latter to be slid past the joint, and allows the two shafts to be disengaged without removing the box. This form of coupling, though apparently simple and effective, is liable very speedily to get out of repair, inasmuch as the bearings are apt to wear unequally; the result of this is, that in such revolution one or other of the shafts will be lifted off its bearings; this produces unsteady motion, and hence farther twisting and wearing of the coupling. This form is therefore rarely used in heavy mill-work, being chiefly confined to small machinery. The "round coupling" is shown in fig. 117, part of which is shown in section, the upper figure being a cross section. In this form the ends of the shafts are made cylindrical, and faced so as to lie close up to one another; a coupling-box is passed over the ends, and secured by pins passing through the box and shafts at right angles to one another. In this form the shafts and box can be more accurately fitted; but as the strain is obviously concentrated on the pins and holes, the former in a short time become loose, and have to be replaced by new ones; these, of course, not being fitted with the same accuracy to the holes as in the first instance.

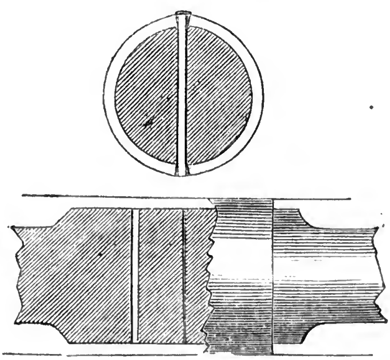
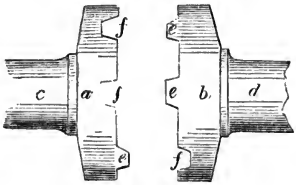


fig. 117.

In some cases, shafts having two bearings—as those last described—are coupled together without the use of coupling-boxes; in this case the couplings are denominated "clutches," or "glands." "Glands," says an eminent authority, "are an excellent mode of coupling for double bearings, and have the advantage of throwing the stress farther from the centre of motion than in the square coupling as commonly executed." In fig. 118, *d* and *c* are parts of the shafts to be coupled, having the bearings at *c, d;* at the ends of the shafts, round plates, *a, b*, are cast; in the face of these, projections and recesses are cast; the projections go into the recesses, thus locking the two plates fast. Another form is given in fig. 119: the shafts, *d' a*, having their bearings at *d e*, have crosses, *c c*, *h h*, attached to the ends; one of these, as *h h*, has its extremities curved; these, as may be seen, catch hold of the extremities of *c c;* thus, one shaft set in motion actuates the other.



g. 118.

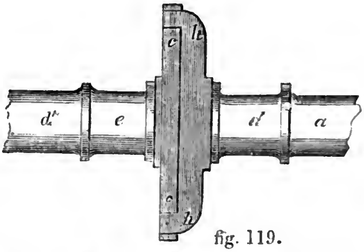


fig. 119.

Couplings having two bearings being attended with much friction, they have been to a certain extent abandoned, and those having only one bearing used. The square and round couplings already described, by some small modifications can be adapted to couplings having only one bearing. In fig. 120 a modification of the square coupling is shown: the end *b* of the shaft *a* is made square, and provided with a projection *d*, which fits into a recess made in the end of the shaft *c;* a coupling-box passes over both squares, and is secured either by two pins passing through it and the shafts at right angles to each other, or by keys. The journal or bearing of one shaft is near the square, while the other is farthest from it. In fig. 121, the round coupling for one bearing is figured; it is called the "half-lap:" the shafts *a, c* are cylindrical at the ends, and are made with semi-cylindrical extremities, *b, d*, so that when laid together they form a perfect circle; the round coupling-box *ee* embraces both extremities, and is prevented from moving by the key *f*. When carefully constructed, this coupling is not only elegant in

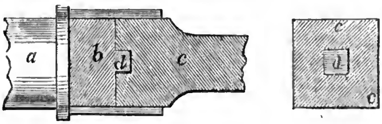


fig. 120.

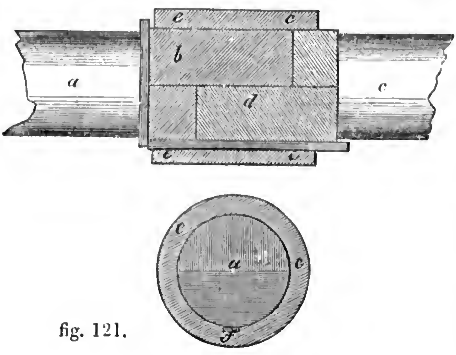


fig. 121.

form, but comparatively durable; it is now almost universally adopted in the better class of modern mill-machinery.

Where shafts require to be coupled, which are inclined to each other in their line of direction, the contrivance known as the "universal joint," invented by Dr. Hooke, is sometimes employed. A modification of this joint, as applicable to heavy mill-work, is shown in fig. 122: strong plates, *cb*, are cast on the ends of the shafts *a a*; these have bearings, *dd*; *e* for supporting the journal or gudgeon. In cases where this joint is used, the angle of inclination of the shafts should never exceed 15°; when above this, a double joint should be adopted, or a pair of bevil wheels acting as in fig. 123.

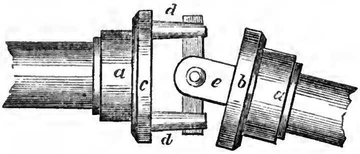


fig. 122.

When the engagement or disengagement of certain parts of machinery is desiderated, other forms of couplings are adopted: these we shall explain and illustrate in another part of this treatise.

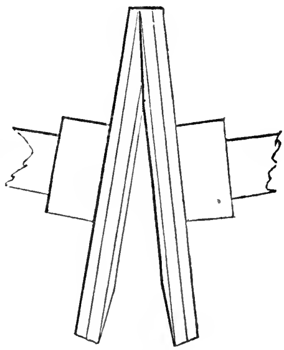


fig. 123.

As oil and other lubricating substances are employed in reducing the friction between the journals of shafts, and the brasses or pillows of the bearings on which they revolve, various plans are adopted for economically applying the lubricating substance or fluid to the parts required. The simplest method adopted is by boring a hole in the upper part of the cover of a block, or the shafts of a connecting-rod or side lever, *bb*, fig. 124, as at *c*. This is generally made tapered, and is what is termed counter-sunk at its upper part, *a*: this forms a kind of cup in which to

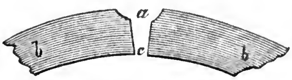


fig. 124.

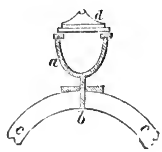


fig. 125.

retain the oil. An ornamental cup is sometimes placed above the aperture, as in fig. 125, where *cc* is part of the strap of the rod, *b* the aperture, *a* the vase or cup, *d* its cover. In place of having the oil to run directly to the part to be lubricated, thus creating a considerable waste, an ingenious and philosophical contrivance is adopted: in this, advantage is taken of the property of capillary attraction possessed by some bodies. An ornamental cup or vase, *aa*, fig. 126, is fastened at its base, *b*, to the part to be lubri-

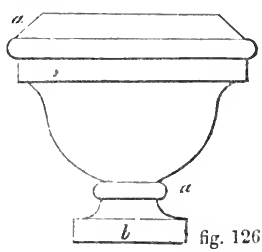


fig. 126.

cated; a tube, *c c*, fig. 127, communicates with the part to be lubricated, and reaches nearly to the top of the vase; a roll of worsted is passed

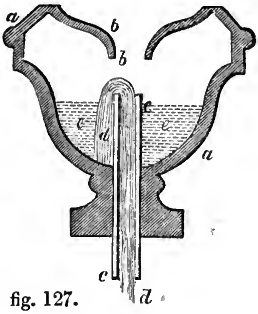


fig. 127.

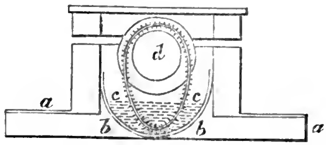


fig. 128.

through this tube; one end is nearly in contact with the rubbing surface on the journal of a shaft, and the other reaches nearly to the bottom of the vase. The oil is conveyed throughout the whole length of the worsted. In mills, the oil is supplied to the bearings of shafts from a can with a long spout; to save as much as possible of the oil dripping from the shafts, a receptacle is placed below. To obviate this inconvenience and loss, Messrs. Vaughan and Hossack of Manchester have devised a very ingenious lubricator: we show it in fig. 128. Suppose *a a* to be the plummer-block, in which the shaft *d* revolves; a circular receptacle, *b b*, is placed beneath this; a metallic endless chain, *c c*, passes round the axle, and dips into the oil placed in *b b*. The shaft revolving, keeps the chain continually dipping different parts into the oil: a supply is thus continually taken up to the shaft.

CHAPTER VI.

CONTRIVANCES FOR EFFECTING VARIOUS MOVEMENTS IN MACHINERY.

In this portion of our work we intend explaining and illustrating various combinations of those parts of machinery which we have already noticed, when these are adapted with reference to some particular motion, required in carrying out the purposes for which the machine may be devised. In every machine at all complicated the motions are numerous: in examining the movements in detail, some parts are seen having invariably a uniform motion; in some, wheels are revolving now fast, now slow; one part having circular motion is seen imparting that which is reciprocating, while, on the converse, reciprocating is changed into a circular movement; again, wheels revolving with amazing rapidity are seen to be connected with others turning at a slower speed. In some machines, as in those of the cotton-manufacture, the movements are so complicated, and apparently confused, that to the eye of the uninitiated there is presented nothing but an interminable range of whirling wheels, shafts, and spindles, the due understanding of which would seem to be a matter of almost hopeless difficulty. But to the mechanic who has studied mechanism in its various aspects, and who has been taught to analyse its movements, the difficulty is only apparent; and in process of time, by an analysis, brief but searching, the whole movements are unravelled, and from the confused and whirling mass order and regularity are deduced; and the talent of the master-mind who originated the whole machine, so capable of effecting the purpose for which it was designed, is thrown out in bold relief. It is our purpose in the present chapter to introduce the reader to this method of mechanical analysis, by which he will be enabled not only to understand the working details of perfect machines, but also to arrange and modify the simple elements of mechanism, considered individually, into the collective form which may be designed for special purposes.

In fig. 129 is shown a method of CHANGING THE DIRECTION OF MOTION. Thus, the motion is first given to the wheel *a a*, as that of a fly-wheel of a steam-engine; it is first transmitted to *b* by the belt *c*, the pulley *e* is moved by the belt *d d* from *b*, and *g* from *e*: the pulley or shaft *g* may be driven by a diagonal belt, as seen by the dotted lines. In fig. 32, motion is communicated from the wheel *a* to *b* by the belt; in this case the movement of both wheels is in the SAME DIRECTION. In some cases it is desir-

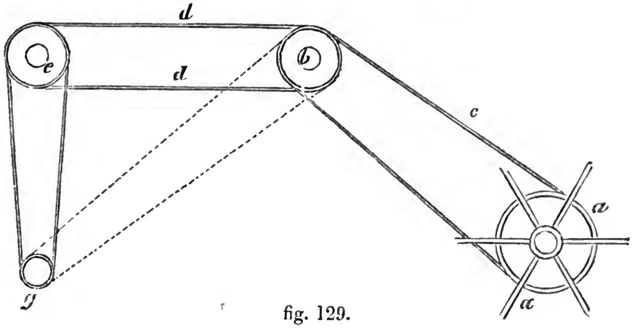


fig. 129.

able to give the driven wheel *b* a motion in the REVERSE DIRECTION of the driving wheel *a*. This is effected by crossing the belt, as in fig. 130.

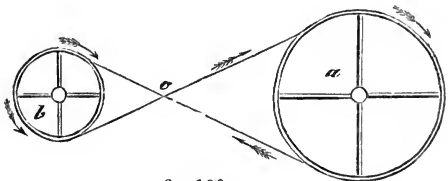


fig. 130.

Where a wheel drives a pinion, they revolve in contrary directions; by the interposition of a third wheel, as *b*, fig. 131, the driven wheel *c* will revolve in the same direction as *a*, the driving wheel. In the contrivance known as the annular wheel, fig. 132, the driving wheel *a* has its motion in the same direction as the driven wheel *b b*.

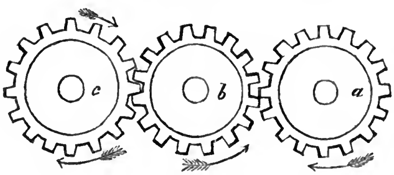


fig. 131.

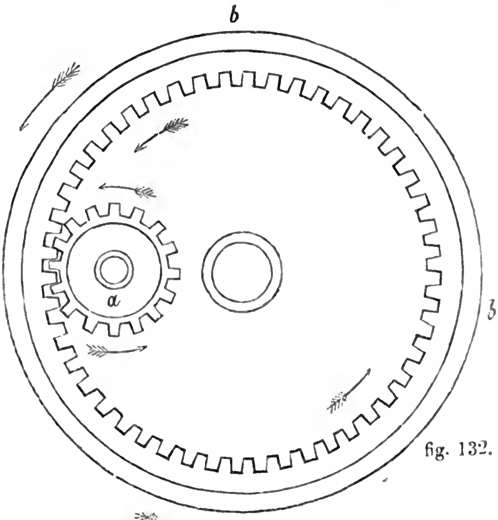


fig. 132.

The RELATIVE VELOCITY of wheels, shafts, &c. may be altered and modified by simple means. Thus, suppose in fig. 31 (p. 19), the large wheel is three times the diameter of the small, then it is evident that the former will revolve only once, while the latter will revolve three times. Again, in fig. 32 the small pulley revolves faster than the large one just in proportion as it is smaller. Fluted rollers revolving in contact, as *ab*, fig. 133, move at the same speed if of the same size; but if *b* was only half the size of *a*, it would move twice for *a* once. In cotton-machinery rollers are much used; fig. 133 will explain one of the many modifications. Suppose *a* and *b* to be revolving in contact, and making six revolutions per minute; and *cd* half the size of *ab*, consequently revolving twelve times in a minute; let *efe* be fibres of cotton passing through between the rollers *a b*, and taken up by *c d;* suppose *a b* deliver eighteen inches per minute; as *c d* revolve twice as fast, they are manifestly capable of pulling through thirty-six inches of fibre every minute; but *a b* only deliver eighteen inches in that time; consequently, the fibres must either be torn asunder or elongated at *f*, or somewhere between the two pair of rollers. This is just exactly as designed. The relative velocities of the rollers are so adjusted, that a certain degree of draught is given to the cotton fibres. Simple as this contrivance appears, it is that which has enabled cotton-machinery to be so marvellously quick in its operation; and without which, it may safely be said, the manufacture must have failed to reach the height of its present comparative perfection. In toothed wheels, the relative velocity of each is modified or changed by merely altering the number of teeth and diameter of wheel. Thus, in fig. 134, the velocity of the pinion *a* is nearly three times greater than that of *b*; by making *a* the driving wheel, *b* revolves only once for *a* thrice. This is the method employed in cranes for lifting heavy goods: *a* is turned by means of a handle, or winch, attached to its axis; the object being to give the wheel *b*, on the axis of which the barrel for winding the chain or rope is fixed, a slow motion.

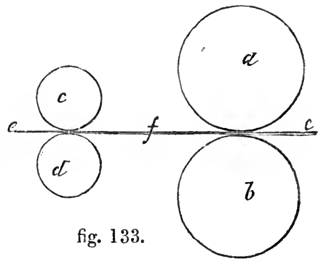


fig. 133.

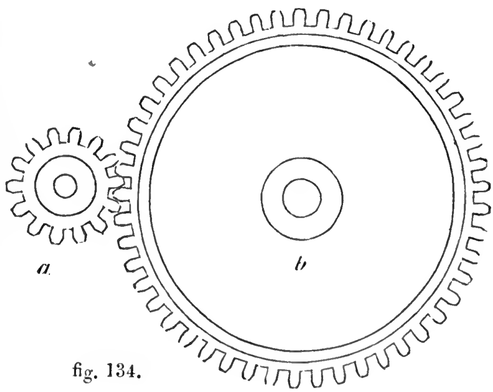


fig. 134.

Where a VARYING velocity is required to be given to shafts, &c., the contrivance known as the "speed-pulley" is used. Suppose *a a*, fig. 135, to be the driving shaft, communicating motion to *a′ a′* by means of pulleys and belts; drums of different diameters, as *b′*, *c′*, *d′*, are fixed on *a a*, as also on *a′ a′*, as at *b c d;* the small one, *d*, is placed opposite the large one, *d'*; by shifting the belts it is obvious that the ratio of the speed of the two shafts may be altered as desired: this form is used principally in

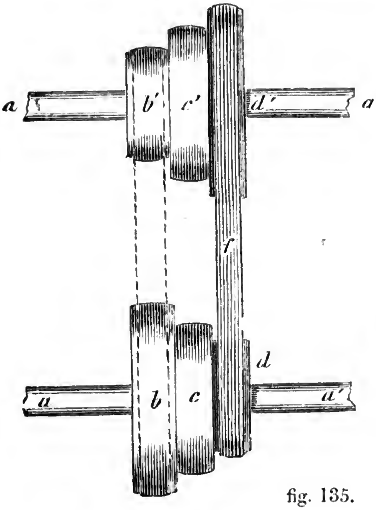


fig. 135.

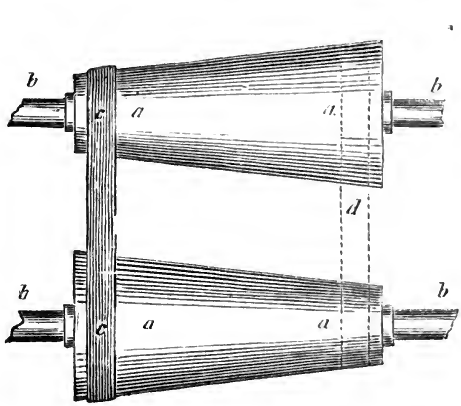


fig. 136.

lathes. Another form is used, represented in fig. 136, being two conical drums placed conversely; *a a* being the drum on the driving shaft *b b*, *a' a'* being that on the driven *b' b'*; by moving the belt *c* the relative velocities of the two shafts may be changed: this modification is used in the cotton-machine known as the "throstle."

The fusee of a watch is a modification of this contrivance. As is well known, the moving power is supplied by a spring wound up within a cylindrical box or barrel, *cc*, fig. 137, revolving on an axis in the plate *bb*. On first starting after being wound up, the spring exerting its greatest force, it would have a tendency to make the watch go very fast, this gradually decreasing as it got unwound. To make its effect on the mechanism equal throughout, a chain, *d*, is employed to give motion to a conical drum, *a*, on the surface of which a spiral path or groove is cut: the two are so arranged, that on first starting the chain acts on the small end of the drum, thus exerting a slight leverage; but as the spring uncoils and winds up the chain on its surface, it acts on the larger end of the drum, thus exerting greater leverage. This mechanism thus introduces an equal movement of the fusee *a*, compensating for the unequal one of the barrel containing the spring (see p. 36). The velocity of the shaft *d* is made to vary as required: a wheel, *a a*, fig. 138, supported on the vertical shaft *b*, gives motion to the wheel *c*, the natural roughness of the surfaces creating sufficient hold between them;

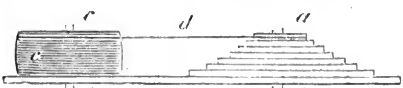


fig. 137.

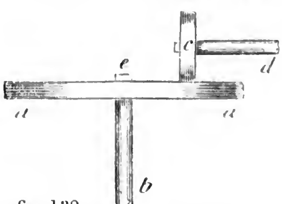


fig. 138.

the shaft *d* is capable of being moved laterally by means of a screw ; the nearer *c* is placed to the centre *e* of the wheel *a a*, the slower is its motion, and *vice versa*.

TWO DIFFERENT MOTIONS can be given by the revolution of one wheel or shaft. Thus, in fig. 139, let *a a* be a cylinder revolving in an inclined position on the bearing *c;* it is desired to make this revolve at a slow speed in one direction, while the internal shaft *b b* is to revolve at a high speed in the contrary direction: a bevil wheel, *e e*, is made to revolve by the handle *m ;* it works into a slightly bevilled wheel, *d*, placed at the end of the shaft *b b ;* the other end of *e* works into the face-wheel *f;* the two motions are thus effected : as thus arranged, the mechanism is that used in a patent "rice-cleaning machine."

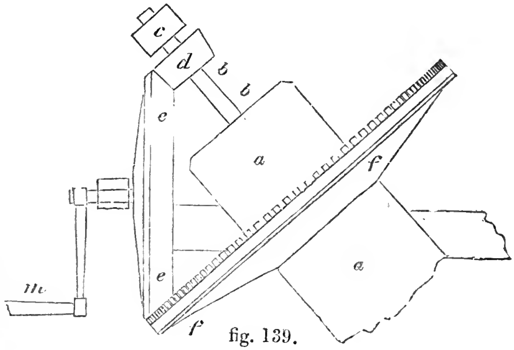


fig. 139.

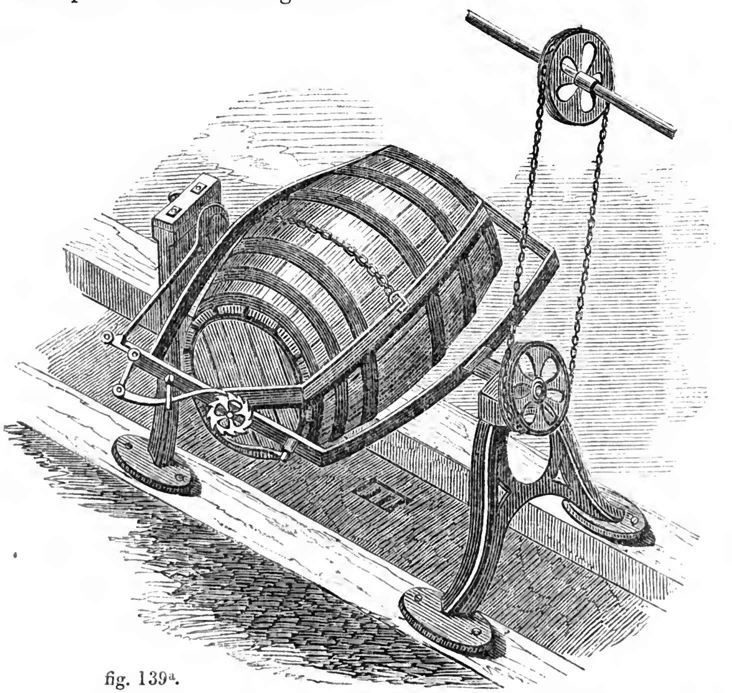


fig. 139ª.

In the patent "cask-cleaning machine," fig. 139ª, two motions are obtained. Each cask is placed in an iron frame or cradle, which revolves within another cradle; while the outer frame makes one revolution in the direction of its length, the inner cradle revolves at right angles to the outer; the revolutions of the inner cradle are regulated by an eccentric placed on the shaft, actuating a lever and ratchet fixed on its axis; the inner frame makes one revolution for every twenty of the outer. A chain of a peculiar construction is attached to a plug placed in the bung-hole; and by the double action above described, this traverses the whole of the interior surface of the cask.

A VARYING motion is produced in a patent flax-machine. To effect a certain purpose, the two rollers *a a*, fig. 140, are required to advance and recede from each other. This desideratum is thus obtained. The bearings *b b*, on which the rollers revolve, are made so as to slide easily on slotted bars, *c c*; a cross-head, *e*, which has a vertical reciprocating, or up-and-down motion given to it by the rod *f*, has two links, *g g*, fastened at each end; these links are passed round the ends *d d* of the shafts of the rollers *a a;* the links *g* are made to incline as in the sketch. Suppose *f* to be moved upwards, the cross-head *e* and links *g g* partake of the motion; as the space between the links thus increases, the bearings *b b* slide outwards on *c c*. The fullest extent they can be separated is clearly equal to the extent between the centres of the links at their widest part; on the rod *f* descending, the space between the centres of links decreases, and the bearings *b b* move inwards and approach each other.

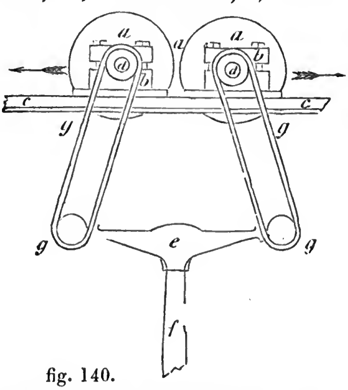


fig. 140.

In the "warp-mill" used in cotton-factories, the yarn is laid regularly on the mill by a varying motion thus: *a a a a*, fig. 140ª, is the frame on which the yarn is to be regularly laid; it is made to revolve by a strap passing round the pulleys *b* and *c*, the latter being worked by the crank-handle *c′*; the full bobbins containing the yarn are made to revolve hori-

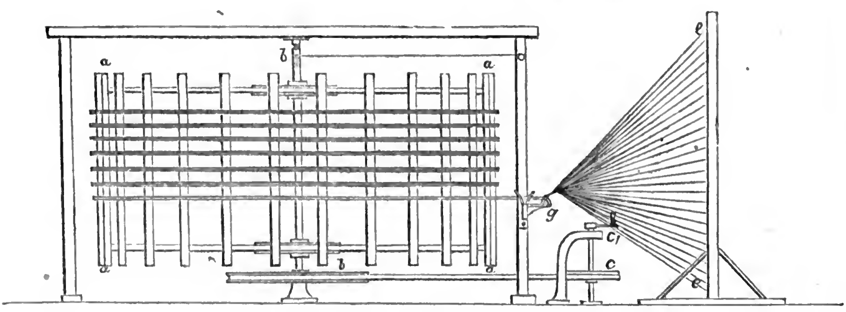


fig. 140ª.

zontally on wires or rods in the frame *e e;* the threads pass from each through eye-holes in *g*; this moves up and down on the vertical part to which it is attached; a cord passing round the frame-spindle *b*, and over pulleys to *g*, by the revolution of the spindle *b* gives the required up-and-down motion of *g*. The yarn from the rollers, *hh*, of a cotton-slubbing frame, fig. 140ᵇ, is laid evenly on the bobbins *bb*, which revolve on the

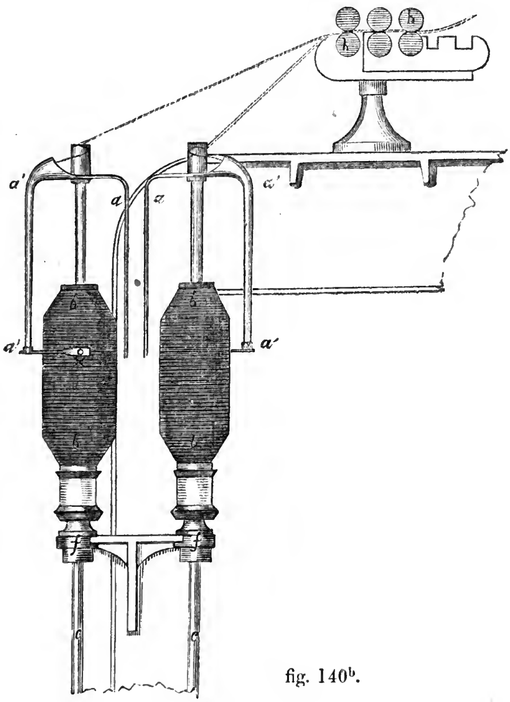


fig. 140ᵇ.

spindles *cc*; the yarn is delivered to the bobbins at *x*, passing from the rollers through the hollow leg of the flyer *a′a′*; the bobbins rest loosely on the copping-rail *ff*; this rail is made to rise and fall by means of racks and a pinion, thus making the bobbins pass up and down on the spindles *cc*, and opposite the "finger" *x*; thus each part of the bobbin is presented to the delivery-finger at *x*.

An INTERMITTENT motion is frequently desiderated in machines; in fig. 141 we show a simple method of effecting this: a ratchet, *a a*, is moved one tooth forward each time the wheel *b* revolves, the projecting tooth *c* catching one of those of the ratchet. It is obvious that by arranging the relative velocity and size of the wheel and ratchet, and the number of teeth, the ratchet *aa* may make a certain number of revolutions in any desired time. An intermittent motion required in the patent flax-heckling machine is

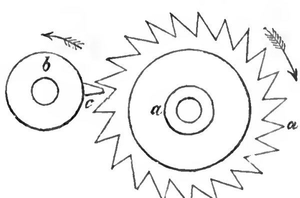


fig. 141.

produced as follows: a shaft attached to the ratchet-wheel *h h*, fig. 142, is required to revolve only a certain portion at stated intervals; a camb, *a*, gives motion to a lever, *b*, the centre of motion of which is at *c;* at the end *d*, a vertical rod, *e*, is connected at its upper end to the bell-crank lever *f g i*, the centre of which, *g*, is firmly secured to the ratchet-wheel *hh;* there is a catch placed at *i*, which takes hold of the projections of the wheel *h h;* as the lever *b* rises, the rod *e* causes *f* to rise; this makes the catch *i* slide over the surface of each tooth on the wheel *hh;* on the lever *b* falling, *f* is pulled downwards, and the catch at *i* taking hold of the projection, causes the wheel *hh* and its shaft to move a certain portion of its revolution. An intermittent motion is often used in looms for weaving cloth by power. As the cloth is woven, it is wound upon a roller called a "cloth-beam;" in order that the cloth be taken up by this beam just as fast as it is produced, and no faster, it is necessary to make it revolve at a certain speed: this is effected by mechanism somewhat resembling the above contrivance. A camb or wiper placed on the central shaft of the loom give an alternating motion to a lever; this acts by the intervention of another lever, furnished with a catch at its upper end, upon a faced ratchet-wheel, somewhat like the crown-wheel of a watch; the shaft of the ratchet-wheel has an endless screw at one end, working into a toothed wheel placed on the end of the cloth-beam. By this mechanism the cloth-beam is turned round at certain intervals, depending on the velocity of the shaft on which the camb is placed, which moves the levers; and as this central shaft is connected with the cloth-producing motions of the loom, it is evident that the motion of the cloth-beam will be in direct ratio to the speed at which the cloth is produced. In practice, however, a slight variation exists; to counteract which, various ingenious devices have been brought out. Another simple method of giving an intermittent motion may here be noticed. In a machine called the "flax-heckling machine" it is necessary that a contrivance called a "holder" should be moved along bars placed above the main cylinder at certain intervals. In fig. 143 let *a a* be the holder, and *a'* the suspended flax; *b b* the bars on which *a a* is supported; it is desired to move *a a* along *b b* at certain stated intervals: let *c c* be a light bar, parallel to *b b*, but capable of lateral movement in two directions, as shown by the arrows; from this bar let fingers, *d*, be suspended at intervals, and movable on joints, but provided with catches as *m*, which will prevent the fingers moving in any other direction but one; on moving *c c* towards the left, the finger will slide over the top of *a a*, as seen by the dotted lines at *e;* but on reaching a certain part it will drop perpendicularly at the end of *a a;* the motion of the bar *c c* is now changed, and moving towards the right, the finger *d* prevented from moving in the wrong direction by the catch *m;* the holder *a a* is thus necessarily moved along *b b*.

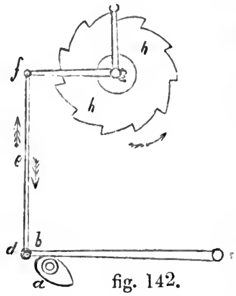


fig. 142.

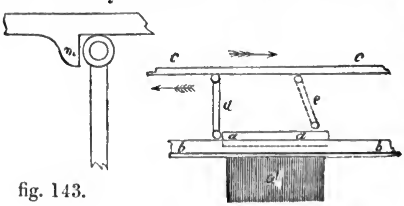


fig. 143.

By modifying the speed of the bar *cc*, and the length of its movement right and left, and the number and distance from each other of the fingers, the holders may be moved along at any desired ratio.

An ALTERNATING motion is obtained by the revolution of a crank, connected with a "doffer knife," *cc*, by the side rods *bb*, fig. 143[a] (the crank is not shown), of the "cotton-carding engine," the doffing cylinder of which is shown at *aa*: the cotton filaments caught on the card-teeth on the surface of *aa* are stripped off by the doffer knife *cc* (which has a quick up-and-down motion), in the shape of a beautiful light fleece, *dd*; this is contracted and passed through a trumpet-mouthed orifice *e*, and passing through rollers *f*, is placed in a tin can below *g*. The alternating motion of the threads in a loom is obtained by pressing alternately on heddles, *GG*, fig. 143[b]. In weaving, one-half of the horizontally stretched threads or yarns, *CC*, are required to be lifted up; each alternate thread is passed through between the loops of the threads of the healds *DD*, these being suspended from the top of the frame, and attached at the foot to the heddles; on moving each of these alternately, thereby depressing its heddles, it is evident that the threads passing through the loops will be moved out of the line of the others.

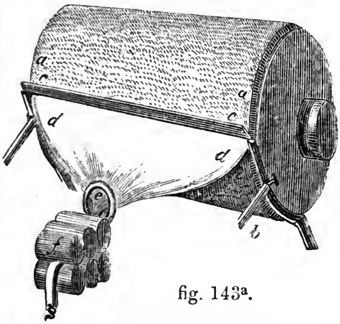


fig. 143[a].

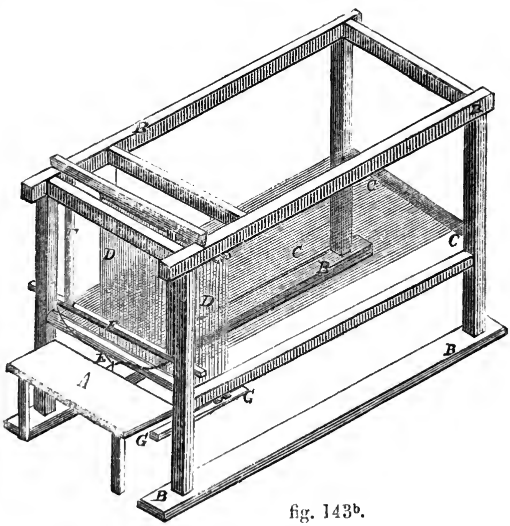


fig. 143[b].

A CIRCULAR MOTION IS CHANGED INTO A RECIPROCATING by what is called the rack and pinion. Thus in fig. 144, *aa* is the horizontal rack, the upper part of which is provided with teeth; the teeth of the pinion *b* work into these, and cause the bar to be moved horizontally; by turning the engraving, so as to make *aa* vertical, the method of making the circular motion of *b* impart a vertical one to *aa* is at once obvious. By giving the motion in the first place to the rack, it is clear that the wheel *b* will have a circular motion.

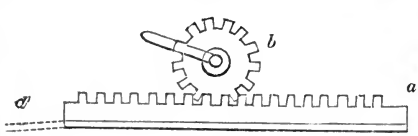


fig. 144.

An INTERMITTENT CIRCULAR MOTION is made to impart an INTERMITTENT HORIZONTAL one as follows: Suppose *a a*, figs. 145 and 146, to be part of the holder-frame of a flax-heckling machine; on each side of this, vertical racks *f f* are placed; small pinions, *c c*, revolving in bearings *b b*, work into the teeth of these; the shaft of the pinions carries a toothed wheel *d* in its centre; this works into the teeth of a horizontal rack, this forming part of the finger-bar which moves the holders. On the table *a a* rising, the pinions *c c* are made to revolve by coming in contact with the teeth of the racks *f f*; the wheel *d* partakes of the motion of *c c*, and in its turn moves the rack *e*, and the finger-bar to which it is attached. In this piece of mechanism, the changing of a vertical motion into a circular one is seen by the racks *f f* moving the pinions *c c*, and the changing of a circular into a horizontal by the wheel *d* moving the rack *e*.

To change a reciprocating circular motion into a continuous circular motion.—In fig. 63 the beam *a a*, vibrating on the centre *b*, affords an exemplification of reciprocating circular motion, the end describing part

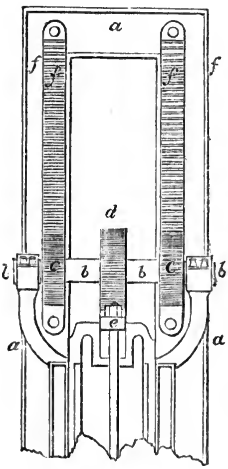


fig. 145.

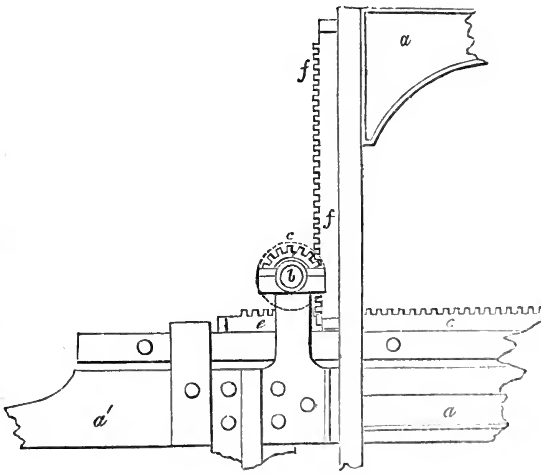


fig. 146.

of a circle. In fig. 70 we have illustrated and described a very common method of effecting the above change of motion: *d* is the connecting-rod attached to the end of the reciprocating beam; *b* is the crank, fastened on the end of a shaft at *e;* the connecting-rod is attached by a movable pin at *c*. In fig. 72 we have given a familiar illustration of this contrivance in the foot-board, crank, and wheel of the knife-grinder's machine: *a a* corresponds to half of the reciprocating beam; *b* is the rod connecting it with the crank. The motion used by Watt to change the motion of the beam of his steam-engines to a circular one is another contrivance which may be here noticed: it is known as the "sun-and-planet motion." The toothed wheel *c*, fig. 147, is fixed to the end of the fly-wheel shaft, which is to have a continuous circular motion. Another toothed wheel *b*, of equal diameter with *c*, is attached at its centre to the end of the connecting-rod *a*, and is capable of revolving on its centre. The two wheels are kept in gear by means of a slotted link. An up-and-down stroke of the connecting-rod, or one complete oscillation of the beam, will have made one revolution round the centre of the wheel *c c;* but both wheels being

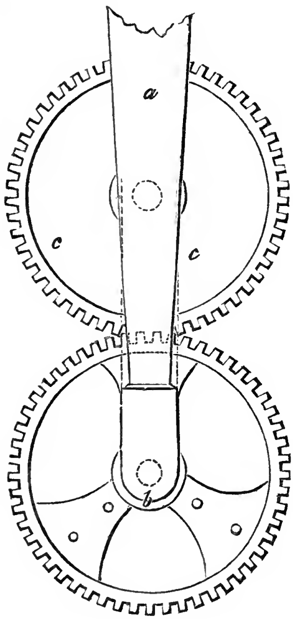


fig. 147.

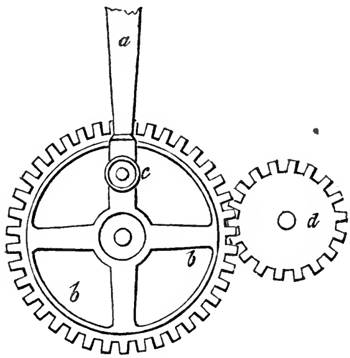


fig. 148.

fixed to their centres, the wheel *b* will revolve round *c c*, each tooth coming in contact with those of *c c*. If the two wheels are of equal sizes, the wheel *c c* will make two revolutions for each time the wheel *b* travels round its circumference. Another method of effecting the change of motion under consideration is illustrated in fig. 148: let *d* be a toothed wheel fixed on the end of the revolving shaft, and *b* one twice the size gearing into it; let the end of the connecting-rod *a* be attached by a movable joint at *c* to one of the arms of *b;* then the reciprocating circular motion of the beam to the end of which the rod *a* is attached is changed into a continuous circular one at *c*. In fig. 148ᵃ we give a method of changing a vibrating motion of a beam *g g* into a rotary one of the fly-wheel *n n*. Two sets of teeth, *l* and *m*, are formed on the segment, which take into two pinions placed loosely on the fly-wheel shaft, the teeth being in different planes for that object. The pinions have spring-palls attached, which take into the teeth of ratchet-wheels fixed to the shaft. The teeth of these ratchets are set in opposite directions; so that while one pinion is transmitting the motion of *g g* to the main shaft, the other pinion is revolving on the shaft in the reverse direction, and its pall slipping backwards over the teeth of its appropriate ratchet-wheel.

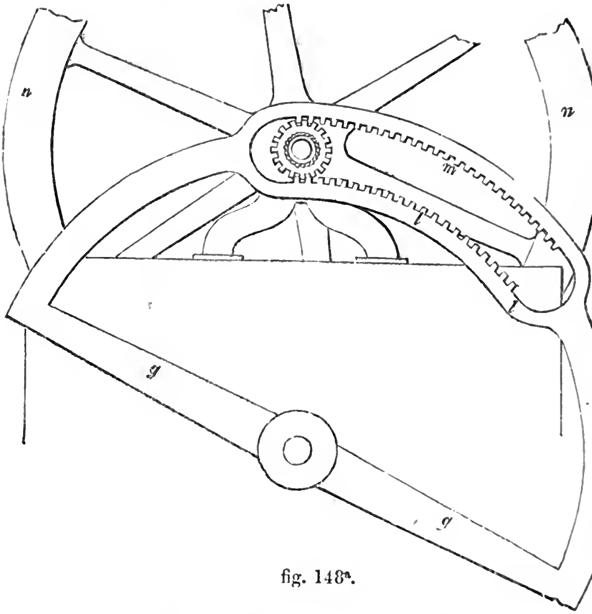


fig. 148a.

To change a reciprocating rectilinear motion into a circular one.—Let *a a*, fig. 149, be the piston-rod of a steam-engine, moving horizontally in

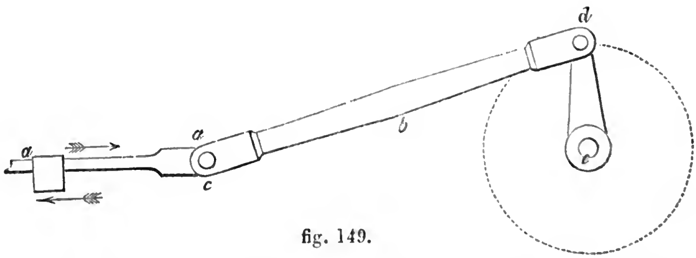


fig. 149.

guides, backwards and forwards, as shown by the arrows; a connecting-rod *b*, moving on the centre *c*, and attached to the crank-pin at *d*, will give the shaft *e*, to which the crank is fixed, a continuous circular motion. This is the movement used in steam-engines where the cylinder is laid *horizontally*. In small steam-engines, where the cylinder is vertical, and the crank above the cylinder, the piston-rod moves vertically up and down in a guide attached to the framing of the engine. Thus, in fig. 150, *c c c* is part of the framing of the engine, or standard, on the top of which, in a suitable bearing, the crank-shaft revolves; *a a* is the piston-rod, which moves up and down sliding in the guide *b b*, which is attached to the standard by bolts *d d;* the connecting-rod is attached to the end of the piston-rod, and at the other to the crank-pin. This modification is that used in the form of high-pressure engine known as the "crank overhead."

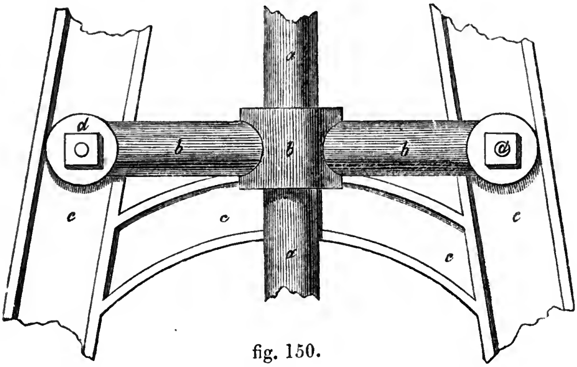


fig. 150.

Another modification is given in fig. 151. The piston-rod *c* is provided with a cross-head *d d,* the ends of which are provided with circular parts

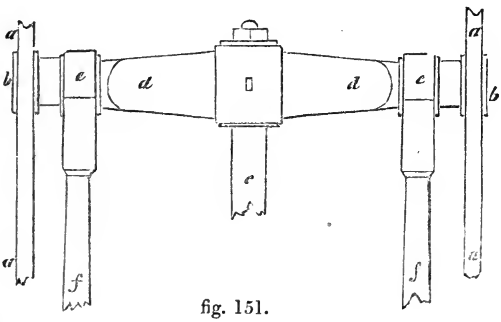


fig. 151.

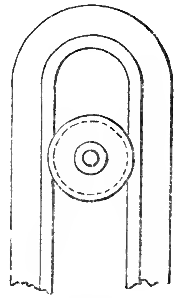


fig. 152.

sliding within a slot in the side framing *a a,* a side view of which is shown in fig. 152. The connecting-rods *e f, e f,* are attached by straps and brasses to journals made in the cross-head *d d,* the other ends to two cranks placed beneath the cylinder, which stands on a frame.

The method employed by Dr. Cartwright for changing the up-and-down motion of the piston-rod of his steam-engine into a continuous circular one, is shown in fig. 153. The cross-head *d* of the piston-rod *a* has two connecting-rods *m m,* jointed at *c c,* and attached to two cranks *c′ c′* fixed to the axes of two toothed wheels. While the piston *a* makes an up-and-down stroke, the large wheels make a complete revolution: the rate of motion of the small pinion fixed in the main shaft depends upon the number of teeth in *n* compared with that in *o.*

To change a continuous circular motion into a reciprocating rectilineal one.—A simple method of doing this is shown in fig. 87, where *a,* continually revolving, brings the wipers *b b* in contact with the projection *c,* placed on the vertical beam *d.* This is the motion used in mills where stampers are employed. Again, suppose *c,* fig. 154, to be a stamp or punch, moving vertically in a fixed guide *d d;* by attaching a connecting-rod to the end *m,* and its other extremity to a pin *n,* placed in the face of the wheel *a,* at a

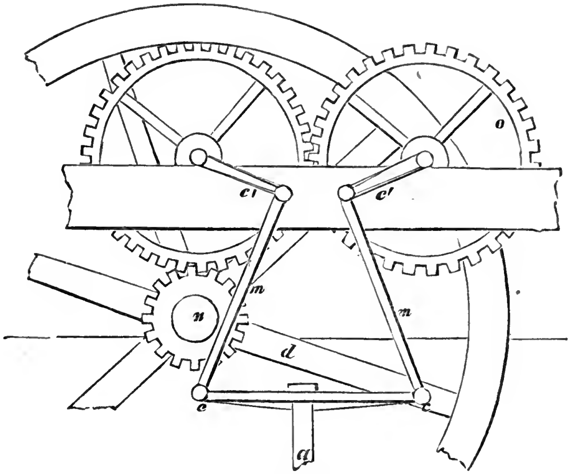


fig. 153.

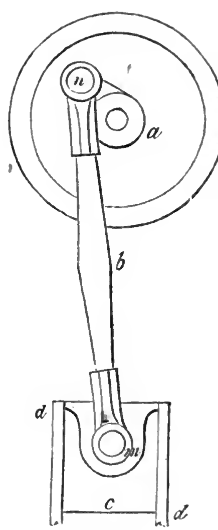


fig. 154.

certain distance from its centre, the stamp or punch *c* will have an alternate movement up and down, while that of *a* is a continuous circular one.

The continuous circular motion of the camb *a a*, fig. 155, revolving on its centre *b*, gives motion to the lever *c*, the centre of movement of which is at *d;* and this, again, a vertical reciprocating movement to the rod *f*. This is the movement used in a flax-heckling machine, to give the holder-table an up-and-down motion. The small wheel *e* serves to reduce the friction

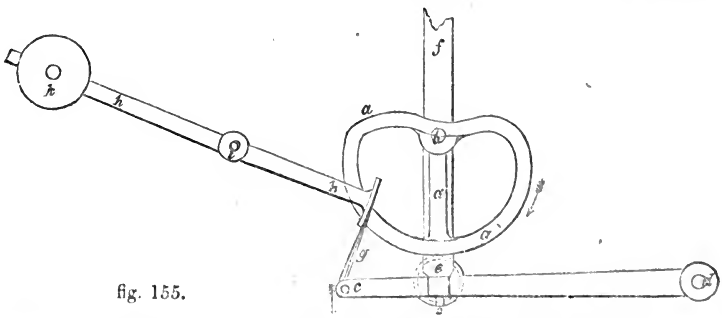


fig. 155.

between it and the revolving camb *a a* (see fig. 51, p. 32). The camb is only used to *pull down* the table, it being raised by the lever *h h* moving on the centre *k*, a heavy counterpoise being at one end; the other end of the lever being attached to the end *c* of the lever *c d* by the link or strap *g*. In fig. 87 the continuous circular motion of the camb *c c* gives a vertical reciprocating one to the rod *d e*. The parts of mechanism used in clock and watch machinery, known as "escapements," are employed to convert a continuous circular motion into a reciprocating one. The continuous circular motion of the camb *b b*, fig. 156, revolving on the centre *a*, gives reciprocating motion to the rod *g*; the edge of the camb works in contact with the friction-wheel *c*, attached to the end *d* of the bell-crank lever *d e f*, vibrating on the centre *e*; a counter-weight *h* gives regularity to the motion. This contrivance is used in the "expansion-gear" of marine engines.

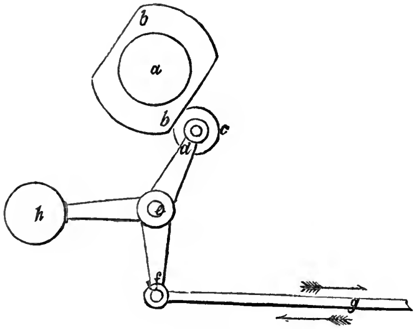


fig. 156.

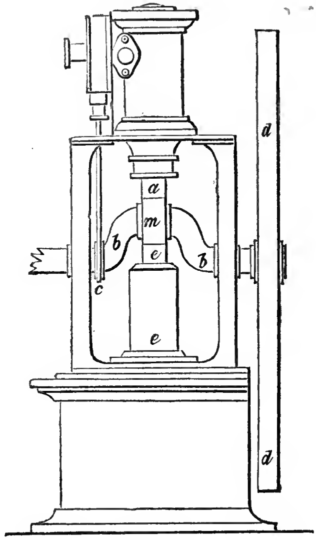


fig. 157.

In the "steam-pump," an elevation of which is shown in fig. 157, the reciprocating motion of the piston-rod *a* gives a rotatory motion to the crank *b b*, fly-wheel *d d*, and eccentric *c*: by the movement of the crank in a longitudinal, horizontal, slotted cross-head *m*, the reciprocating motion of the pump-rod *e* is obtained; by the movement of the piston-rod *a*, the circular motion of the fly-wheel is obtained, applicable to driving machinery; while at the same time the necessary motion of the pump-rod is derived.

If the rack in fig. 144 (p. 75) had only a few teeth on its face, and the pinion *b* with teeth only on half of its circumference, then the continuous circular motion of *b* would give a reciprocating up-and-down motion to the beam on which the rack might be fastened: in this case the rack and beam are supposed to be vertical. On the teeth of *b* catching those of the rack, the beam would be lifted up; but on the toothless portion of *b* presenting itself, the beam would fall, ready to be moved upon the toothed portion of *b* again coming round. If the rack were horizontal, as soon as the teeth of *b* passed round, the rack might he pulled back again by a weight and cord passing over pulleys. In this case the power of *b* would be exerted in moving the rack and beam, and also the weight.

To change a continuous circular motion into a reciprocating circular one.—The contrivance usually adopted for this purpose is that known as the "eccentric." This is merely a circular disc of metal firmly fastened on a revolving shaft; instead, however, of the disc being fixed at its true centre on the shaft, its centre of motion is placed at some distance from it. Thus, suppose fig. 158 to represent the circular disc, the true centre of which is at m, the centre of motion is placed at n. The edge of the disc or circumference is not plain, but is turned so as to have projections at each side, thus forming a kind of groove. This groove admits of the eccentric rings or hoops a a', fig. 159, being passed round: the rings are made in two halves, and secured, after being passed round the disc, by bolts

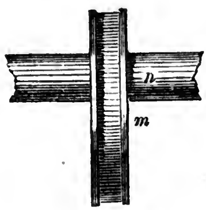


fig. 158.

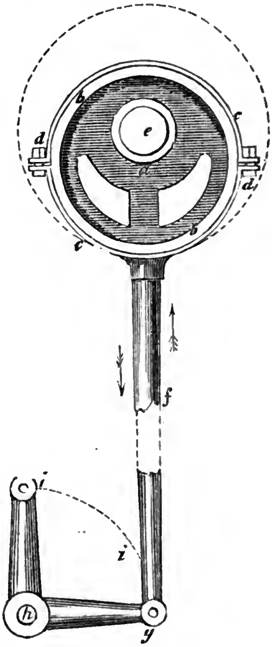


fig. 160.

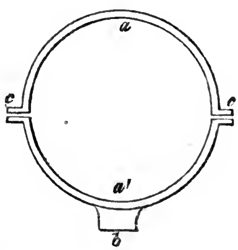


fig. 159.

at the projecting snugs c c; the eccentric-rod is generally screwed into the part b. A form of eccentric with hoop and rod is shown in fig. 160, where a b b is the eccentric disc, its true centre being at a, its centre of motion at e; the rings c c are secured by the bolts d d, the rod f is connected to the bell-crank h g at g; the centre of vibration is at h; the end i describes a portion of a circle; a rod jointed at i will have a reciprocating motion; the disc a revolves easily within the rings c c, which are kept well lubricated to reduce the friction: the ring and rod f thus partake of the motion of the disc, and an alternate reciprocating motion of the rod f is produced.

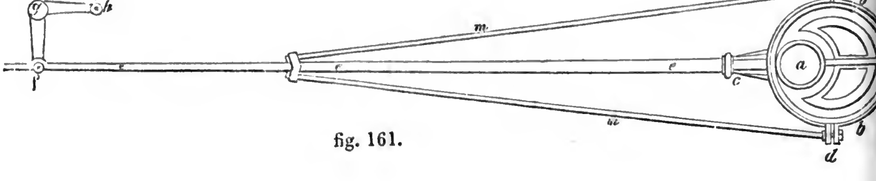


fig. 161.

We give in fig. 161 a form of eccentric gear adopted in large steam-engines: *a* is the centre of motion, *b b* the rings, bolted together at *d d*; *c e e* the rod, strengthened by lateral stays, *m m*; *f* the pin of the bell-crank vibrating at *g*; a vertical rod jointed at the other pin *h* will have a reciprocating motion. In fig. 162 an enlarged view is given of that part of

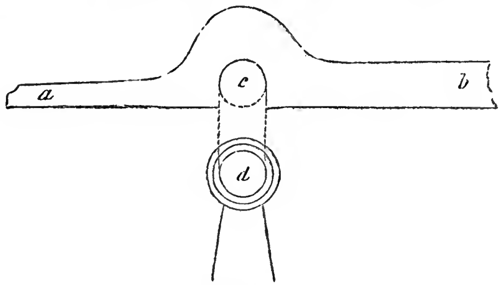


fig. 162.

the eccentric-rod which is attached to the crank-pin: a slot with circular end *c* passes over the pin *d* of the crank; when the motion of the eccentric-rod *b* is not required to give motion to the lever *d*, the attendant takes hold of the end *a* of the connecting-rod, and lifts it off the crank-pin; it is then allowed to slide along a portion of the rod *b* near *a*, or the end *a* is tied to a rope attached to any convenient part. Another method of converting a continuous circular motion into a reciprocating circular one is shown at fig. 163: a wheel *m g* has a crank or lever *h* fixed

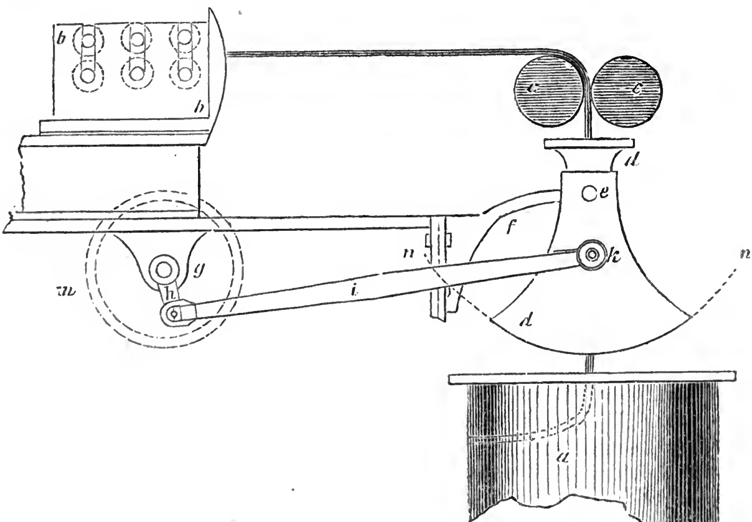


fig. 163.

to the end of its shaft; a connecting-rod *i* is attached by a joint at *k* to a trumpet-mouthed deliverer *d d*, vibrating at *e* on the standard *f*: the part *d d* has a circular reciprocating motion, as seen by the dotted line *n n*. The object of this contrivance is to deliver the long "sliver" or riband of cotton fibres passing through the rollers *b b*, *c c*, to the tin can, part of which is shown at *a*, in a regular layer.

To change a reciprocating circular motion into a reciprocating rectilinear one.—This change is seen exemplified in beams of steam-engines, where, as already stated, the end of the beam, *a*, in fig. 63 (p. 44), moving in a portion of a circle, communicates a reciprocating rectilinear motion to the piston-rod *d d*. In Newcomen and Watt's single-acting steam-engine, where the beam was only pulled down by the pressure of the atmosphere acting on its piston, the weight of pump-gear at the other end raising it again, the means adopted for the straight up-and-down motion of the piston-rod, while the end of the beam moved in a circle, was very simple; we show it in fig. 164. To the top of the piston-rod *d* a chain *c* was attached; this passed over the circular end *b b* of the beam *a a*, and was fastened to the upper end. The sector *b b* was described from *m*, the centre of the beam; on the beam oscillating, the chain coiled and uncoiled on the sector, the line of the piston-rod forming a tangent to the arc *b b*. This contrivance was only available where the piston exercised a pulling motion; but where the impulse of steam was given not only to depress but

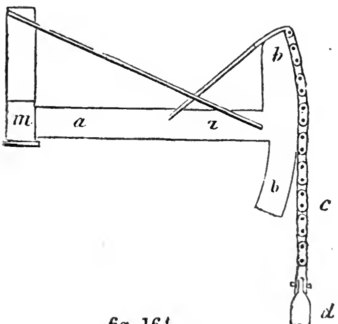


fig. 164.

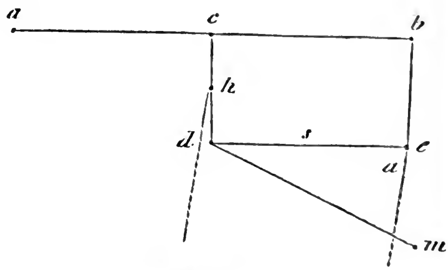


fig. 165.

to raise the piston, another contrivance was obviously necessary. The genius of Watt, the great improver of the steam-engine, was equal to the difficulty of the task; and the beautiful and philosophical mechanism known as the "parallel motion" was the result of his attention to the subject. The above diagram illustrates the motion. Let *a b*, fig. 165, be half of the working beam, vibrating on the centre *a*; let *c* be a point half-way between *a* and *b*; a rod *d m*, called the "radius-bar," equal in length to *a c* or *c b*, is fixed with a movable joint to a point at *m*, and at the other to the end of a link *c d*, movable on pins at *c* and *d*. Suppose the beam *a b* to oscillate on its axis *a*, the point *c* will describe a portion of a circle of which *a* is the centre, and at the same time the point *d* will move in a circle of which the centre is *m*; the result of these movements is, that the middle point *h* of the link *c d* moves in a straight line,—at all events, so nearly that the deviation in practice is of no moment. This movement, so far described, gives an explanation of the principle; but the movement as carried out in practice is made complete by the following additions.

Another link be, equal in length to cd, is attached at b to the end of the beam by a movable joint or stud; "a parallel bar" s, parallel to the beam ab, joins cd and eb by movable joints at d and e; the point e will move in a straight vertical line eb'; the air-pump rod is attached to the point h, and the piston-rod to the point e. In fig. 63 is shown the method in which the parallel motion of a steam-engine is arranged: where aa is the beam; m the radius-bar, the fixed centre of which is at h; g is the parallel bar connecting the links e,f. The form of parallel motion used in marine engines is given in fig. 166: where ab is the beam, which is placed at the foot of the cylinder and framing; cc the side lever, attached to the end of the piston cross-head e; f the "parallel bar," g the "radius-bar," h a rod connected with the beam and radius-bar. In high-pressure steam-engines, the piston-rod is made to move in a straight line by pulleys attached at each end of the piston cross-head, and sliding between two vertical guides: thus, in fig. 167, a is the piston-rod, d the pulleys, c the guides, b the connecting-rod. The movement known as "White's parallel motion" is also available for this purpose. In fig. 168, let a a be a large annular toothed wheel fixed at the points b b to a framing; let e e be the piston-rod, d the crank-pin, which is fixed to the circumference of a small toothed wheel cc; the vertical movement of the piston-rod causes the wheel aa to roll within the inner circumference of the annular wheel aaa: if the diameter

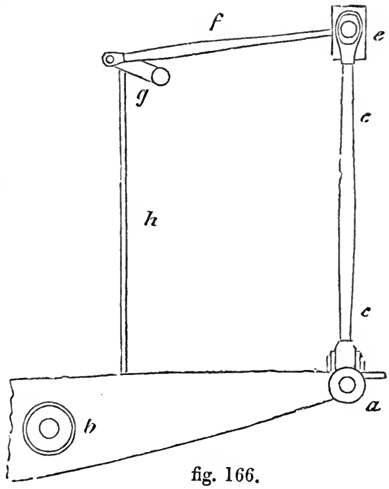


fig. 166.

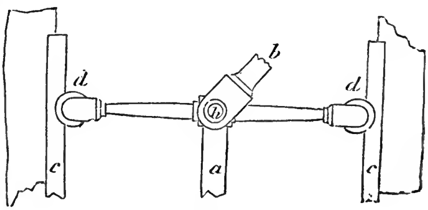


fig. 167.

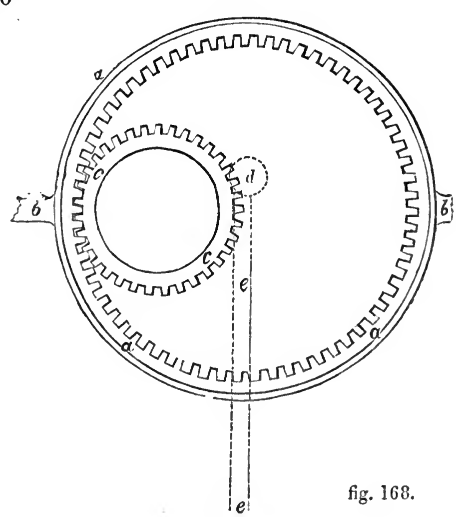


fig. 168.

of the wheel *c c* is one-half of that of the wheel *a a*, or equal to its radius, then the point *d* will describe a straight line in the direction *d e*; if the proportions are different from the above, the point *d* will generally describe a curve known as the hypocycloid.

A recently patented "parallel motion," applicable to horizontal steam-engines, is given in fig. 168[a]. Let *a a* be the piston-rod; *c c* part of a vertical frame, having a slot, *d*, near the top; at the joint *f*, to which the connecting-rod *b* is attached, a link is placed, the stud at the other end, *e*, of which moves up and down the slot *d*; at *h'* another lever, *h*, is attached, oscillating on the centre *g*. A vibrating motion given to the pinion *b*, fig. 144, will change its circular reciprocating motion to a reciprocating rectilinear one, by making the rack move up and down.

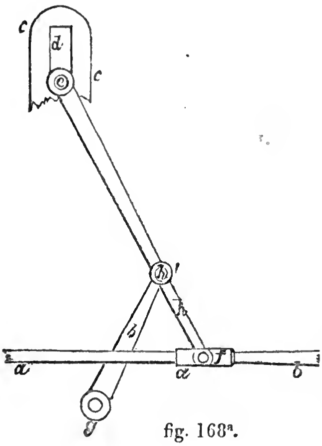


fig. 168[a].

We have now to notice the contrivances adopted for *regulating* motion. These are generally applied in cases where a movement is not uniform: thus, in the use of a crank, there are certain points where the connecting-rod has no influence in producing circular motion of the shaft to which it is attached. Thus, in fig. 70, p. 46, if the crank-pin *a* was at a point exactly beneath the centre *e*, it is evident that any force exerted by the connecting-rod would be expended merely in pressing down on the crank-pin and shaft; in like manner, if the point *a* was placed exactly vertically above the centre *e*, the force of the connecting-rod would be only a pull upwards, thus tending to raise the crank-shaft out of its bearings. These two points are called technically the "dead points," inasmuch as the power communicated to the connecting-rod is inert or useless in giving circular motion to the crank-shaft. To obviate this inconvenience, advantage is taken of the momentum of a heavy body. A large wheel with heavy rim is attached at its centre to the crank-shaft; the momentum acquired by the heavy mass during the period when the full force of the connecting-rod is given out, is sufficient to carry the crank past the "dead points." Thus the alternate motion of the beam is changed, by the intervention of the connecting-rod, crank, and fly-wheel, into a continuous circular one.

In marine and locomotive engines, where no fly-wheel is used, two engines work together, but the cranks are placed at right angles to each other; thus while one crank is at its dead point, the other is receiving the full impulse of the engine. In fig. 169, *a a* is the main crank-shaft, on which the paddles or driving-wheels are fixed; *c c* a crank, *d d* a similar one shown in dotted lines, but at right angles to *c c*; that is, the end of it is only seen, as at the double-dotted lines at *d*. In Mr. Brunel's "oblique engine," two cylinders are employed to give motion to one crank. The cylinders are inclined to each other at an angle of 60°; thus the framing takes the form of an equilateral triangle, the cylinders rest on the side, and the main shaft works on bearings placed on the apex of the triangle. "The piston-rod is preserved in its rectilineal course by metal rollers running upon guide-plates. . . . . When the piston of one of the cylinders is at half-stroke, the piston of the other is at the termination of its stroke or nearly so; and thus the irregularities of the one cylinder

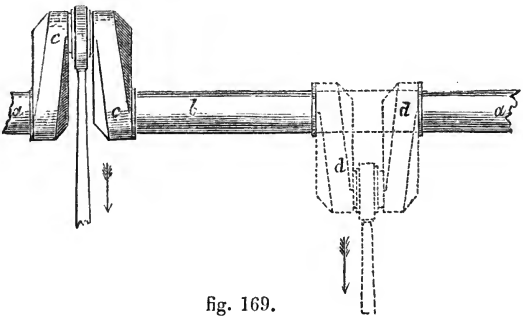


fig. 169.

partly counteract the irregularities of the other." We may here notice the ingenious contrivance adopted by Mr. Buckle, and termed a "pneumatic equaliser." "It acts upon the principle of causing the engine to drag up a piston against the pressure of the atmosphere, when the energy of the moving power is above the average; the power thus consumed being returned to the engine by the atmosphere forcing down the piston, when the energy of the moving power is below the average." The fusee of a watch, described and illustrated in fig. 137, is another method of regulating motion. The "steam-engine governor" is another important regulator. In fig. 170 we give an elevation of this beautiful piece of mechanism: *m m* is a vertical rod revolving in bearings at top and bottom, and put in motion by the pulley *e;* two heavy balls *c c* are fastened to the ends of bent levers *a a a′ a′*, the centre of which is at *b*, these levers passing through a slot made in the rod *m* at *b*, and secured by a pin passing through both sides of this and the two levers; the levers thus turning on the pin *b* can be made to recede from or be drawn towards each other, like the arms of a pair of pincers; the ends *a′ a′* are attached to small links *n n*, joined to projecting snugs *o o* by small studs or pins; to keep the levers *a a* in their true position, they are made to move within guides *f f;* a stop *d d* is sometimes fastened to the rod *m*, having circular parts cut out at the extremities. When the "governor" is at rest, the balls rest on this stop; on the rod being put in motion by the pulley *e*, the centrifugal force generated causes the balls to fly outwards, thus opening the extent between *a a*, and on the contrary lessening the distance between *a′ a′;* this acting upon the links *n n* causes the projecting snugs and attached ring to slide upwards on the rod *m;* this raises the end of the lever *s s*, depresses the other end and the lever *t t*, thus turning the valve attached to the lever in the steam-pipe *v*. The action thus described takes place whenever the engine revolving too fast, causes the governor-balls to fly out, and shuts in a corresponding degree the valve in the steam-pipe; thus less steam is admitted to the cylinder, the engine necessarily goes slower, the governor revolves at a less speed, the centrifugal force is lessened, the balls fall inwards towards the rod *m*, the

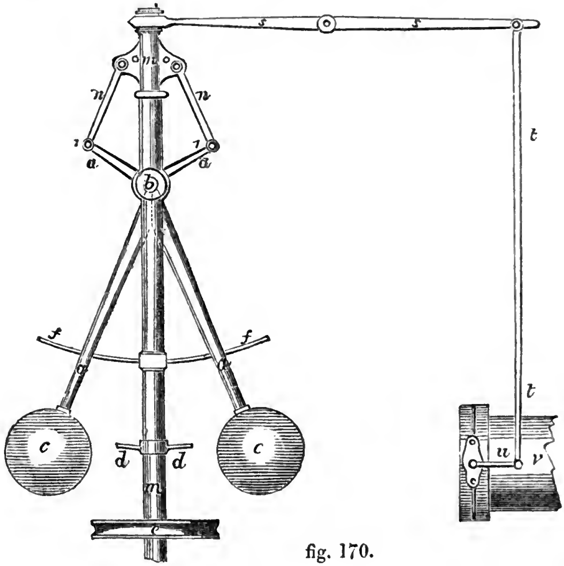


fig. 170.

ring *m o o* slides downwards, the lever *t t* is pulled upwards, and more steam is admitted to the cylinder by the opening of the valve; the speed of the engine is again accelerated, again to be checked if too high, and so on; thus keeping the engine at a nearly regular speed. This is one of the beautiful self-acting motions which make machines adjust their various movements almost with creative intelligence, and examples of which will be found in numerous departments of practical machinery. In figs. 171, 172 we give other forms of governors. A form of governor in which the inclined plane is a noticeable feature is shown in fig. 173: the vertical spindle *a* turns on an upright bearing, and is made to revolve in the ordinary manner; a disc *b b*, having two circular inclined planes *c c* on the outer edges, is firmly keyed on to the spindle *a*; a cross-head *d d*, having wings or fans *e e* at its extremities, is mounted on the spindle *a*, so as to have a vertical sliding motion up the spindle, and yet capable of revolving; friction-pulleys *f f* run on the circular inclined planes or edges of the disc *b b*; a heavy ball *g* is carried by and rests on the cross-head *d*; this keeps the rollers *f f* at the lowest point of the inclined planes; the end of the throttle-valve lever *h* rests upon the top edge of the ball; this moving up or down according to the speed of the engine, shuts or opens the steam-valve, and thus regulates the supply of steam to the cylinder. The operation of the governor is as follows:—on the engine starting, the spindle *a* begins to rotate, and carries round the cross-head *d*; as, however, the speed increases, the resistance of air to the fans *e e* retards its progress; the wheels *f f* consequently raise up the circular inclined plane, and thereby raise the ball *g* and the lever *h*. In order to prevent the wheels being carried over the top of the planes, stop-pieces are

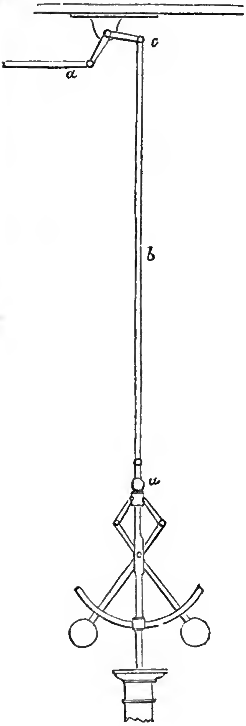


fig. 171.

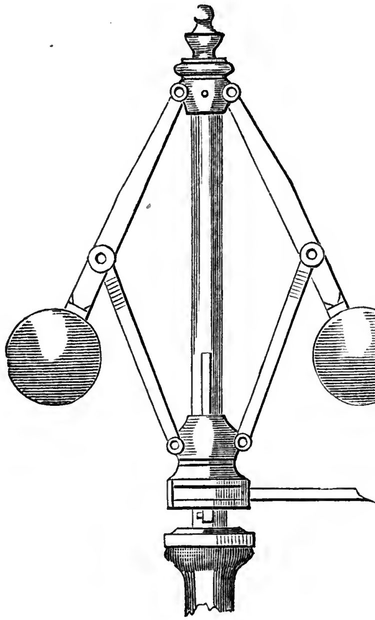


fig. 172.

there placed, or a lip *j* may be made at the lower end of the ball or weight

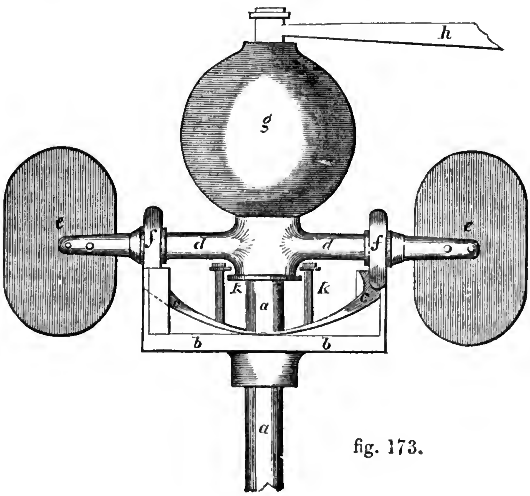


fig. 173.

g, and two pins *k k* screwed into the disc *b b;* the pins are furnished with adjustible buttons, the lip *j* will come in contact with these, and prevent the wheels from rising too high.

The fly-wheel is a contrivance for accumulating power. Thus the power expended on it is given out while the crank is at its dead points. Buckle's pneumatic equaliser is also another method of accumulating power. A familiar example is met with in the coining and embossing machine: a quick running screw works in a vertical frame; at the lower end a punch or die is placed; beneath this, on a small table, the coin to be struck, or the article to be embossed, is placed; to the upper end of the screw a horizontal lever with long arms is firmly fixed; heavy balls or weights are fixed at the extremities of the lever; the workman whirls the lever and weights rapidly round; the power thus accumulated is given out, in making the screw descend with great force. A modification of this machine is used in making the slits in steel pens, and in punching the eyes of needles.

Engaging and Disengaging of Machinery in Motion.—The couplings, which we have already described, are contrivances by which shafts are not only connected together, but admit of their disconnexion when required. It is obvious, however, that this can only be attained when the shafts are at rest. In almost every variety of machine it is necessary to have means whereby the motion from the prime mover can be applied to, and as readily taken from the actuated machine, and this without stoping or altering the power. In the ingenious and complicated machines employed in the cotton manufacture, it is matter of surprise to the uninitiated how easily the attendants can set one part in motion or stop it; and this without altering in any way the movement of the other parts, or of the shafts which communicate the motion from the prime mover.

The simplest, and certainly the most perfect contrivance for engaging and disengaging machinery, is that termed the "fast-and-loose pulley." Let *a a*, fig. 174, be the shaft to which the motion is to be applied when required, a pulley *b* revolving loosely on the shaft; the pulley *c* is of the same diameter, and is fixed on the shaft by means of a key; when the belt from the driving pulley is running on *b*, the shaft obtains no motion, as the pulley freely revolves on it; but on the belt being shifted by hand to the pulley *c*, the shaft begins to revolve. This movement is almost universally used in machines of every kind. Simple as it appears, it is so effective that the start is effected with little or no shock; a desideratum

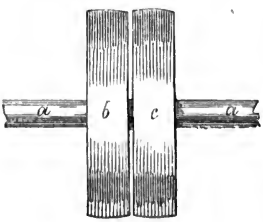


fig. 174.

the value of which may be known, when we state that before its introduction many machines could not be driven by continuous power. In many cases the belt is moved from one pulley to another by hand; this is, however, attended with some danger, as the hand of the operator is sometimes drawn in by the revolving wheel. A method by which the movement is effected is seen in fig. 174[a], where *d d* are the pulleys, and *a* the belt; the belt moves within the forked end of a lever *b b*, the centre of which is at *c;* by moving this lever from side to side it is obvious that the belt can be easily moved from pulley to pulley. Another method some-

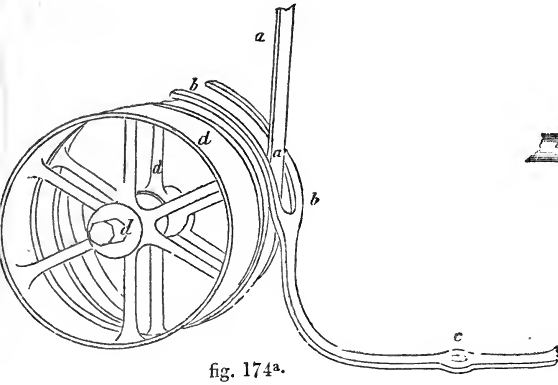


fig. 174ª.

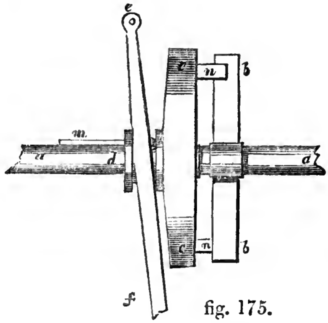


fig. 175.

times used is shown in fig. 175: where *a* is the shaft; *c c* a pulley driven by a belt from the moving power, and revolving freely on the shaft; a clutch *d* is attached to the side of the pulley *c c*; a lever movable at *e* lies on the upper side of the clutch; a gland or cross-piece *b b* is fixed to the shaft; and cross-pieces *n n* are placed near the circumference of *c c*: by moving the lever *f*, the clutch and pulley are moved along the shaft till the projecting pieces *n n* catch the gland *b b*; the shaft *a a* is thus set in motion. Instead of having the lever, as in fig. 175, movable at a centre *e*, it is sometimes made with a fork as at *b b*, fig. 175ª: this embraces the coupling *a*, yet allows it to revolve freely; the centre is at *c*. To avoid the shock in setting shafts too suddenly in motion, various plans are used; the fast-and-loose pulley is a very effective plan, but it is not always convenient to apply it. The following is a method of effecting the engagement and disengagement of machinery without incurring a shock; it is termed the "friction-cones." On the end of the shaft *a*, fig. 176, a clutch

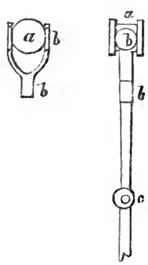


fig. 175ª.

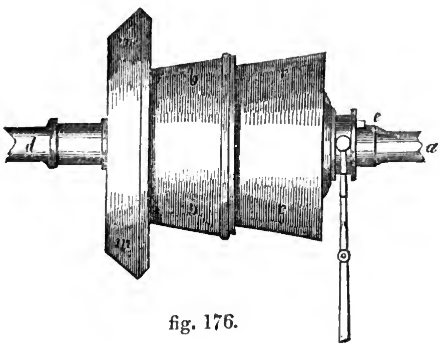


fig. 176.

and conical piece are fixed, capable of longitudinal motion on the shaft *a*, but made to revolve with it; this is effected by having a key *e* fixed on the shaft, along which the clutch moves in a slot made in its interior surface. Suppose *m* to be the wheel fixed on the end of the main shaft *d*, provided with a conical piece *c*, the interior of which receives the exterior cone *b*; by means of the lever the clutch and cone *b* is moved along the shaft; on *b* entering *c*, the friction created is sufficient to move the shaft *d* and wheel *m*. When in gear they are held by means of a screw or by a weight. On either of the shafts *a* or *d* being stopped, the cones fall out of gear, and the connexion is stopped. Another mode adopted for obviating the shock in engaging and disengaging machinery is illustrated in fig. 177. A pulley is fixed on the end of the shaft *a;* this being tightly embraced by a friction-band *c*, projecting snugs *b b* are placed on the periphery of the band; a clutch and cross-piece, *n n*, on the shaft *m*, has projections or prongs *d d;* on the clutch being moved along the shaft

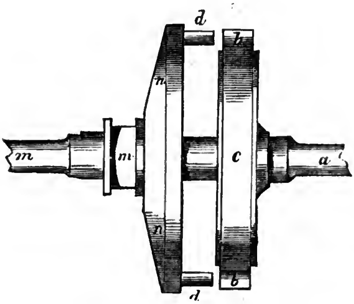


fig. 177.

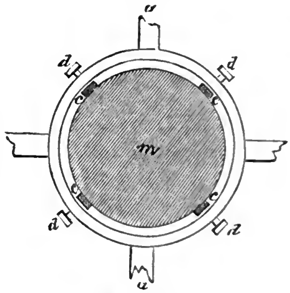


fig. 178.

m by the lever, the prongs *d d* catch the snugs *b b* on the friction-band; this slips round on the pulley, till the friction becomes equal to the resistance, and the shaft gradually attains the motion of the clutch. A modification of this method is exemplified in the "friction-wheels." Let *a a*, fig. 178, be the pulley or wheel which is capable of being set in and out of gear by any of the methods we have shown; the eye of this is made as large as possible; in the inside of this small pieces of brass *c c* are fixed in such positions, that pinching screws *d d* pressing upon them are placed between the arms of the wheel or pulley. On the shaft to be driven a boss or friction-wheel is accurately turned, so as to fit the eye of the wheel *a a;* by means of the screw *d d*, the brasses *c c* are made to press on the surface of *m*, and are so adjusted that the friction created is equal to the resistance offered by the wheel: as soon as the resistance by any means exceeds this, the wheel *a a* begins to move over the boss *m*, the shaft *m* continues its motion, and the wheel becomes stationary; thus the breakage of the teeth of the wheel or of the pulley is avoided. When machinery is suddenly stopped, or its direction is reversed, as the shaft beginning to turn the wrong way, it is necessary to have some means of stopping the motion of the driving shaft. A contrivance for effecting this is shown in fig. 179: to the clutch *a* on the shaft *m*, and the wheel

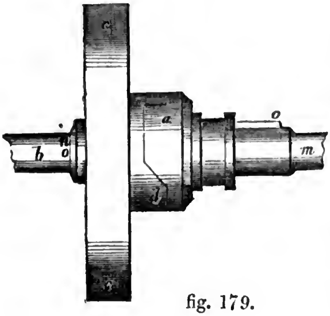


fig. 179.

c on the shaft *b*, projections with oblique faces are attached; these exactly fit into each other when in gear; the wheel *c* and clutch *a* are allowed to move on the shafts, the wheel *a* being capable of moving round on it; longitudinal motion, however, being prevented by two pins placed at each end as at *n n*, the clutch moves longitudinally along the shaft, but cannot revolve thereon by the intervention of the key *o*, as before described. On the clutch *a* being moved along the shaft by a lever, the faces come in contact, and the shaft *m* is moved; on the wheel *a* receiving any increase of speed or pressure, the oblique faces fall out of contact.

CHAPTER VII.

PROCESSES AND MACHINES USED IN THE MANUFACTURE OF MACHINERY.

For the purpose of facilitating the putting together and arranging the constituent parts of machines, certain preliminary operations or processes are to be performed. The material used in their construction has to undergo certain modifications of form or shape before being fit for the special purpose of its design; hence the pattern-maker and moulder are required to produce certain parts in cast iron, the smith or forger those in malleable iron. Again, after they leave those departments, the articles are further subjected to processes having for their object the making of smooth and accurately-bored apertures, the straightening of rough and uneven into smooth and plain surfaces, the fitting of one part to another so as to insure their accurate adjustment and the easy play of the movable portions of the machines, and the turning of accurate cylindrical surfaces. The various operations here noted come under the general department of "fitting," "finishing," or "bench-work."

In giving a somewhat cursory account of the operations performed in the "Machine-shop," we shall first notice the methods employed in performing these by manual labour, and then the mechanical contrivances as substitutes for them.

The operation of drilling and boring will be first discussed. In making a small aperture in wood or other comparatively soft material, the carpenter uses a small sharp-pointed instrument termed a "sprig-bit:" partly by giving it a semi-rotatory motion, but chiefly by pressure, it is made to enter the wood; when withdrawn, an irregularly-shaped aperture is produced. A "gimlet" is used also for this purpose; it is provided with a sharp point at the end of a spiral screw. The "augur" is a modification of the gimlet, but larger; it is used for boring large holes in the timber of ships and scaffolding: to facilitate the operation, the tool has a complete continuous circular motion given to it. By means of a cross-handle of considerable length the chips are turned out in spiral pieces, and are received into a semi-cylindrical part above the spiral screw-cutting portion: this semi-cylindrical portion has one of its edges comparatively sharp; this tends to keep the interior of the perforation clean. In the contrivances above noted, different sizes of instruments are required, according to the size of aperture to be made. To obviate this inconvenience for general work, the contrivance known as "the brace and bit" is used; by this the operation of boring holes is much facilitated. A series of "bits" proportioned to the sizes of holes required are made; the point *f*, fig. 180, enters the wood, rotatory motion is given to it, and the cutting edges *h f* cut out a circular hole. The revolving motion is given to the bit by the "brace." The cranked part *m b d* has a conical projection at *b*; this fits into a circular conical aperture in the head *a*. The bit *c* is passed into a square hole made at *m*: the ends of the bits are all made of the same size, so that the whole set fits into *m*. The workman places the point *f* of the bit at the point in the wood where the aperture is to be made, and presses against *a* with his body, and turns the brace at the part *b*; the brace revolving at the points *b* and *m*, causes the edges

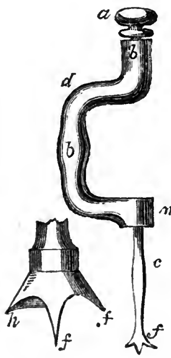


fig. 180.

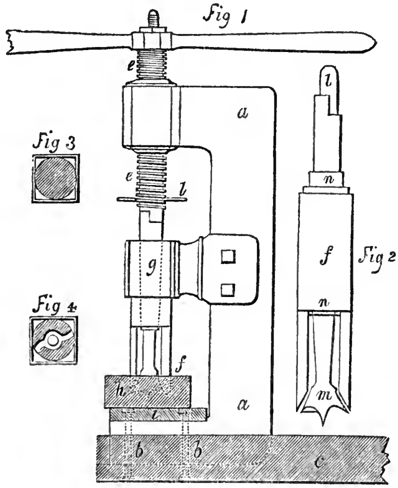


fig. 181.

of the bit to cut the aperture quickly. Machinery is used to give a very rapid and continuous motion to the drill or bit; the most noted instance of its application for this purpose was seen during the erection of the Great Exhibition building, when many thousands of apertures were made in the sash-bars daily. A very ingenious method of making square perforations in wood, while a circular motion is used, is thus described in the *Engineer's and Mechanic's Cyclopedia*. At *a a*, fig. 181, is a strong iron frame or support, fixed by screw-bits *b b* to the work-bench *c*; *d* is an octagonal iron socket, containing a brass bush tapped to receive the vertical screw *e e*; to this screw is affixed, by a circular tenon and mortice, the square perforating instrument *f*, which accurately fits and slides up and down through a rectangular hole in a guide of brass *g*, when the screw *e* is turned by the cross-handle at top, so that the square incision is made by direct pressure downwards, at the same time that the revolving centre-bit *m* cuts out a completely round hole, the chips rising up and pressing out at the two open sides of the square cutter; *h* represents a piece of wood in the act of being bored, the dotted lines showing the depth to which the perforation has reached; a small piece of wood *i* is placed underneath, to prevent injury to the cutting-tool, by coming in contact with the cross iron plate *k*; the bolts *b b*, passing through *i* as well as *k* secure both firmly to the bench *c*. Fig. 2 exhibits the cutting part of the instrument separately on an enlarged scale, with the lowermost portion in section: the tenon *l* is inserted into a cavity in the screw *e*, fig. 1, and made fast by a cross-pin which goes through both; by this arrangement the instruments can be readily exchanged for others of different sizes. The lower extremity of this revolving piece is formed into a centre-bit *m*, which, owing to the collars *n n*, cannot ascend or descend without the square instrument, which accurately cuts out the angles beyond the range of the circular incision made by the former. The square cutting-tool is made of a bar of steel, with a hole drilled out of the solid, in the manner shown by the end view, fig. 3; and the edges are then formed by filing and grinding them to the bevils, shown in section at fig. 2. Fig. 4 represents a similar view of the end of the instrument with the centre-bit in its place.

We now come to notice the instruments in use for boring holes in substances of greater density than wood, as iron, brass, &c. The form of drill shown in fig. 180 would not answer for iron, &c.; the cutting edges being too fine and fragile, would break at once. The form generally used is shown in fig. 182. Where the angle of the cutting edges is very acute, as at *a*, the instrument is apt to break, or at all events to produce an aperture rough and jagged in its interior, from the bit trembling or jarring; this is obviated by having the angles more obtuse, as *b c*. The

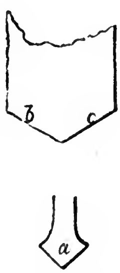


fig. 182.

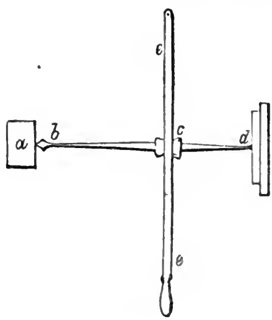


fig. 183.

angle of the cutting edges, however, varies according to the material for which the bit is designed; the angle for wrought-iron bits is different from that of bits used for making apertures in cast-iron. The obliquity of the angles should not be too great, as they then have a tendency to make the hole out of the circular. Where the holes are of small diameter, motion is given to the bit by what is called the "bow-drill," in fig. 183. The cutting edges and stock are formed in one, and provided with a small pulley *c*; the workman holds the drill horizontally, inserting the tapered end *d* in a hole made in the face of a metal plate *d*, against which he presses with his body; the end *b* bores the hole in the material *a*; an elastic bow *e e* is worked to and fro, its string or cord being passed once round the pulley *c*; a semi-rotatory motion is thus given to the drill. Continuous motion is given to the drill, by using a modification of the carpenter's brace already described. The working spindle, *a a*, fig. 184, has a conical projection at *e*, working into a small hole in the under side of the lever *f g*, the fulcrum of which is at *f*—a flat bar of iron is generally used as a lever; the drill *d* is inserted at *c*, and the brace is worked by the hand at *b*. A piece of thin sheet-iron is passed round the spindle at *b*, and prevents the necessity of its turning round in the workman's hand; the metal *h* to be bored is generally fixed in a bench vice. A modification of this contrivance is adopted sometimes, by which the lever *f* can be fixed at different elevations: one end turns upon a transverse pin, "between two uprights pierced with various holes, to allow facility of fixing it by means of the pin at different elevations; the other end of the beam traverses between two uprights, and carries a heavy weight, which, acting as a lever, necessarily keeps the drill to its work." In many cases this cannot be used; a

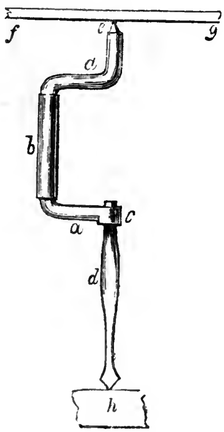


fig. 184.

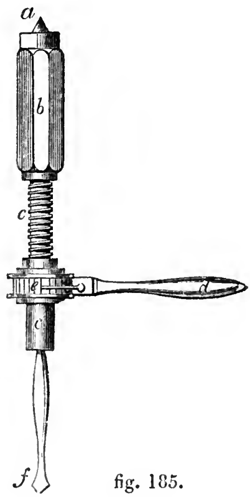


fig. 185.

simple lever, as in fig. 184, is then used, a hole in the wall being used as the fulcrum at *f*, the assistant bearing with the weight of his body near the end *g*. In some cases where holes are required to be drilled in machinery, it is impossible to have space in which to turn the brace completely round; the ingenious contrivance in fig. 185 is then used; it is also used in many other cases, as the effective power applied to it is always acting at a great advantage. It is made in two parts: the nut *a b* has a projection *a* at its upper end, as in the brace last described; the lower part of it has an internal screw, into which the screw *c c* works; the handle *d* is fixed on *c c*, part of it is cut out to allow a ratchet *e* to be properly fastened on it; to the handle a small click is placed, and kept in contact with the teeth of the ratchet by means of a spring. By putting the drill *f* and the conical projection at *a* in their places, and applying the pressure at *a*, an intermittent circular motion is given to the drill as follows: On moving the handle *d* in a certain direction, corresponding to that which the cutting edges of the drill ought to have to be effective, the catch turns the ratchet-wheel, and thereby with it the spindle *c c* and drill *f*; by thus moving the nut *b*, the drill is kept to its work. By giving motion to the drill-spindle *a b*, fig. 186, by means of the bevil-wheels, the shaft *c*

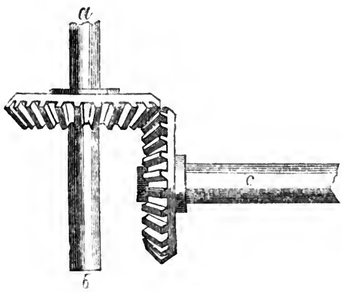


fig. 186.

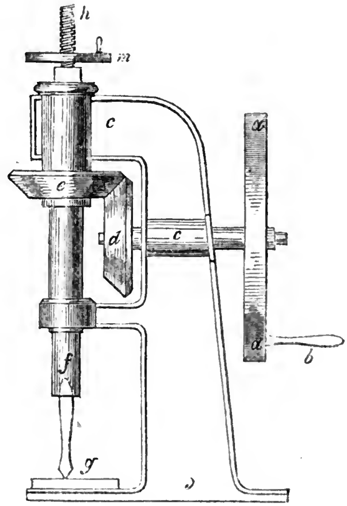


fig. 187.

being turned by a winch or handle, holes may be rapidly drilled. This motion is used in the "portable drill" of Mr. Nasmyth, the arrangement of which is given in fig. 187 : where *c c* is a cast-iron frame, *a a* fly-wheel turned by the handle *b* giving motion to the wheel *d*, which working into *e*, gives a rapid rotatory motion to the drill *f*; the drill is advanced as the perforation in *g* increases, by turning the wheel and screw *h m*. In another modification of the drilling-machine by the same gentleman, the downward pressure to the drill is given by the foot of the workman pressing on a foot-board in front of the machine. This acts on a lever at the top by means of a back vertical rod ; the end of the top lever works into a sliding bearing on the top of the drill-spindle ; the feed of the drill can thus be regulated at the pleasure of the operative. The table on which the article rests to be drilled can be placed at any convenient height, being movable by means of suitable gearing. The drilling-machine is sometimes made self-acting; that is, not only the rotary motion of the drill, but the pressure necessary to keep it up to its work, is given by the same prime mover. We first notice one of the many methods introduced for giving the self-feeding motion. Let *a a*, fig. 188, be the drill-spindle, revolving on bearings at *d e* ; motion is given to it through the wheel *c*, and *b* on the driving shaft *a*. Immediately above the lower bearing *d*, a small pinion is fixed; this works into a wheel *n* ; the shaft of this is continued upwards, and is provided with a pinion *o* working into a wheel *h h;* this latter is fixed on the end of a drill-spindle, which is there screwed. The bush or centre of *h h* forms the nut, working the screwed portion of the spindle; the wheel *n* is provided with a clutch *m*, and vertical lever *n;* by this means, by moving the lever up, the wheel can be thrown out of gear with the pinion *f*, thus stopping the downward pressure of the drill.

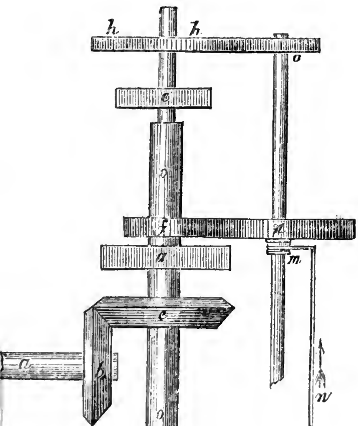


fig. 188.

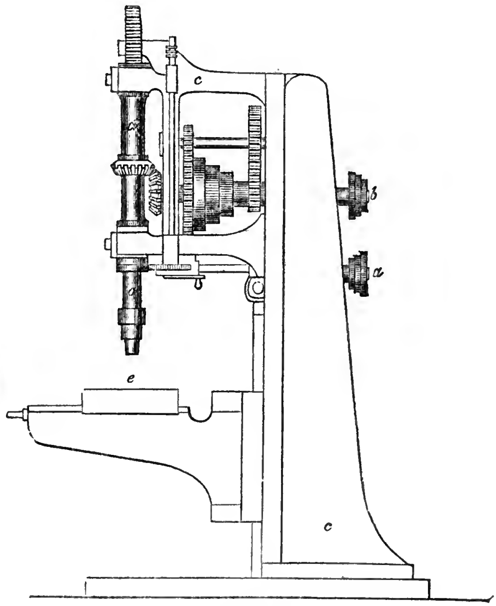


fig. 189.

In fig. 189 we give the elevation of a self-acting drilling-machine by Whitworth of Manchester: *a b* the speed pulleys, *c c* the framing, *o o* the drill, *e* the table on which the article to be drilled is placed.

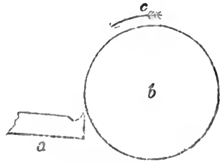


fig. 190.

We shall now notice the operation of turning. Suppose *b* to be a rod of iron turning continuously in the direction of the arrow *c*, fig. 190; and a cutting tool to be held at *a* in contact with its outer surface. It is evident that the strips of metal taken off by the tool *a* would leave the surface of *b* truly cylindrical. In fig. 191 we give the elevation of a "foot-lathe;" that is, where the actuating power is the pressure of the foot on the board 4, the centres of oscillation of which are at 5 5; the up-and-down motion of the board is changed into a continuous circular motion by the connecting-rod 3, crank 2, and crank-shaft *v v*, and fly-wheel 6 6. The "fixed head-stock" is *o o*, the movable or "shifting" one at *b;* the spindle and pulley *t t* revolve in a bearing on one side of *o*, the other on a pinching screw *s s;* the motion of the fly-wheel

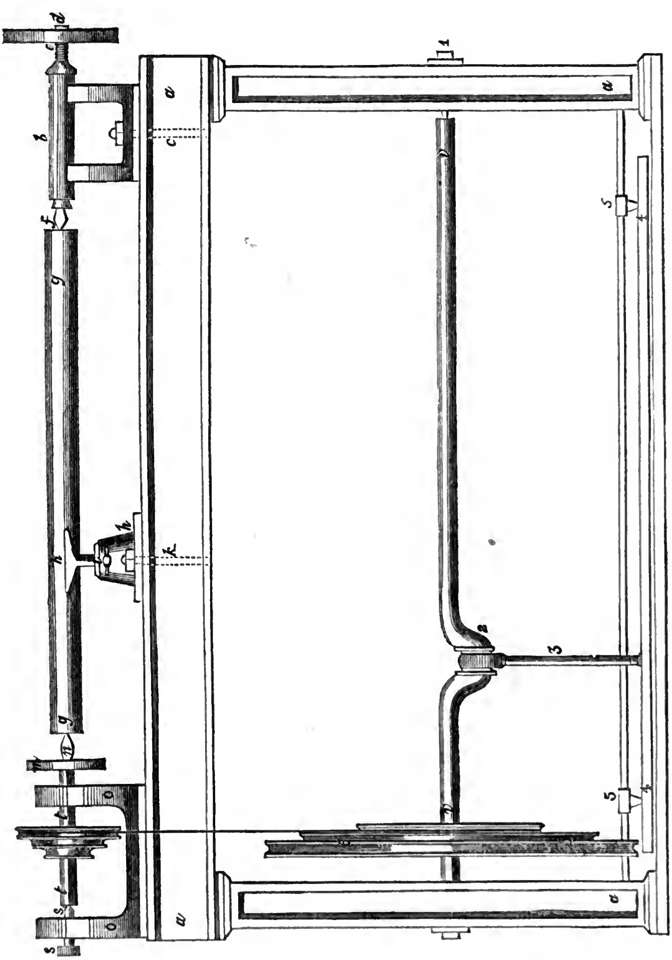


fig. 191.

is imparted to the pulley on *t t* by means of a cord or band; *m* is a circular piece of metal called the "chuck"; the "centre" *n* is placed in an aperture in the centre of this. A ring with projecting end is placed round the article to be turned, as *g g;* the end of this ring catches the chuck, the motion whereof is thus given to *g g;* the other extremity of *g* revolves on a centre *f*, which is moved out and in by the wheel *e* in the screwed spindle *d;* the "shifting head-stock" is moved along the top parallel slides of the lathe, and is fixed at any desired distance from *o o* by the bolt and nut *c*. The "rest" *h'*, for supporting the cutting tool *h*, is fixed by a small pinching screw *i;* the rest is fixed at any desirable part of the lathe by means of the bolt and nut *k*. In this simple form of lathe the cutting tool is held by hand; in the improved machines, the tool is placed on, and kept in one position by a contrivance called a "slide-rest." The introduction of the slide-rest opened up a new era in the art of making machinery. "It is not, indeed, saying at all too much," remarks Mr. Nasmyth in an excellent essay on tools, "to state that its influence in improving, and so extending the use of machinery, has been as great as that produced by the improvement of the steam-engine in respect to perfecting manufactures and extending commerce; inasmuch as without the aid of the vast accession to our power of producing perfect mechanism which it at once supplied, we could never have worked out into practical and profitable forms the conceptions of those master-minds who, during the last half-century, have so successfully pioneered the way for mankind ever after attaining the otherwise latent treasures of the material world, even although opposed by time, space, and the elements. . . . The STEAM-ENGINE itself, which supplies us with such unbounded POWER, owes its present perfection to this admirable means of giving to metallic objects the most precise and perfect geometrical forms. How could we, for instance, have good steam-engines if we had not the means of boring out a true cylinder, or turning a piston-rod, or planing a valve-face? It is this ALONE which has furnished us with the means of carrying into practice the accumulated results of scientific investigation in mechanical subjects." The rationale of the principle will be best explained in the words of the same eminent authority. Instead of the workman holding the tool in his hands, let us suppose that he had it bolted firmly to the rest, "and that while it was cutting a shaving from the bar in the lathe, he had the means of SLIDING THE REST WITH ITS TOOL along the bed of the lathe, parallel to the axis of the work; it is evident that, in so doing, we should

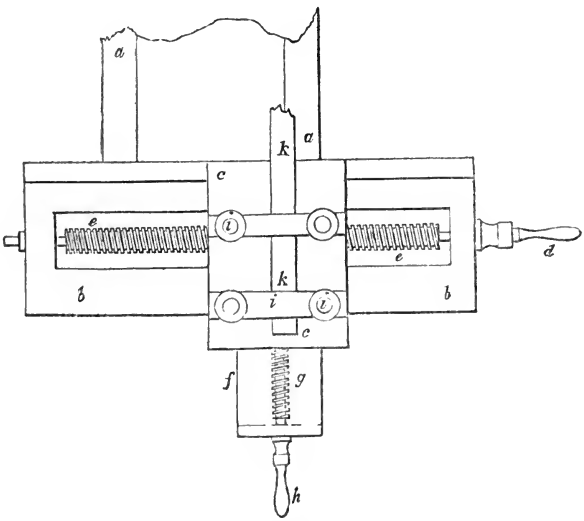


fig. 192.

be able to turn the bar quite true; and if a screw was provided for the purpose of giving this sliding motion, we should then have a SLIDE-REST: exactly in such a manner was this truly admirable tool introduced in the mechanical world." Thus, in fig. 192, let *a a* be part of the rest bolted to the "shears;" the table *c c* moves along *b b* by means of the screw *e e*, turned by the handle *d;* the tool *k* is kept fast in its place by the cross-bars and nuts *i i;* the tool is advanced to the article in the lathe, according to the depth of cut required, by means of the screw *g*, turned by the handle *h;* when the depth of cut is adjusted by the screw *g*, the slide *c c* and its accompanying tool can be moved along the article to be turned by the handle *d*. This can be rendered completely SELF-ACTING as follows: on the end of the screw *e e*, in place of the handle *d*, fix a toothed ratchet-wheel *c c d*, fig. 193; on the end of the turning article *b b* fix firmly a piece of iron having a projecting finger; this coming in contact with one tooth of the ratchet each revolution of *b b*, the screw *e e*, fig. 192, will revolve and move the tool along a certain distance. In large lathes, the whole of the movements are derived from a prime mover, as a steam-engine. In fig. 193a we illustrate a late improvement in lathes introduced by the celebrated mechanician, Mr. Joseph Whitworth; it is called the "duplex lathe:" part of the lathe-bed is at *m m;* the guide-screw for moving the rest along the length of lathe is shown at *n;* *a a a* the bottom slide-rest; upon this the compound slide-rest *e* is carried; *d* is a similar rest at the other side of the lathe; the tools *f f* are advanced to, or made to recede from, the article *n* to be turned by the right and left screw *c c c*, worked by the handle *b;* the tools are thus acted upon simultaneously. "Not only is double the work performed by this lathe as compared with the common single-cut plan, but it is accomplished with a less expenditure of power, owing to the saving by the lessened pressure against the stay. The work is also executed in a superior manner, there being a perfect balance of forces, and consequently all vibration is done away with; and from the greater durability of the tools so applied, only one-half the usual amount of error arises from wear."

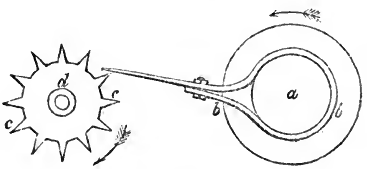


fig. 193.

Where metallic surfaces are to be made smooth and level, the operation of "chipping" and "filing" is performed. The former method consists in removing the rough outer portion by means of a hammer and chisel, much in the same way as a mason levels the surface of a stone with his mallet and tool. The latter is sufficiently indicated by the name. As may be supposed, the rendering of a large surface to a true plane by these manual operations is a matter of some difficulty, and one which involves much time. Indeed, accurate surfaces are scarcely attainable by hand processes; machinery has come to the aid of the mechanic in this department. The illustration in fig. 194 will explain the rationale of machine planing, by which plane metallic surfaces are obtained with undeviating accuracy and remarkable celerity, as compared with the manual processes of "chipping" and "filing." Suppose *a a a* to be a movable carriage, capable of being moved to and fro horizontally in the direction of

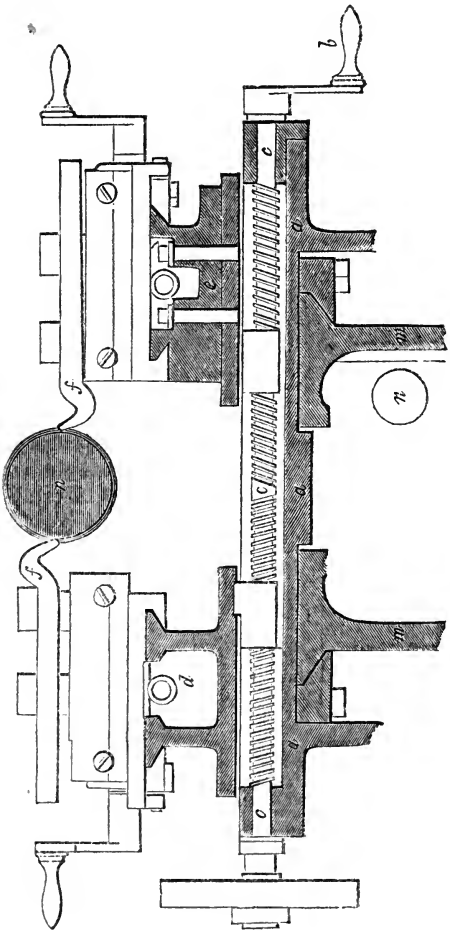


fig. 193a.

the arrows *m m* at a certain speed, and with great accuracy of adjustment; let *b b* be the article to be planed, firmly secured to the lower table; let the tool *c*, with cutting edge *c'*, be fixed in a "holder" above the table, and capable of adjustment by suitable means in two directions, namely, from side to side, as shown by the arrows *o o*, and vertically: the first motion moves the tool across the breadth of the article to be planed; the last brings

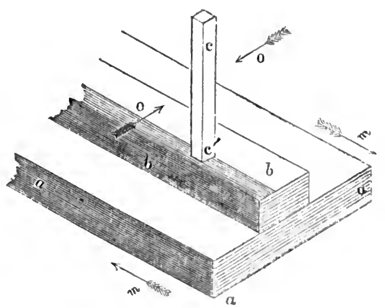


fig 194.

the cutting edge nearer to the metal, in order to take a deeper cut, or the converse. Now if the whole is accurately adjusted, and the carriage *a* moves towards the left hand, the tool will plane or pare away a certain portion of the surface of *b b*. Now suppose the tool to have reached the end of the article, the table *a* takes a quick return motion towards the right; the tool in the mean time being adjusted to its proper place, ready to take another cut, on the table being again moved to the left. In large planing-machines, all these movements are made by ingenious machinery to be self-acting.

In a form of planing-machine now much used, a reciprocating motion is given to the table on which the article to be planed rests, in the following manner. A horizontal disc is placed beneath the table, and worked by hand or power by bevil-gearing; a groove or slot is cut quite across the face of the disc, a link is connected at one end with the under side of the sliding-table, and a pin at the other is fixed at any desired part of the groove in the disc. The revolution of the grooved disc causes a reciprocating motion of the table, proportioned to the distance from the centre of the disc at which the pin is placed. A method of giving the "feed-motion" to the tool-holder is as follows. A small projecting stud is fixed at any desired place in a groove or slot in the side of the table, extending along its length. This stud presses against a movable lever, keyed on the end of a shaft which carries another lever; this acts upon the teeth of a ratchet-wheel, fixed on the end of the horizontal screw which actuates the tool-holder. In planing-machines where the tool cuts while the table moves only in one direction, it is of importance to bring the table back again, in readiness for another cut, with considerable speed. If the return stroke, as it is called, is made at the same speed as the cutting one, it is obvious that much time will be unnecessarily lost; to obviate this, many contrivances have been employed. A description of one of these will suffice for our purpose. It is the arrangement employed in one class of their machines by Messrs. Nasmyth and Co.

A hollow shaft has a pulley fixed on it, near its extreme end and close to the first pulley a second revolves freely; through this shaft another shaft is passed, having at its extremity a pulley keyed on; the three pulleys are thus close together; the centre is merely used to carry the driving-belt when the machine is not in use. The first pulley drives the hollow shaft, the second the central shaft; at the end of the hollow shaft furthest from the pulleys a pinion is keyed on; this works into a wheel; this wheel is keyed on the shaft which carries the pinion working into the rack, which moves the table forward. On the end of the central shaft a small pinion is also keyed; this works into an intermediate wheel, which in its turn gives motion to a wheel fixed in the rack-pinion shaft. When the driving-belt is applied to the pulley on the hollow shaft, the table is moved forward; when it has reached to the end of the cut, the belt is moved to the pulley on the central shaft, and the table is reversed; its return stroke being so much quicker than the forward one, just in proportion to the difference between the size of the wheels on the rack-pinion shaft.

In various parts of machines grooves or slots are frequently required to be cut in some part; thus in cutting the key-seat in the centre eye of a wheel, as in fig. 98, when done by hand, the size of the groove is first marked, and the metal cut out of the solid by means of the chisel; this is afterwards filed up to the proper shape. When machines are used to perform this operation they are termed "slotting machines," and may be defined as a modification of the planing-machine, with movable tools.

In the illustration in fig. 195, suppose *d d* to be a piece of metal in which a groove *e* is to be cut; *c c* the table to which it is fixed during the operation; *ff* a vertical guide, with a groove *g* in its face. In this groove a cutting-tool *a b* slides up and down. Suppose the whole to be adjusted, so that when the tool is made to descend in the guide *g* by appropriate means, its edge will pare a thin cut off the edge of the metal *d d*; the tool is then raised up in the groove *g*; but before it descends, the metal *d d* is moved forward, so that another portion is subjected to the cutting-edge. Thus by alternately raising and depressing the tool, and moving the article to be cut regularly forward to meet the cutting-edge, a groove of any depth can be cut in the metal, the breadth of which is obviously equal to the width of the cutting-tool, and the length to the thickness of the metal in which the groove is to be cut.

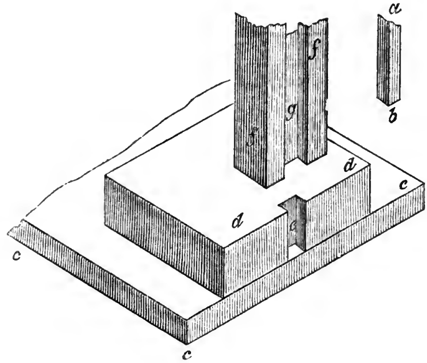


fig. 195.

In fig. 196 we give an elevation of a slotting-machine, where *a a b* is the framing, *c c* the vertical guide-bar in which the cutting-tool slides up and down, *s s* the table on which the article to be grooved is placed: it is moved to and fro on the under part of the framing by the wheel and screw *m m o*; *g* is the driving speed-pulley, *h h* the fly-wheel, giving motion by the toothed wheels *i*, *k* to the eccentric *d d*, to the face of which the connecting-rod *f* is attached by the pin and nut *e*. The way in which the reciprocating motion of the cutting-tool is kept up will now be familiar to the reader on inspection of the drawing: its rationale is described in figs. 160 and 154.

Where a number of holes are required in malleable iron plates, they are made by what is called the "punching-machine." Suppose *d*, fig. 197, to be a fixed table, on which a rest *a* is fixed by bolts *b b*; this rest has an aperture sunk in its surface, or a hole bored through and through it in the direction of its length. A punch *f* is attached to *e*, which has a vertical reciprocating motion given to it. If a plate of iron is placed on the rest *a*, and the punch *f* made to descend with sufficient force, a portion of the metal is forced out, making a circular aperture corresponding to the diameter of punch. The punching-machine employed at the erection of the building for the Great Exhibition of 1851 perforated 3000 holes in a day. Some of these machines in use in the workshops of engineers are of such great power, that holes one inch in diameter can be made through plates of iron three-quarters of an inch thick, with as much apparent ease as the grocer cuts a hole in tasting the merits of a cheese.

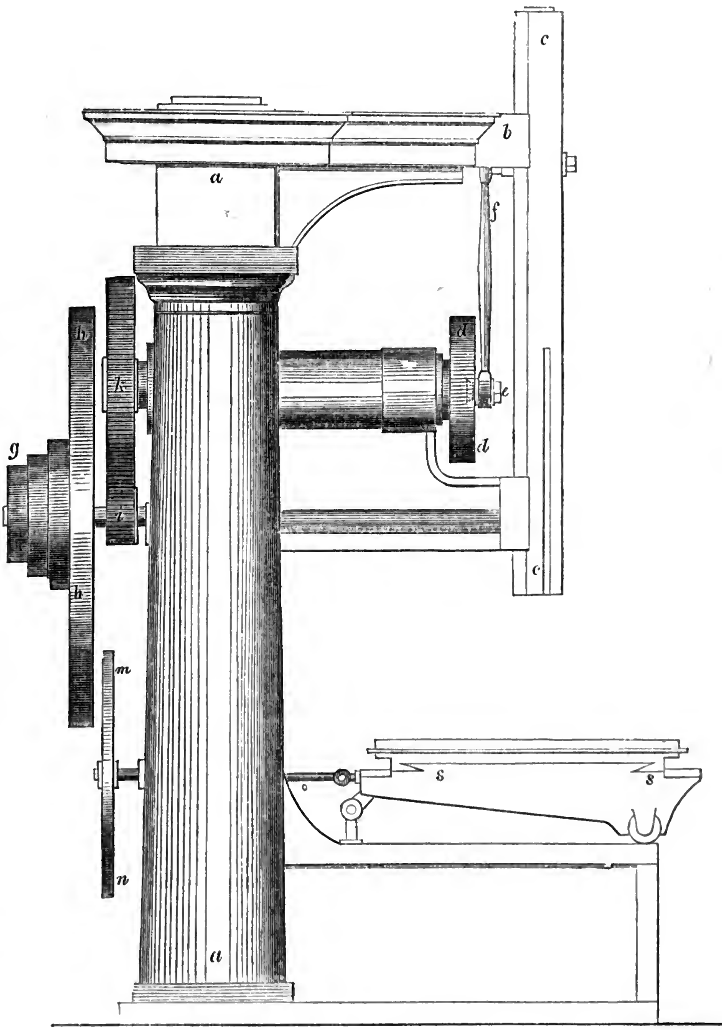


fig. 196.

In dividing plates and bars of malleable iron by HAND, the line of direction is first traced on the surface, then by laborious applications of the hammer and chisel the plate is divided. The blacksmith in cutting a bar asunder places it on a sharp-edged instrument fixed at one end of his anvil, and the heavy tilt-hammer strikes the upper side of the bar till it is divided. In the "shearing-machine," the iron to be divided is placed upon a sharp cutting edge *b b*, fig. 198, fixed by bolts *c c* to the lower table *m m;* the upper cutting-tool *a a* is fastened to *d d*, which has an up-and-down motion; the down motion cuts the plate placed on *b b*. In fig. 199 a simple shearing-machine is shown: *h* the metal to be cut, placed between the cutting-edges *f g;* the upper edge *f* is part of a lever *f d d*, vibrating on the centre *e;* a reciprocating motion is given to the lever *d* by the eccentric wheel *a b* and friction-pulley *c*. In fig. 200, which is a patent punching and shearing machine by Mr. Roberts of Manchester, the up-and-down motion of the cutting-tool *g' f f* is given by means of the eccentric wheel and rod *f f*. The driving-shaft is at *a a*, *c c* the fast-and-loose driving-pulleys, *b b* the fly wheel, *d*

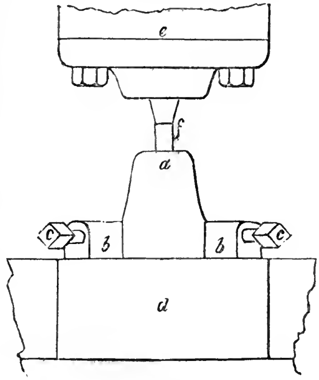


fig. 197.

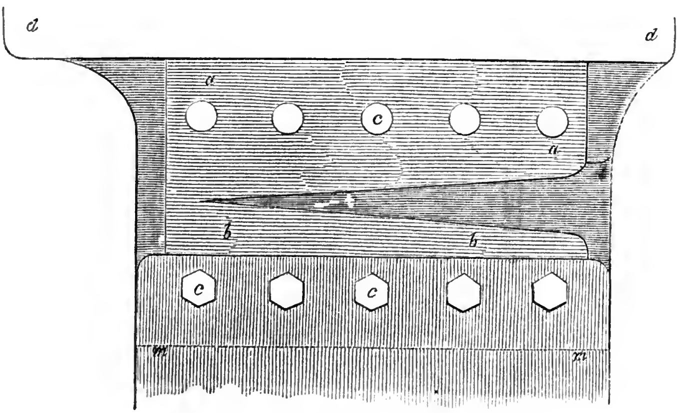
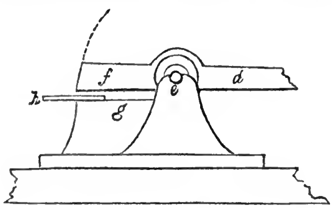


fig. 198.

a pinion fixed on the fly-wheel shaft, working into the wheel *e e*, which gives motion to the eccentric shaft; *h i* is the "punching" part of the machine.



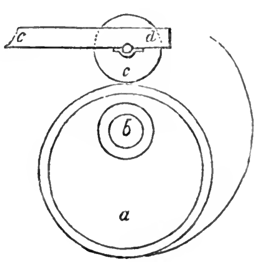


fig. 199.

In making screw-bolts by hand two methods are employed: first, the screw-plate, which in its simplest state is a flat piece of metal, as *a b*, fig. 201, in which are made a series of graduated screw-holes; by passing the circular rod of iron first through the largest hole, and successively to the smallest, the finished screw is obtained; the handle *b* is used for

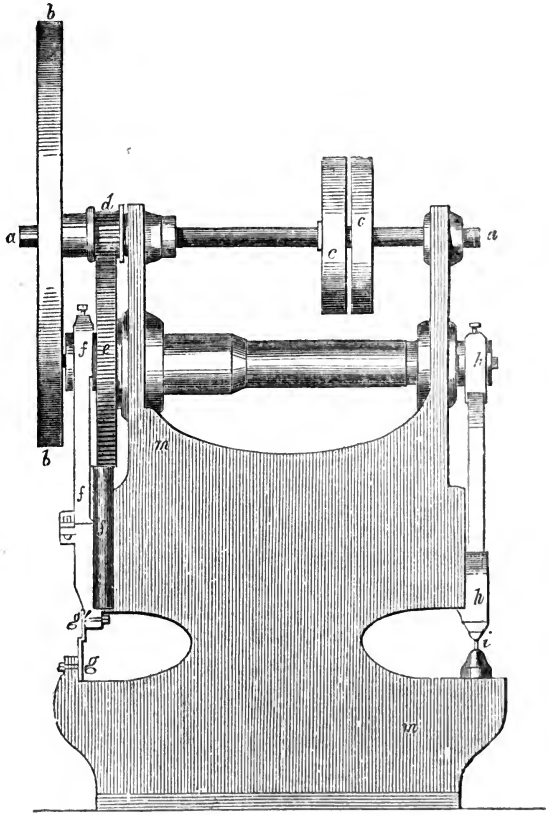


fig. 200.

working the screw-plate: this form is chiefly used for small work. At *e e* another form for larger screws is shown. It is obvious that for each distinct size of screw-bolt to be made, a screw-plate will be required. To obviate this inconvenience, and to obtain from one plate different sizes, the contrivance called the "screw-stock" is used. In this movable dies for cutting the screw are employed, a small pinching-screw being used to bring them close up to the bolt as the cutting proceeds. The most improved form of screw-stock is that known as Whitworth's "guide-stock." It is shown in fig. 202: *d d* are the handle-levers by which the stock is worked; *c c c* the cutting-dies, one of which at the centre is fixed, the other two are movable by the pressure of the screw-nut *b b;* so that they embrace closer as the work proceeds. The bolt to be screwed is placed

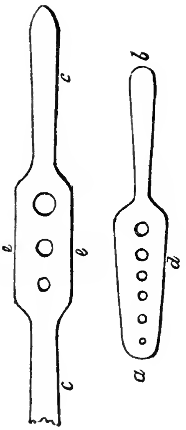


fig. 201.

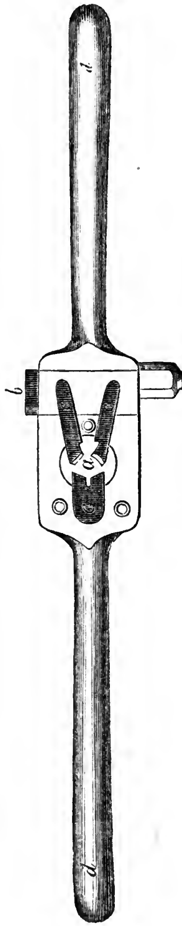


fig. 202.

at *a*. This form of screw-stock is a great improvement on the old. "The steadiness of the guide-stock, and its easy action in screwing, are equally remarkable. In using it, not one-half the force consumed by the common stock is required. The inner edges of the moving dies, which act principally in cutting out the metal, are filed off to an acute angle ; this enables them to cut with extreme ease, and without in any degree destroying the thread, while they take off shavings similar to those cut in the lathe." Nuts are screwed on the inside, so as to fit their particular bolts, by what is called a "tap," having on its surface a screw cut, with pitch corresponding to the dies which cut the thread of the bolts. The form of tap generally used is tapered, the lower end being filed or turned so as to reduce the depth of cutting-edges ; this enables the tap to enter the nut freely, and gradually cuts the thread deeper and deeper as the tap advances in the direction of its length; two or three circular grooves are cut along the length of the tap; these form channels by which the tool clears itself of the cut metal. The end of the tap is square-headed. This is taken hold of by a lever, which serves as the moving power to turn the tap while working. The method of cutting screws by machinery will be understood by the following diagram, fig. 203. Suppose *a a* to be a cylindrical bar of iron, on the surface of which a screw is to be cut, and revolving in a lathe; *c d* a tool-holder and tool, the latter in contact with the cylinder *a a*, the former moved along the guide-screw *b b*. Now, if a toothed wheel be fixed on *a a*, working into another fixed on the guide-screw *b b*, the tool *d* will be made to move along the surface of the revolving cylinder *a a*, and trace out thereon a spiral thread or groove. By arranging the relative proportion of the toothed wheels, a screw of any desired pitch may be cut in the bar *a a;* then suppose the guide-screw to have eight threads in one longitudinal inch, each revolution of the guide-screw will move the tool *d* forward an eighth of an inch; thus if the driving-wheel on *a a* is equal in diameter to the driven wheel on *b b*, a screw will be cut on *a a* having a pitch equal to that on *b b*; but if the driving-wheel on *a a* is double that on *b b*, then the pitch on *a a* will be double that on *b b*, as for each revolution of *a a*, *b b* will make two. But, on consideration, it will be seen that the direction of the thread cut on *a a* will be the reverse of that on *b b*; thus if the latter is a right-handed screw, that on *a a* will be left-handed, from the circumstance of the cylinder *a a* and guide-screw *b b* revolving in contrary directions. To obviate this inconvenience, intermediate wheels gearing with those on the cylinder and guide-screw are used. In practice, the driving and driven wheels are placed towards the left hand of the lathe, the driving-wheel being fixed on the lathe-spindle, the cylinder to be screwed being fastened to the centre-point and chuck in the usual way.

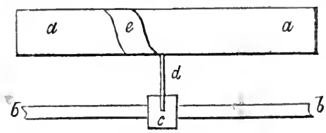


fig. 203.

For making small screw-bolts the lathe is superseded by the "screwing and tapping machine," of which the following description will suffice to make the principle of its operation understood. The bolt to be screwed is placed in a chuck *a*, fig. 204, fixed at the end of the lathe-spindle; the dies are placed on a frame *c*, which travels on two parallel bars *d*; the dies are made to embrace the bolt to be screwed, so as to have sufficient hold of its surface; it is then made to revolve, which causes the frame with the dies to traverse along the bolt. On the die-frame being made to traverse as far as required on the bolt, the driven wheel *e* on the lathe-spindle is thrown out of gear with the driving-wheel *f* by means of a clutch and lever *g*; at the same time, the other end of the clutch locks into another wheel *m*, and this again gears into another *n*; by this means the lathe-spindle and bolt is reversed, and the die-frame moves on the parallel bars outward from the bolt; as it is essential to save time in the return or reverse motion of the die-frame, this is effected by the increase of diameter of the wheel *m*, gearing into that which reverses the lathe-spindle *n* over *f*, that which gives the direct motion thereto. By substituting a tap in the lathe-chuck for the cylinder to be screwed, and fixing a nut in the die-frame, it is obvious that on the tap catching the nut,

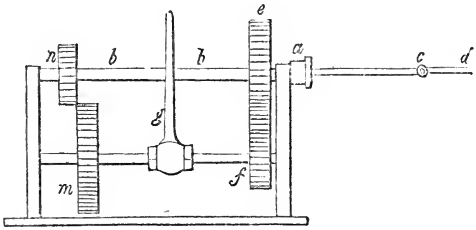


fig. 204.

it would be pulled forward by the revolution of the tap, and its interior screwed. Nuts are made of different shapes, square, hexagonal, or octagonal. In finishing them, so as to bring their sides square, flat, and polished, by hand, they are placed in a vice, and by means of the hammer and chisel are first brought to a comparatively flat surface; they are then rough filed, next smooth filed, and brought to a polish when perfectly flat by means of emery and oil. This operation is a tedious one, and moreover expensive, when the nuts are numerous; machines have, therefore, in large establishments been employed to cut the faces of nuts and bring them rapidly to true surfaces. In an efficient form of "nut-cutting machine," the faces of the nuts are cut by the action of a revolving cutter fixed at the end of the spindle of the fixed head; the nut is placed on a table capable of being moved forward to meet the cutter, by means of a handle, wheel, and screw. The different faces of the nut are presented at the required intervals by causing the table on which it is supported to revolve horizontally for a certain definite distance, it being retained in this position till the face is cut by means of a spring-catch fitting into notches in the periphery of the lower part of the table. The feed-motion of the table can be made self-acting by simple means: corresponding speed-pulleys are fixed, one at the end of the driving spindle which moves the cutter, the other on a horizontal shaft placed beneath the table, and extending along the side of the machine; at the end of this shaft, and immediately beneath the table on which the nut to be cut is fixed, a small worm or endless screw works into a toothed wheel; on the shaft of this is a small pinion, which gears into a rack placed in the lower part of the table.

Rivets are used in mechanical operations for tightly securing plates

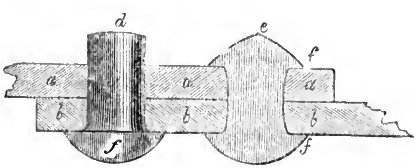


fig. 205.

together, as the edges of boiler-plates: thus, suppose *a a*, *b b*, to be the edges of two boiler-plates; holes are punched in each, so that when the plates are laid together the holes will correspond; rivets made of malleable iron, and circular, are passed through the holes; they are longer than the combined thickness of the two plates; the rivets are passed through the holes red-hot, and while one man holds tightly on with a hammer, pressing on the part *f*, one or more workmen hammer quickly on the part *d*, and speedily bring the head into the shape as shown at *e f*. The noise produced by this process is very great, especially when the boiler approaches completion; the reverberations in the interior adding to the noise of the repeated blows on the ringing metal. There are many objections to riveting by hand; it is tedious and costly; moreover, from the repeated blows given to the rivets, the iron is crystallised, and the heads are apt to break off. Steam machinery is now largely employed for riveting. The "steam riveting-machine" was first introduced by Mr. Fairbairn of Manchester; we give an elevation of it in the Frontispiece. The principle of the machine is that of the mule-joint lever; a revolving camb gives motion to this lever, at the extremity of which the ferule for compressing the rivet is fixed. This machine is quite noiseless in its operation; it acts by compressing the iron while hot; it is capable of fixing, in the firmest manner, eight rivets three-quarter inch diameter in a minute, with the attendance of two men and two boys to the plates and rivets, whereas the average work that can be done by two riveters with one "holder on" and a boy is forty similar rivets per hour; the increase in quantity of work done by the machine being at the rate of twelve to one, exclusive of the saving of one man's labour. The riveting dies are of various descriptions, adapted to every description of flat or curved work; even the corners are riveted with the same ease as other parts, so that vessels of any shape may be completed without recourse to the old hammering process. Messrs. Garforth of Dukinfield exhibited in the "Crystal Palace" a steam riveting-machine, capable of being worked at a high speed. The pressure of the steam is applied directly to give the compression to the rivet; the cylinder is horizontal, and the die is fixed to the end of the piston-rod; to get the desired pressure a large cylinder must be used, as there is no mechanical contrivance adopted between the point of power and that of resistance; hence the expenditure of fuel and steam must be very considerable; they are nevertheless coming rapidly into use.

The forging of large and small pieces of iron into proper shapes by means of machinery is fast superseding, for many kinds of work, the costly and tedious manual labour of the "blacksmith" and "forger." The method of bringing red-hot masses of iron into shape by means of the anvil and hammer is too well known to need description. The "steam-hammer" of Nasmyth (fig. 206) is the most perfect and controllable of any yet introduced for forging large articles. In this steam-hammer the piston-rod *a* of an inverted high-pressure cylinder *b* is attached to a mass of cast iron *c*, sliding between two upright guides. The steam is let in *under* the piston of the cylinder, which is lifted up together with its attached hammer-block to any required height, when by its own motion the steam is allowed to escape, and down comes the hammer with vast energy on any substance placed on the anvil *d*. By the controlling machinery at *e*, the height of the fall, as well as the velocity, may be so completely controlled, as to bring the hammer down with its full power, or so gently as merely to drive in a nail.

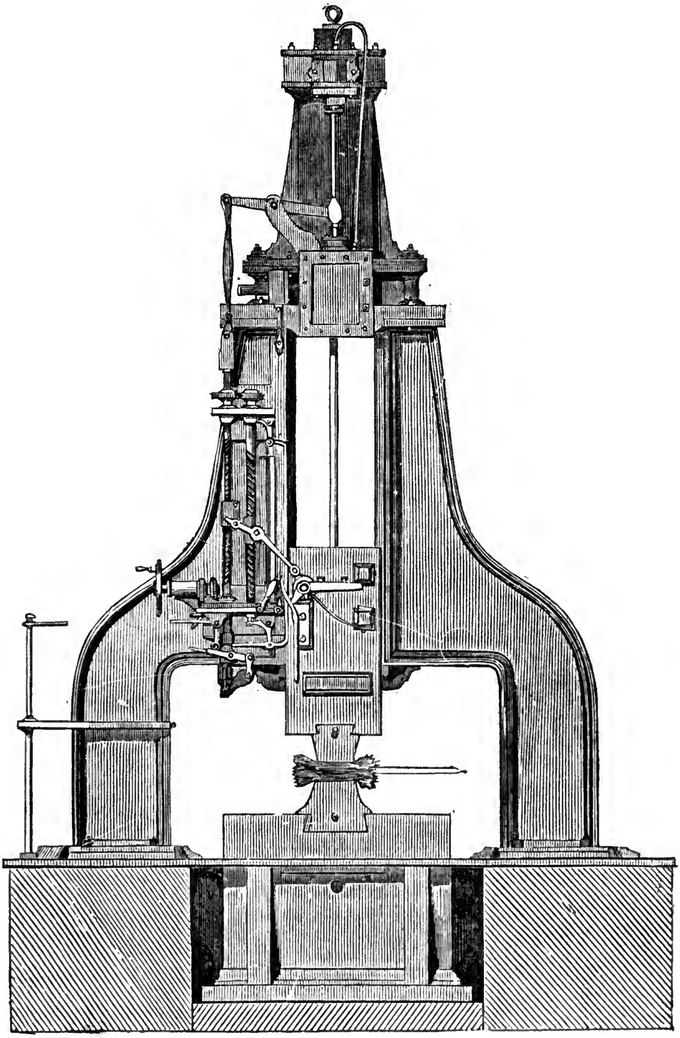


fig. 206.

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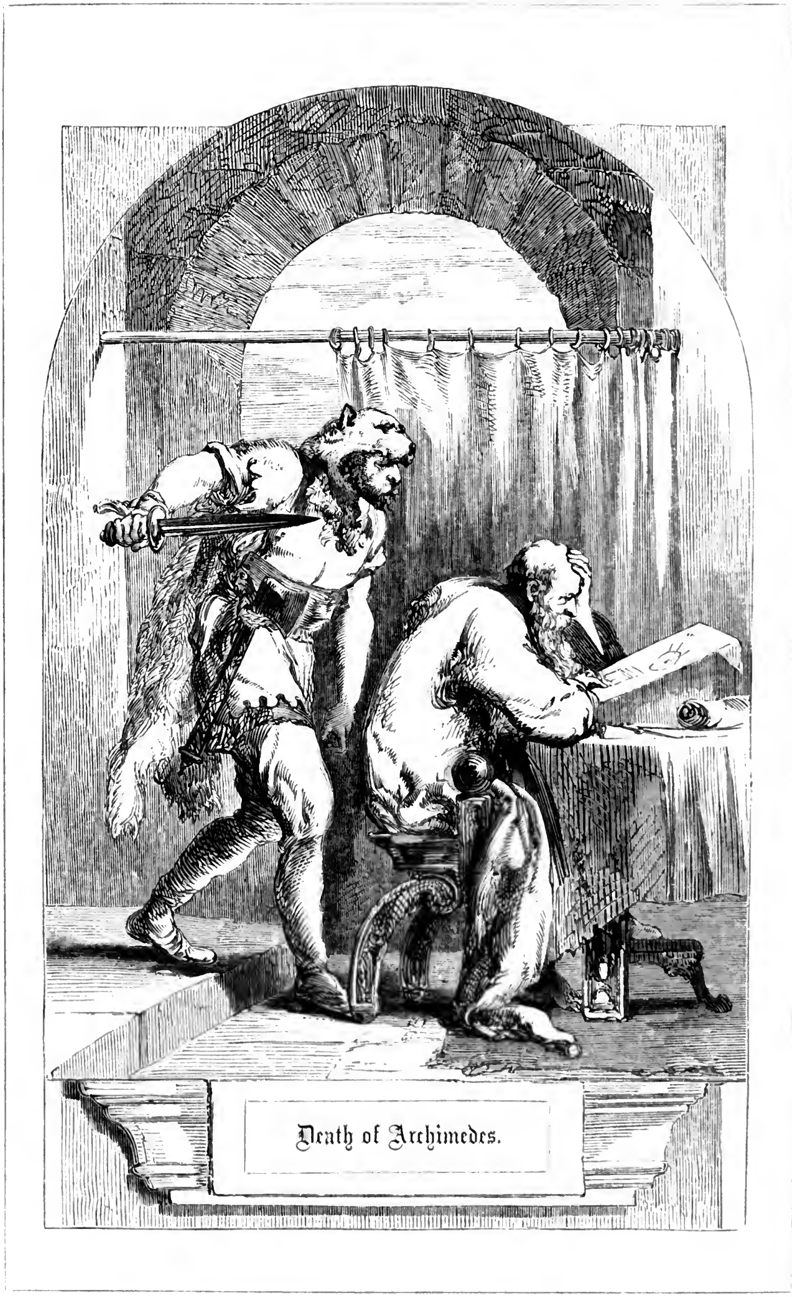


Death of Archimedes.

THE ILLUSTRATED LONDON GEOMETRY.

THE ILLUSTRATED LONDON

PRACTICAL GEOMETRY

AND ITS APPLICATION TO

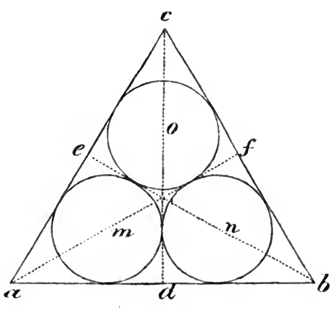
ARCHITECTURAL DRAWING.

FOR THE

Use of Schools and Students.

By ROBERT SCOTT BURN, M.E. M.S.A.

EDITOR OF THE "ILLUSTRATED LONDON DRAWING-BOOK," "MECHANICS AND MECHANISM," ETC.



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GEOMETRY APPLIED TO ARCHITECTURAL DRAWING.

INTRODUCTION.

The term *Geometry*, according to its strict derivation, means the "art of measuring the earth." The science is supposed to have originated with the Egyptians. The annual overflowings of the Nile caused frequent destruction to the marks and boundaries of the fields on its banks, hence the first impulse to the discovery of means whereby a knowledge of their extent and boundaries could be ascertained and recorded. Whether this be the true history of the origin of the art or not, it is not within our province to determine; like many other theories, it may be more fanciful than correct. We are rather inclined to think that the science has been a strictly progressive one, a slight knowledge of its use and elements being possessed by man even in the early stages of the world's history. In daily contact with material things, the eye becomes accustomed to measure distances and scan altitudes, the river's breadth, and mountain's height,—the hand, in grasping objects, to ascertain their figure and estimate their bulk. The science of Geometry is now, however, that which investigates the properties of magnitude generally, and its relation to number,—its objects are, extension and figure.

Geometry is divided into two parts or branches—Theoretical or Demonstrative, and Practical or Constructive: in the former the principles of the science are treated abstractly; the latter shews their application to the useful purposes of every-day life. In the varied branches of the arts and sciences, numerous are the operations performed by its aid. In the warlike operations of the "tented field," the soldier is indebted to it for assistance in razing the fortress and cannonading the "leagured town,"—the sailor, ploughing the pathless deep, owes his safe arrival in his destined port to its unerring guidance,—the architect, in designing his specimens of the beautiful,—the engineer, in carrying out his gigantic operations,—the mechanic, in planning an automaton machine, a steam-engine, or a power-loom; all are indebted to a knowledge of its properties, and a facility in performing its constructions. And not less observable is this in the humbler walks of trade and commerce; for in almost all of them may its influence be traced and its importance exemplified.

Practical Geometry is the basis of all drawing. As the combination of lines and curves of the various letters form the foundation of written language, so the like combinations in geometrical construction form, we conceive, the foundation of the art of general drawing in all its branches. We do not insist so much on the fact, that the lines and figures known as geometrical are to be found more or less strongly indicated in all the varied and graceful forms scattered before us—floating in the air—waving in the trees—adding beauty to the rich landscape, or mirrored in our glassy ponds; but we would rather impress upon the mind of the reader the importance of the truth, that a knowledge of Geometry is essentially requisite before an acquaintance with accurate drawing is attainable. That a freedom of handling, a finish of touch, or an exquisite grace in pencilling, is attainable by desultory and long-continued practice, we do not deny, and that such attempts will often pass for correct drawing; but let them be carefully examined, and the truth will become evident that their beauty has been merely in the execution, and their accuracy only apparent. Even in artists of acknowledged celebrity, whose works have been scarcely less admired for their originality of conception than for their exquisite colouring, defects are observable by a cultivated eye, which owe their existence to a want of geometrical knowledge. And this fault may be more frequently found than is generally acknowledged. But a short time ago the Master of a School of Design regretted that he could not impart a correct knowledge of the higher branches of the art of delineation to pupils whose delicacy of finish, or other qualities, justified the attempt, because the principles and practice of perspective had to be mastered, and this was not available from their ignorance of the *merely rudimentary* principles of Practical Geometry. To us the remedy seems amazingly simple. Such a work as we now present to the reader may be useful in similar cases, in providing means by which the requisite knowledge so desiderated may be easily imparted. We feel confident that greater progress, even in artistic drawing—a branch generally considered as having but a slight connection with Geometry—would be made, if the pupils were, as a matter of everyday education, rendered familiarly acquainted with geometrical forms and their applications, their construction and proportions, their combination and transposition, the power of estimating distances, and the direction of lines. Drawing, in its widest acceptation, may be defined as "the art of delineating and representing forms and objects;" and as these are susceptible of the greatest diversity of change, dependent upon the position in which they are viewed, it is clearly requisite that the pupil be able to estimate precisely the amount of such change, before the objects themselves can be delineated with accuracy. This facility of estimation is solely to be acquired by a knowledge of the constituent parts of the forms themselves, assisted by a practical adaptation of the mathematical principles which govern the laws of vision. Hence may be deduced the reason why so many fail to delineate objects accurately; having no fixed principles to which to recur, they draw them as they see them, or fancy they see them, not as they really exist or are presented to them. Nor is it till they are acquainted with the structure and combinations of the lines which form all objects, however complicated, and the laws which govern their transmission to the visual organs, that they can see the violent errors of delineation they have committed. And this essential knowledge can only be obtained by the aid of Practical Geometry. We are aware that a considerable prejudice exists in the minds of many, as to the utility of a thorough knowledge of geometrical drawing; it has been generally looked upon as only useful to the architect, the engineer, and mathematician, or to the operative in his workshop. Being thus looked upon as an exclusive branch of education, it has been treated as if exceedingly limited in its application. That it is not so, we trust we have already shewn; and further comment as to its universal usefulness, in this the time of practical science, we deem, here at least, to be altogether unnecessary.

The following treatise has been designed to present a series of useful geometrical problems, the whole of which may be made available in the various departments of practical science. We have given none which require for their construction expensive or complicated instruments—the drawing-board, square, ruler, compasses, pen and pencil, comprising all that are requisite. We have refrained from giving those problems connected with the Mensuration of Surfaces, or Heights and Distances, which require the aid of more expensive instruments, and a knowledge of principles and rules, chiefly as we conceive them to belong to the branches which should be treated of under the distinction of Theoretical and Practical Mathematics. We do not consider it necessary to take up space by describing the instruments essentially requisite; all that is required is their distinctive names, their construction being at once obvious on inspection. Those, however, who are desirous to become acquainted with the more complicated instruments, and their use in the higher Mathematics, we beg to refer to the work above noted, in this series, where a full description will be met with. The requisite instruments are, 1st, the drawing-board: this should be at least 18 inches by 12 broad, made of good seasoned baywood, having cross pieces at the ends to prevent warping. 2d, the drawing-square: the blade must be equal in length to that of the board; one made with thumb-screw and movable stock will be useful in drawing oblique lines. 3d, parallel ruler: the wheel-form is the best and most useful. 4th, compasses: two are requisite; one with a pencil-leg, called "bow compasses," the other having a pen-leg, for inking in the circles, &c.: a pair of small compasses, termed "spring dividers," would be of use in marking off minute divisions; for executing large diagrams a pair of large compasses with movable leg will be requisite—pencil and pen legs will be necessary with this. 5th, "drawing pen:" lines of various thicknesses can be drawn by this, by merely turning the screw. 6th, pencils; a very good kind for general use is Foster's "phonographic" pencil. Cartridge paper will serve admirably for the initiatory lessons; it may be fastened on the board by "drawing pins," or by pieces of gummed paper, or even by wafers.

R. S. B.

May 1853.

THE ILLUSTRATED

LONDON PRACTICAL GEOMETRY.

DEFINITIONS AND CONSTRUCTIONS.

A POINT is that which has no parts—such is the true mathematical definition; it is thus merely an idea, not apparent to our senses. But to perform an operation, we must have something obvious to these; it has therefore been agreed upon to represent a mathematical point, which has merely position, by a physical one, which has comparative size, and is generally made by the point of a pencil, a pin, or compass-leg: the position from which a circle is described, as *a* fig. 14, is termed a point; also the places *a, b, c,* fig. 1, where two lines intersect or cut one another; it is in this case generally called the 'point of intersection.'

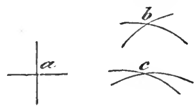


fig. 1.

A *line* is that which has length, but not breadth; it has been defined as the 'flowing of points.' A geometrical line is therefore made by joining a succession of points, and this is done by placing the edge of a ruler to coincide with the points *a, b,* fig. 2, and drawing along it with a

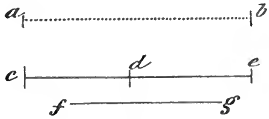


fig. 2.

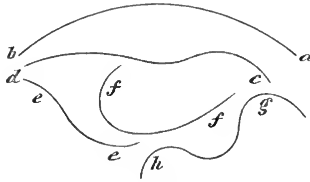


fig. 3.

pencil or graver. A line is termed *indefinite* when it has no obvious termination, as *a b*; *finite,* when terminated by obvious marks, or supposed to have such, as *c, d.* A line is said to be *produced* when it is lengthened in the same direction; thus a line may only extend to *e,* fig. 2, but it may be produced to *d* or *c.* A *circular* line, *a b,* fig. 3, is that which is continually changing its direction and described by compasses from one point, which is termed its centre; the line forming a circle is a completed circular line. A *curved* line, *e d*, is that which is drawn in more than one direction. In geometrical drawing, lines are used in two ways: 'apparent' or 'determined' lines, as *a b*, fig. 4;

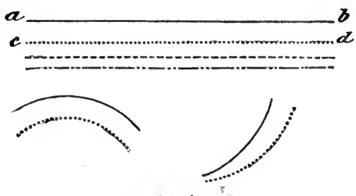


fig. 4.

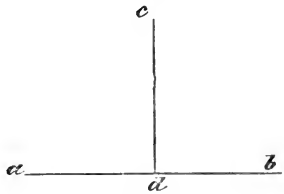


fig. 5.

and 'occult' or 'partial,' as *c d*. In general, occult lines are shewn in diagrams as only useful in constructing them, but meant, after the operation is performed, to be rubbed out, the determined lines being left in. A line is said to be *perpendicular* to another, as *a b* to *c d*, fig. 5, when the angles on each side of the upright line are equal to one another. A line is said to be *vertical*, as *c d*, when it inclines neither to one side nor the other; it differs from a perpendicular line in the fact that it is always straight up, whereas a line may be perpendicular to another, and yet be itself much inclined: thus a ship's mast may be both vertical and perpendicular to the deck in time of complete calm; but if storms arise, and the vessel reels over to one side, the masts are no longer vertical, although still perpendicular to the deck: this distinction should be carefully noted. A *horizontal* line is that which is parallel to the horizon, or at right angles to a vertical line; *a b* is a horizontal line. Lines that are neither vertical nor horizontal are said to be *oblique*, as *a b*, *c*, and *d*, fig. 6. Lines that follow one another at equal distance, and which if produced ever so far both ways never meet, are called *parallel lines*, as *a b*, *c d*, *e f*, *g h*, fig. 7.

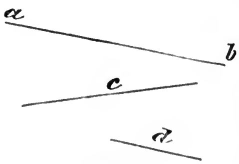


fig. 6.

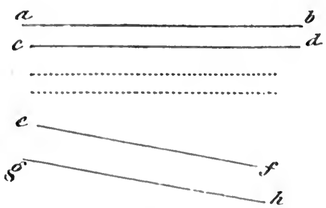


fig. 7.

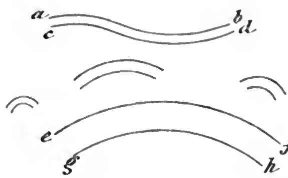


fig. 8.

Curved lines, as *a b*, *c d*, fig. 8, may also be parallel, and circular lines, *e f*, *g h*; these are termed also *concentric*, as in fig. 86 are two concentric circles. The *sides* of a figure, or the *boundary-lines*, are those within which the figure is contained, as *a b*, *c d*, fig. 13, are the sides of the figure *a b c d*; the line *c d* is called the *base*, on which the figure rests or is constructed. Lines that incline towards one another, as *a b*, *c b*, figure 9, and if produced would meet in a point, are angular lines, and form an angle, as the angle *a b c* or *c b a*; when the lines are right or straight lines, *a b*, *c b*, the angle is *rectilineal*, but if curved or circular, as *f g*, *h g*, it is a *curvilinear* angle. When a perpendicular line cuts another, as *a b*, *c b*, fig. 10, the angle formed at the point of intersection is called a *right* angle. If an oblique line meets a horizontal one, the angle formed at the point of intersection is either an acute or an obtuse: an *obtuse* angle, *a b c*, fig. 11, being greater than a right angle, or more than ninety degrees; an *acute* angle, fig. 12, less than a right angle.

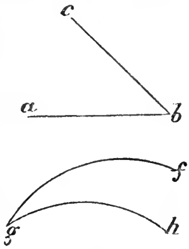


fig. 9.

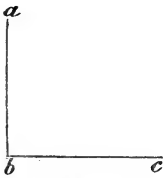


fig. 10.

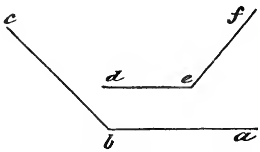


fig. 11.

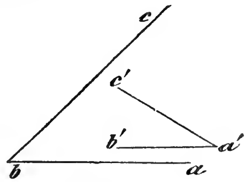


fig. 12.

A *superficies*, or *surface*, is that which has length and breadth, but not thickness; hence it is that which is formed by boundary-lines, as *a b d c*, *e f h g*, fig. 13. A *figure* is that which is contained by three (fig. 19) or more (fig. 31) sides. A *diagonal* is a line drawn across a figure, as *c b*, *f g*, fig. 13, joining opposite angles. Figures bounded by right lines are termed *rectilineal*; those by curved, *curvilineal*. A *circle* is drawn by placing one leg of the compasses in the centre, as *a*, fig. 14, and opening the compasses till the other leg reaches the point *b*, then cause this leg to revolve round the point *a* till it returns to itself; the distance

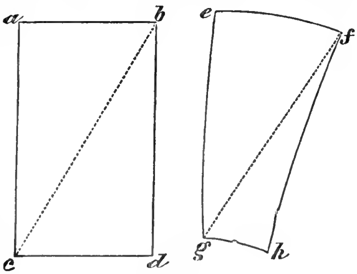


fig. 13.

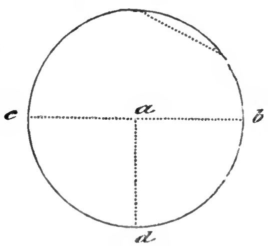


fig. 14.

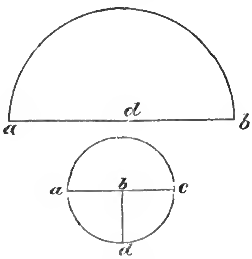


fig. 15.

by which the circle is described, as *a b*, is called the *radius*, and the *diameter*, as *c a b*, is double the radius; the boundary-line is called the *circumference.* There are 360° in a *circle,* 180° in a *semicircle,* *a d b*, fig. 15, and 90° in a *quadrant,* as *c a b*, fig. 16. The semicircle is described from the centre *d*; the quadrant from *a*; two lines, *a b*, *a c*, being first drawn at right angles to one another. A *segment,* as *a*, *b*, fig. 17, is a portion of a circle contained by part of the circumference and a straight line joining its extremities, as *c d*, *e f*; this straight line is called the *chord,* and an *arc* is part of the circumference of a circle. A *sector* is part of a circle bounded by two radii, or semi-diameters, as *a b*, *a c*, fig. 18, and part of a circumference.

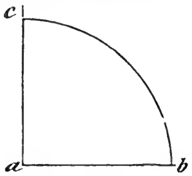


fig. 16.

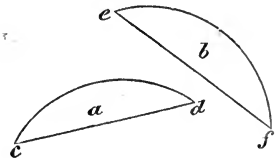


fig. 17.

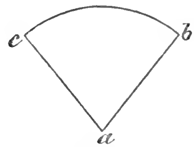


fig. 18.

An *equilateral triangle* is a right-lined figure, having three equal sides, as fig. 19.

A *right-angled triangle* is that which has a right angle, as fig. 20; *a b* is called the base, *b c* the perpendicular, and *a c* the hypotenuse.

An *isosceles triangle* is that which has two equal sides, as fig. 21.

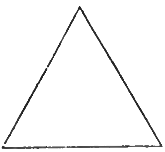


fig. 19.

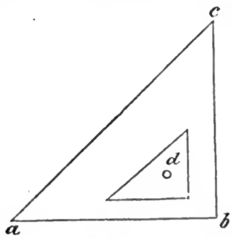


fig. 20.

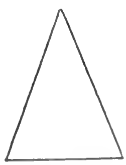


fig. 21.

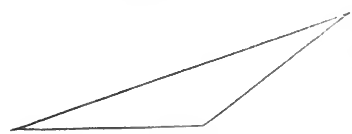


fig. 22.

An *obtuse-angled triangle* is that which has an angle greater than a right angle, as fig. 22.

An *acute-angled triangle* is that which has three acute angles, as fig. 22 *a*.

A *scalene triangle* is that which has three unequal sides, as fig. 23.

A *square* is a figure contained within four equal sides, all the angles of which are right angles, as fig. 24.

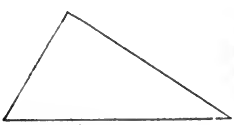


fig. 22 *a*.

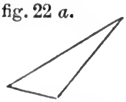


fig. 23.

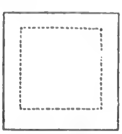


fig. 24.

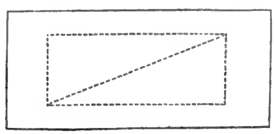


fig. 25.

A *parallelogram* is a rectilineal figure, contained within four equal sides, two of which only are equal, as fig. 25.

A *rhomboid* is a quadrilateral, or parallelogram, but has no right angles, as fig. 26.

A *rhombus* is a quadrilateral, the sides of which are equal, but has no right angles, as fig. 27.

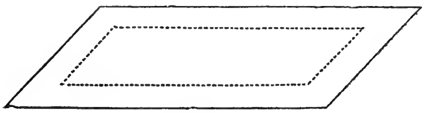


fig. 26.

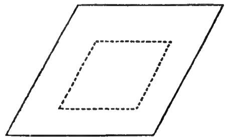


fig. 27.

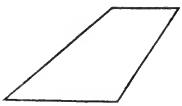


fig. 28.

A *trapezium* is a quadrilateral, the opposite sides of which are neither equal nor parallel, as fig. 28.

A *trapezoid* is a quadrilateral, none of its sides being equal, but two parallel, as *a b*, *c d*, fig. 29.

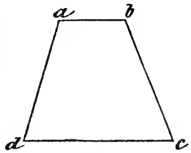


fig. 29.

A *pentagon*, *a e d c b*, is that which has five sides; it is of two kinds, equal-sided and angled, as fig. 30, and irregular, as fig. 31.

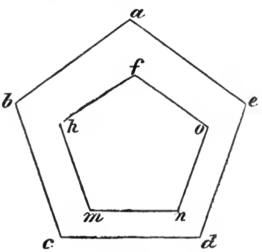


fig. 30.

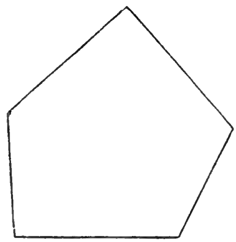


fig. 31.

A *hexagon* is a figure having six sides, *a f e d c b*; it is of two kinds, equilateral and equiangular, as fig. 32, and irregular, as fig. 33.

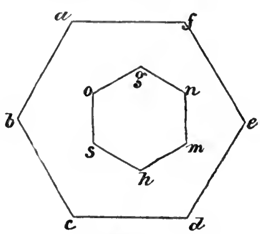


fig. 32.

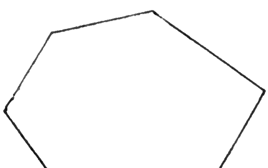


fig. 33.

A *heptagon* is a figure having seven sides; it also is of two kinds, regular, as fig. 34, and irregular, as fig. 35.

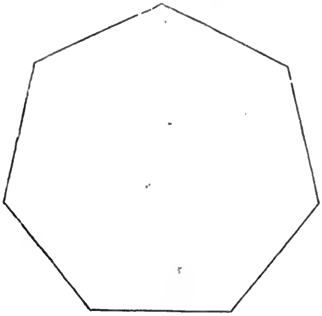


fig. 34.

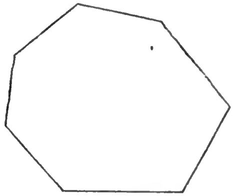


fig. 35.

An *octagon* is that which has eight sides; it is of two kinds, regular and irregular; fig. 36 is a regular octagon.

A *nonagon* is that which has nine sides; fig. 37 is an equal-sided nonagon.

A *decagon* has ten sides; fig. 38 is an equal-sided decagon.

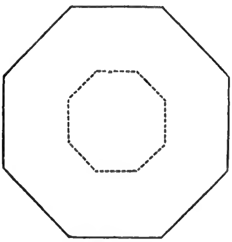


fig. 36.

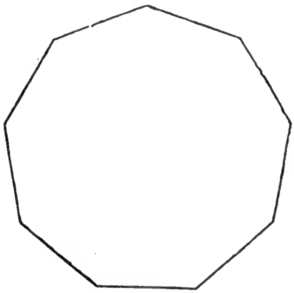


fig. 37.

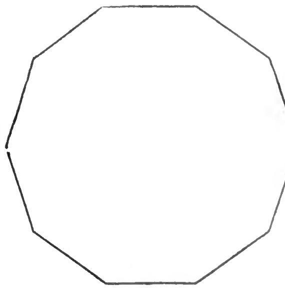


fig. 38.

An *ellipse* or *oval*, as it is more popularly termed, is produced by the section of a cone, *a c b*, by a line *d e*, not parallel, that is oblique, to its base, as shewn in fig. 39. The largest diameter, as *a b*, fig. 40, is called the 'transverse diameter' or 'axis;' the shortest, *c d*, the 'conjugate.' The

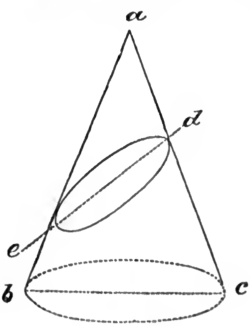


fig. 39.

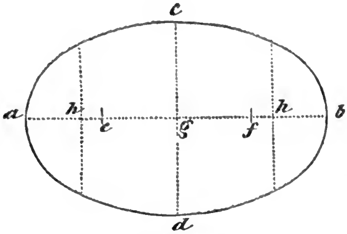


fig. 40.

two centres, *e*, *f*, are termed the 'foci;' they are placed in the transverse diameter, at an equal distance from the conjugate. The 'centre' of the ellipse is at the point of intersection of the two diameters. All lines drawn within the ellipse, parallel to one another, and bisected by a diameter, are called 'ordinates' to that diameter which bisects them, as *h h*. The point where the diameters touch the circumference, or boundary-line of the ellipse, is called the 'vertex.' When the transverse diameter, as *a b*, is cut into any two parts by an ordinate, as *e*, the parts *a e*, *a g* are called 'abscissa.'

A *parabola* is the plane of a section of a cone *a b c* cut by a line *d e* parallel to one of its sides, as shewn by fig. 41. A line, *a b′*, fig. 42, through the middle, is called its 'axis,' *c a d* the 'directrix,' *e* is the 'vertex;' all lines, as *f f*, that cut the axis at right angles are called 'ordinates;' the greatest ordinate, as *b b*, limiting the length of the parabola, is called the 'base;' right lines drawn within a parabola parallel to its axis, as *g′*, are called 'diameters;' the ordinate drawn through the focus is called the 'parameter;' the abscissa is that part contained within the vertex and the ordinate *b b* which limits its length, as *e b′*.

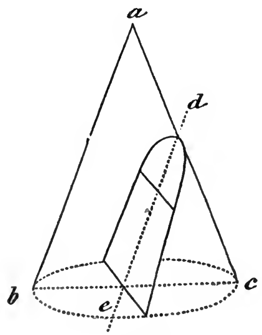


fig. 41.

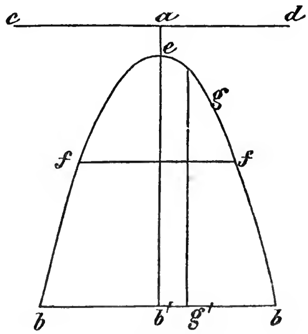


fig. 42.

The *hyperbola* is a figure formed by the plane of a section of a cone, *c b d*, fig. 43, by a line either parallel to its axis, as *g*, or otherwise, as *e a*, so that if the cutting line be produced through one side of the cone, as at *o*, it may meet the other side of the cone, if it be produced beyond the vertex *b*, as to *a*. The figure *h n o n m* is a hyperbola. The line *o g* drawn through the middle is called the 'axis;' that part of it, as *o a*, which is produced till it meets the other side of the cone produced, is called the 'transverse diameter.' Ordinates are lines drawn within the figure at right angles to the axis, as *n n;* that ordinate passing through the focus is the 'parameter;' the middle point of the transverse diameter is called the 'centre of the hyperbola'—from this point lines can be drawn, which will approach

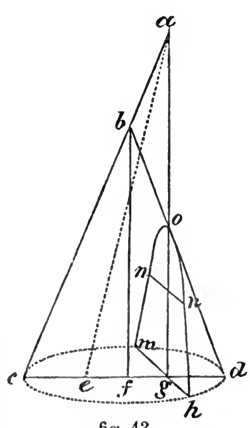


fig. 43.

nearer and nearer to the sides of the hyperbola, yet never really meet, however far the curve-lines be produced; lines thus drawn are termed 'asymptotes.'

The *conjugate axis* is a line drawn through the centre of the hyperbola, terminated by a circle, drawn from the vertex of the curve; the radius of this circle being the distance between the centre and focus of the ellipse. The asymptotes are drawn from the centre through the terminations of the conjugate axis.

The *conchoid,* a conic section or curve, discovered by Nicomedes about the year A.D. 450, the properties of which will be hereafter described; in figure 44, which represents the curve, *a b* is the centre-line, *f e* the 'superior conchoid,' and *d c* the 'inferior conchoid.'

The *cissoid,* another curve or conic section, shewn in fig. 45, was discovered by Diocles, a mathematician who flourished about A.D. 150.

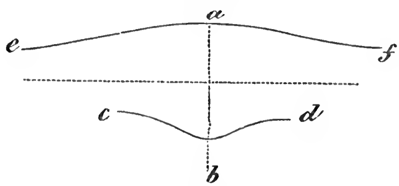


fig. 44.

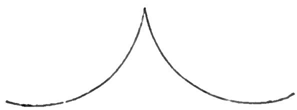


fig. 45.

The *cycloid,* a curve generated in the following manner:—Let *a b*, fig. 46, be a straight line, along which the circle *c d* rolls as a cart-wheel does along a road; if the distance *a b* is equal to the distance which the circle rolls over in one revolution, or in other words equal to its circumference, the point *c* will trace out the curve, as shewn in the diagram.

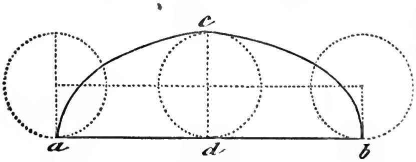


fig. 46.

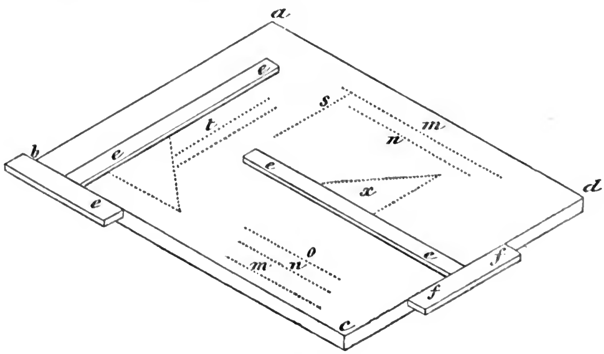


fig. 47.

In fig. 47 we give a representation of the drawing-board, *a b c d;* the square is *e e f f.* Fig. 48 shews the two forms of parallel rulers. Figs. 61 and 62 are various forms of scales. Fig. 69 is a ‘diagonal scale;’ and fig. 65 a ‘protractor.’ These we shall more fully describe hereafter.

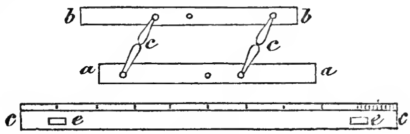


fig. 48.

PROBLEMS.

To draw a right line parallel to another, at a given distance. Let *f e*, fig. 49, be the line, and *d* the distance. With the distance *d* in the compasses as radius, from any two points, as *g*, *h* in the line *f e*, describe arcs at *m n;* touching these draw a line *o o;* it is parallel to *ef*.—Meth. 2d. Let *a b*,

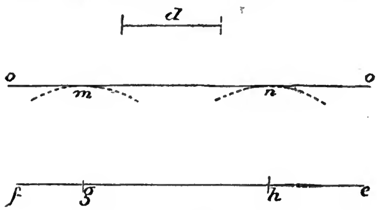


fig. 49.

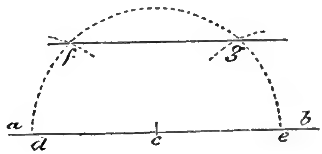


fig. 50.

fig. 50, be the line; another parallel to it may be drawn at any distance as follows : from any point *c* with any radius describe a semicircle; from the points where it cuts *a b* at *d e*, with same distance cut the semicircle in *f g;* through these points draw the desired line.—Meth. 3d. Let *a b*, fig. 51, be the line, and *c* a point above it, through which it is desired to draw a line parallel to it. From any point *d* draw a line to *c;* with *c d* as radius, from *c*, *d* describe arcs; from *d* and *e*, with distance *e c*, cut the arcs in *f* and *c;* through the points thus obtained draw *c f;* it is parallel to *a b*.—Meth. 4th. Let *a*, *b*, fig. 52, be two points through which it is desired to draw two lines parallel to each other. Draw a line *b c* through the point *b;* from *a* describe an arc touching *b c;* from *b* with same radius describe another arc *e;* through *a* draw a line *a e*, touching the arc *e;* *a e* is parallel to *b c*.

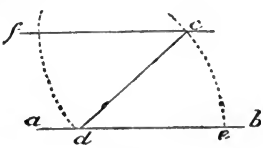


fig. 51.

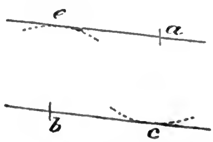


fig. 52.

To draw a line perpendicular to another at a given point. Let *b a c*, fig. 53, be the line, and *a* the point. From *a*, with any radius, describe a semicircle cutting the line in *b* and *c;* from *c*, *b*, with radius *b c*, describe arcs cutting in *e;* join *a e;* it is perpendicular to *b c*.—Meth. 2d. *When the point is above the line.* Let *b c*, fig. 54, be the line, and *a* the point; from *a*, with any radius, describe an arc cutting *b c* in *b*, *c;* in these points, with same distance, describe arcs cutting in *d;* draw *a d*.—Meth. 3d. *When the point is at the end of the line.* Let *a*, fig. 55, be the point, and *a b* the line; take any point *c* above the line, with *c a* describe part of a circle; from *b* draw a line through *c* to *e;* where this line cuts the circle draw to *a*.—Meth. 4th.

Let *a b*, fig. 56, be the line, and *b* the point: from *b* with any radius as *b c*

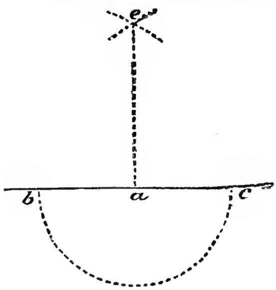


fig. 53.

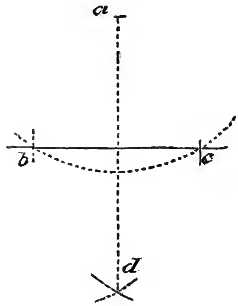


fig. 54.

describe the arc *c e;* from *c* with same distance lay off to *f* and *e;* from these points as centres, with same radius still in the compasses, describe arcs *e g*, *f h*, cutting in *m;* draw *b m*.—Meth. 5th. *When the point is beyond*

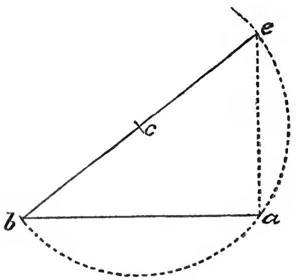


fig. 55.

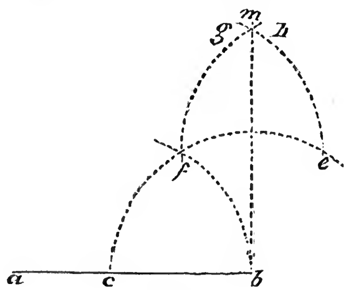


fig. 56.

the line. Let *b c*, fig. 57, be the line, and *a* the point; from *b* as centre, with *b a*, describe the circle *a f e;* from *e* with *a b* cut this in *f*, and from *f* to *d;* join *a d;* it is perpendicular to *b c*.

To bisect a right line, that is, to cut it into two equal parts. Let *a b*,

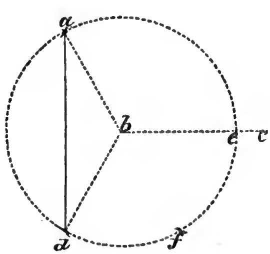


fig. 57.

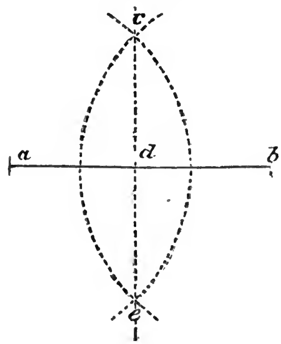


fig. 58.

fig. 58, be the line; from *a b* with any radius describe arcs cutting in points *c*, *e* above and below the line, through these draw a line *c d e; d* is the 'point of bisection.'*

To divide a given line into any number of equal parts. Let *a b*, fig. 59, be the line; from *a* and *b*, with *a b*, describe arcs *a c*, *b d;* from *a*, *b*, with any distance, cut these in *c*, *d;* from *a*, *b* draw through *c*, *d* indefinite lines *a* 6, *b* 6; these will be parallel to one another, but oblique to *a b*. From *a*, *b*, divide the lines into any number of equal parts, always one less than *a b* is to be divided into, as 6 in the diagram; join the points 1, 6, 2, 5 &c.; these lines will mark the points of division on *a b*.

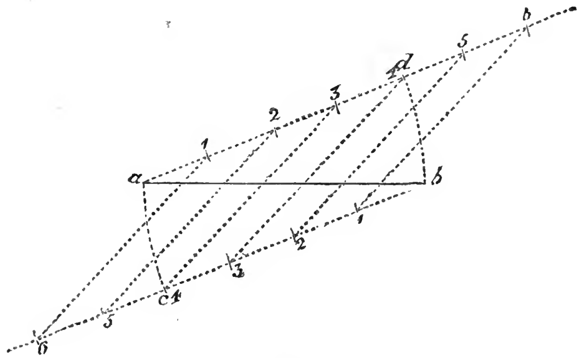


fig. 59.

To cut off from a circle two equal segments. Let *h g c*, fig. 60, be the circle; draw the diameter *a d b;* from its centre *d* draw *d f* perpendicular to *a b;* join *f a*, *f b; a h f*, *f g b* are the segments. The division of lines is of use in the construction of *scales*. The first we shall notice is that of feet and inches. There are 12 inches in one foot: suppose then that any distance is assumed to represent a foot, and this be divided into twelve equal parts, each of these will be an inch; and the longer distance may be multiplied to any extent to denote the number of feet required in the scale. If half an inch is taken as the representative of a foot, then the scale is denoted as 'half-inch to the foot,' and so on. In making a scale, a line, as *a b*, fig. 61, is drawn, and the assumed distance laid on it any number of times, as 7 in the drawing. The division to the left hand is generally used to denote the space of 'inches,' it is therefore divided into twelve parts; in the figure we have only shewn it divided into two; *c* denoting the position of the 6th inch. The line *d e* is divided so as to

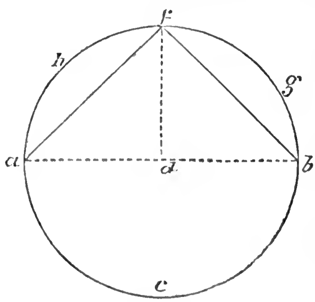


fig. 60.

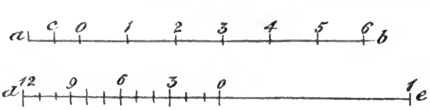


fig. 61.

* The radius of the arcs must be greater than half the line to be bisected. See fig. 82.

make a scale of an inch to the foot—the inch-division is fully marked out. In fig. 62 the method of drawing 'scales' is shewn; the lowest is a scale of ten feet—this is used in architectural plans and surveys. Suppose a line is to be divided for the purpose of making a scale, as *a b*, fig. 63; from *a* with a distance as near half *a b* as the eye can judge, lay off to *d*; by sweeping the other leg round towards *b*, it is found to reach to *e*; the distance *b e* is therefore the measure of the excess of the distance obtained over the actual line to be divided. If then *b e* is bisected, and half of it carried from *d* to *g*, *g* will be found to divide *a b* into two equal parts. To divide a line, as *h m*, into an equal number of parts, as 4, it will be quickest done by dividing it by Problem in fig. 58, till the point is found, as the point *o*, dividing it into two parts; then these divisions, as *h o*, *o m*, into two other parts. To take a distance from a scale: suppose it is 4 feet, on the point marked 4, on the line *a b*, fig. 61, reach to 0; suppose it is 4 feet 6 inches, from 4 reach to *c*, the division denoting the 6th inch.

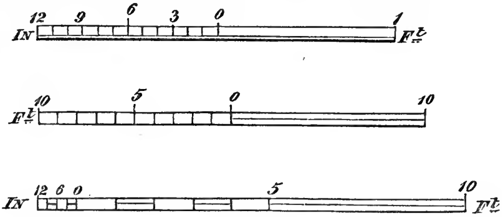


fig. 62.

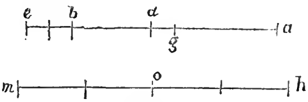


fig. 63.

To construct a diagonal scale for measuring long distances. Draw the line *c* 2, fig. 64, and divide it into any number of equal parts, as three; for use the division should be eleven in number; divide the last division to the right hand into ten equal parts; from *c* draw *c d* perpendicular and equal to this, and divide it into the same number of equal parts; number these as at 2, 4, &c., these denoting 20, 40, &c.; the intermediate ones, 30, 50, &c. From *d* draw *d e* parallel to 2 *c*; from the points in *c d* draw

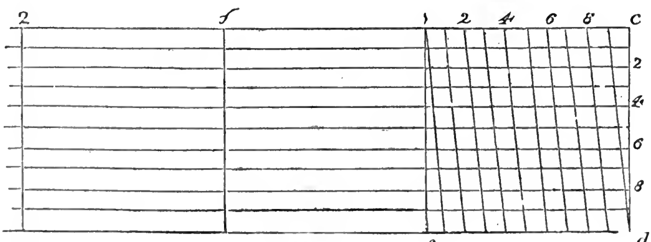


fig. 64.

lines parallel to *d e*; through the large division in 2 *c* draw lines parallel to *c d*. Divide *d f* into ten parts, and from these draw to the division on *c* 2, as in the drawing. To measure distances from this scale proceed as follows: suppose the distance to be taken is 250; with compass-point in the large division 2, open to the point 5 in the division to the right hand: to measure 165; with point of compass in 1, lay off to division 6; then with point in this, bring down the leg in 1 to the 5th horizontal division, then move the point from 6 to the same division. In this scale the distances may have different values: thus, the large divisions may be ten, while the small ones will be each one; or the large one hundred, and the small tens; or the large a thousand, and the small ones hundreds.

To bisect a given angle. Let *a b c*, fig. 65, be the angle; from the apex *a*, with any radius, describe an arc *b e c;* from *b* and *c*, with same radius, describe arcs cutting in *d;* join *a d*, it is the line of bisection.

An angle being given, to draw another similar to it. Let *d b c*, fig. 66, be the angle; draw a line *c d;* from *b*, with any radius, describe an arc *h g;* from *c*, with same radius, describe *h n;* measure from *h* to *g*, where the line *b c* cuts the arc *g h;* lay this distance from *h* to *n*, from *c* through *n* draw a line *c n*—*d c n* is equal to *d b c*.

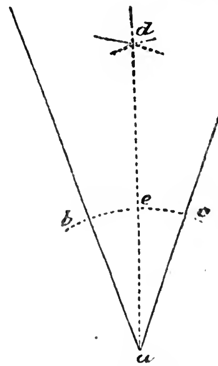


fig. 65.

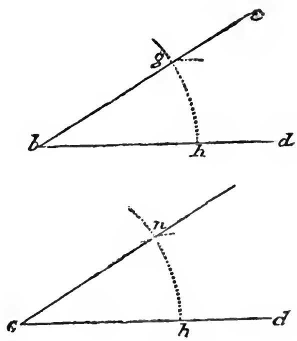


fig. 66.

To bisect a quadrant of a circle. From *a*, *b*, fig. 67, with radius greater than half of the arc *a b*, describe arcs cutting in *d*, *c;* join *c d;* where this line cuts *a b* is the point of bisection.

To construct a scale of chords, by which angles may be measured and laid down. Draw *a b*, *a c*, fig. 68, at right angles; from *a*, with any radius, describe the quadrant *b c;* divide *b c* into nine equal parts; join *b c;* from *b* transfer the divisions in *b c* to this line. Each of these divisions comprises ten degrees, and the chord of 60° is equal to the radius *a b*. The distances on *b c* may be transferred to a straight line, for the convenience of use, as *m n*. Angles are also measured and laid

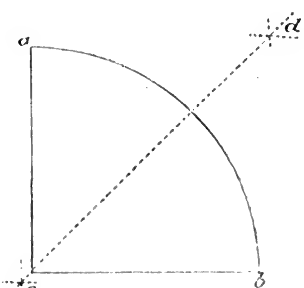


fig. 67.

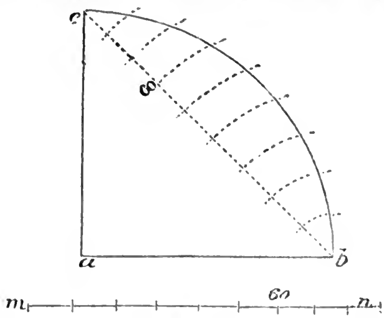


fig. 68.

down by means of an instrument called the 'protractor:' it may be

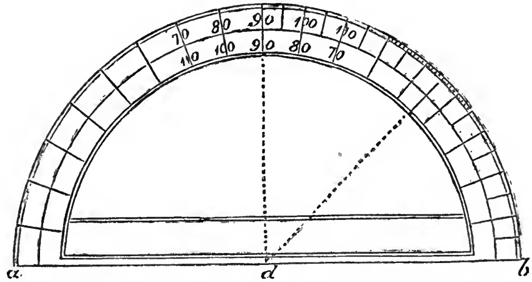


fig. 69.

readily constructed of card-board, or thin veneer. Draw any line *a b*, fig. 69; from *d* describe a semicircle, and draw *d c* at right angles to *a b*; divide the quadrants into nine equal parts, each comprising ten degrees, thus making 180° in the semicircle. From *d* draw lines through these points, the position of the tenth division will be thus marked; by dividing each of these into ten parts, the positions of the degrees will be given. An inspection of the drawing will explain the method of construction.

To construct an angle less than 90° *by means of the scale of chords.* Draw any line *a b*, fig. 70; from *a*, with the chord of 60° as radius, describe an arc *d e;* suppose the angle is to be 40°, take this distance from the scale of chords, and from *d* cut the arc in *e*, from *a* draw *a e; a e* is at an angle of 40° to *a b*.

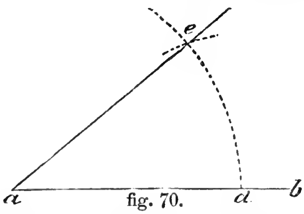


fig. 70.

To measure a given angle. Let *a b c*, fig. 70, be the angle; from *a* with chord of 60° describe an arc *d e;* from *d* measure to *e*, where the angular line cuts the arc; measure this distance on the scale of chords; this point gives the angle.

To construct an angle greater than 90°. Draw any line *a b*, fig. 71; from *a*, with a radius of 60°, describe the arc *d f;* suppose the angle to be 110°, take any angle less than 90° from this, as 60°, and lay it off from *d* to *e;* the difference of 60° and 110° being 50°, lay this angle from *e* to *f;* join *a f;* it is at an angle of 110° to *a b*. Note: It is essentially necessary that the distances of the angles be taken from the same scale as the radius or chord of 60° is taken from.

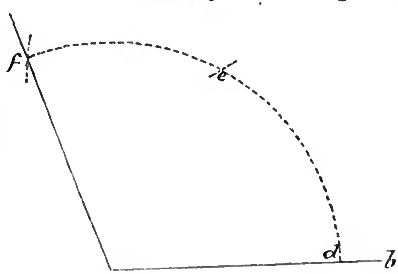


fig. 71.

To construct an angle by means of the protractor. Let *a b*, fig. 72, be the line on which an angle of say 45° is to be constructed; make the base of the protractor coincide with the line $a\,b$, and the central point d, fig. 69, with the point e, from whence the angle is to be made; mark on the paper the position of the point of 45° on the periphery, or outside of the protractor; from e draw a line through this point; it will be at an angle of 45° with $a\,b$; the point c denotes the position of the angle laid down. In like manner, an angle greater than 90° may be laid down, by placing the protractor properly, and marking the position of the point of the angle, which will be found in the left-hand side of the protractor. Angles may also be measured by producing the line if necessary, so that it may reach beyond the periphery of the protractor, when the base is made to coincide with the base-line of the angle. If the central point of the protractor coincides with the point from whence the angular line begins, the point where it cuts the edge of the protractor denotes the angle.

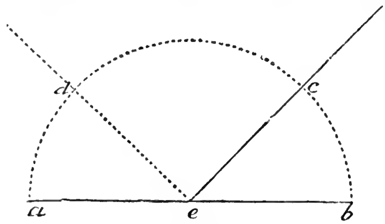


fig. 72.

A given line cut into several parts, to draw another line cut in the same proportion. Let $a\,b$, fig. 73, be the line, and c, d, e the points where it is

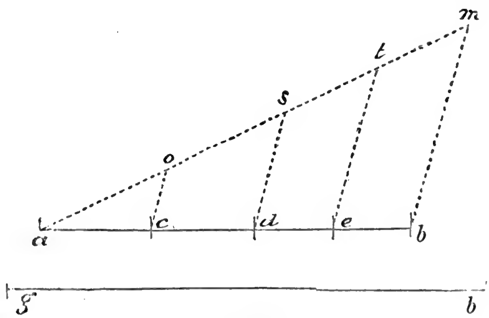


fig. 73.

cut, and $g\,h$ the line to be cut. Join $g\,h$ to $a\,b$, making any angle, as $a\,m$; join $m\,b$; parallel to this, through c, d, e, draw lines to o, s, t—these are the points cutting $a\,m$ equal to $g\,h$.

Two lines being given, to find a third proportional. Let $a\,b$, fig. 74, be

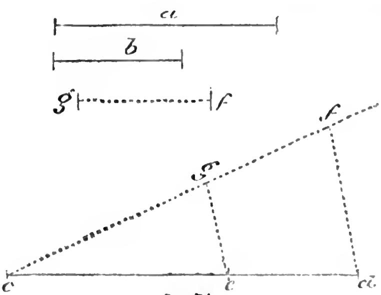


fig. 74.

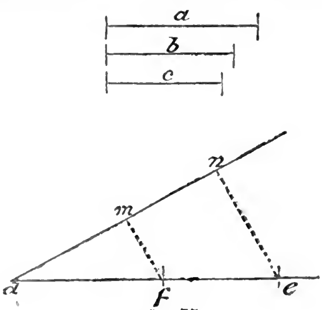


fig. 75.

the two lines. Draw any line *c d*, equal in length to *a b*, joined; from *c* draw a line *c f* at any angle to *c d*, make *c g*=*c e* or *a*, join *g e;* parallel to this, from *d*, draw *d f; f g* is the third proportional.

Three lines being given, to find a fourth proportional. Let *a, b, c*, fig. 75, be the lines. Draw any line *d e*, with *a* from *d;* cut it in *f*, and from same point with *b* cut a line *d n*, drawn at any angle to *d e*, in *m;* join *m f;* from *f* with *c* cut *d e* in *e;* from *e* draw to *n* parallel to *m f; m n* is a fourth proportional to *a, b, c*.

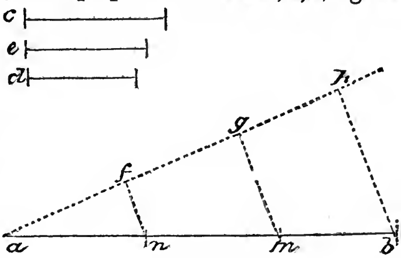


fig. 76.

To cut a given line so that the divisions will be in proportion to lines of a certain length each. Let *a b*, fig. 76, be the line; and *c, d, e* the lengths. Draw *a h* at any angle to *a b;* from *a*, with distance *c*, cut *a h* in *f;* with *d* from *f* cut *a h* in *g;* and with *e* from *g* in *h*. Join *h b;* parallel to this, from *f, g*, draw lines to *m, n;* *a b* is cut in these points as required.

Two lines being given, to find a mean proportional. Let *a, b*, fig. 77, be the lines. Draw any line *c d* from *d*, with distance *a* cut *c d* in *m';* from *m'*, with *b*, cut it in *c;* bisect *c d* in *n*, from *n*, with *n c*, draw a semicircle *d o c;* from *m'* draw to *o* perpendicular to *c d; m' o* is the mean proportional between *a, b*.

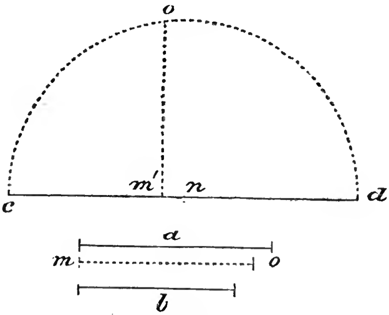


fig. 77.

To divide a line into extreme and mean ratio. Let *a b*, fig. 78, be the line; at the point *b*, with half *a b*, erect a perpendicular *b c;* from *c*, with *b c*, describe a circle; from *a*, through *c*, draw *a c;* from *a* measure to *d*, where the circle cuts *a e*, and lay it off from *a* to *n*. The line *a b* is divided at this point into mean and extreme ratio,—that is, the larger part as *a n*, is a mean proportional between the shorter part *n b* and the whole line *a b*.

A line being given representing the sum of two lines, of which a mean

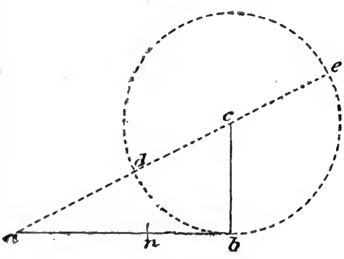


fig. 78.

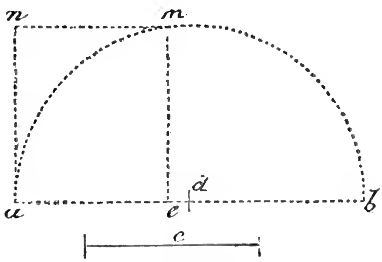


fig. 79.

proportional is also given, it is required to find the point which divides the line into two unequal lengths. Let *a b*, fig. 79, be the line, and *c* the mean proportional; bisect *a b* in *d*, and from *d* with *d b*, describe a semicircle; from *a* erect a perpendicular to *n*=*c*; from *n* draw to *m* parallel to *a b*; from *m* drop a perpendicular to *e*; *a e* and *e b* are the length of the lines, of which *c* is a mean proportional.

Two points being given, to find two other points exactly interposed, so that a rule too short to reach between the original points may be used to draw a line by means of the points found. Let *a b*, fig. 80, be the points. From these with any radius describe arcs cutting in *c, d;* from *c, d*, with radius *c d*, describe arcs cutting in *g, h;* a line may be drawn from *a* to *g*, from *g* to *h*, and so on; thus drawing it, as if it had been done between the points *a* and *b* at once.

Two lines given, to divide them, that the parts will be proportional to one another. Let *a b, c d*, fig. 81, be the lines. Draw *d e*=*a b*, and at right angles to *d e* draw to *f*=*c d;* join *e f;* bisect *d e* in *g*, and describe the semicircle; from *h*, where *e f* cuts the circle, draw to *n*, cutting *d f;* draw *h m* parallel to *d f;* transfer *e m* to *a b* from *a* to *o*, and *m h* from *c* to *t*.

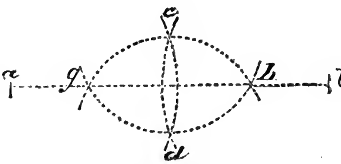


fig. 80.

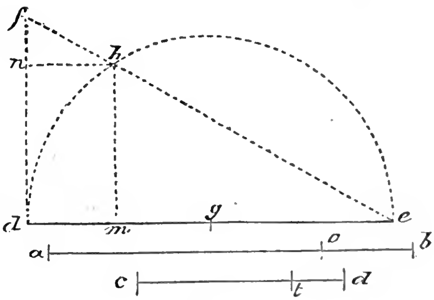


fig. 81.

Two lines converging to a point not given, to draw other lines converging to the same point. Let *a, b, c*, fig. 82, be the lines; draw any parallel lines, as *e f g h m n*, take the distance *h h*, and lay it on *e f* to *e f;* also *i i* to *g h*, and *o s* to *m n;* through *m g e, n h f*, draw lines. In nearly the same way may a given line be cut into divisions similar to a given line. Let *a b*, fig. 83, be the line, cut into divisions as shewn; *c d* may be cut similarly; *c d* must be parallel to *a b;* from *b a* draw lines at any angle meeting in *f;* to this point, from the various parts of division, on *a b*, draw lines; these will cut *c d* as desired.

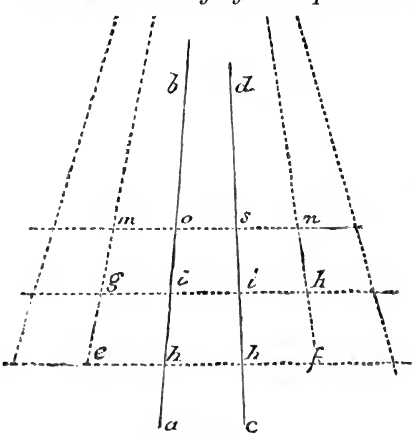


fig. 82.

Through a given point to draw a line, which will be a tangent to a circle. Let *a b c*, fig. 84, be the circle, and *d* the point; from the centre of the circle *a* draw a line to *d*; bisect this in *e*; from *e* describe a semicircle with radius *e d*; through the point where this cuts the circle, as *b*, draw from *d*;

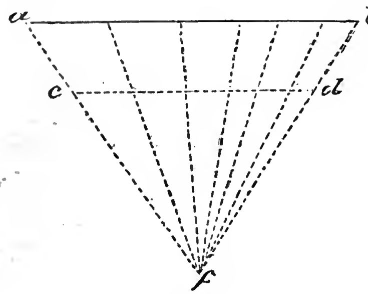


fig. 83.

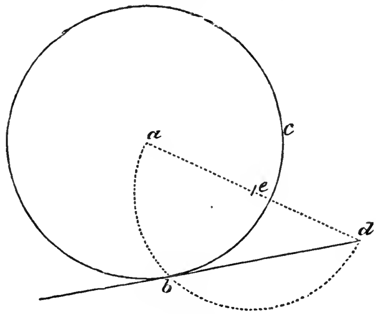


fig. 84.

d b is the tangent—Meth. 2d. Let *b c f*, fig. 85, be the circle, and *c* the point through which the tangent is to be drawn; from *a* draw *a c*; through *c* draw *e c d*, at right angles to *a c*; *e c d* is the tangent.

A circle and its tangent being given, to find the exact point of contact. Let *b c g*, fig. 86, be the circle, and *e c d* its tangent; from *a*, the centre, drop a perpendicular *a c f*; the intersection *c* will be the point.

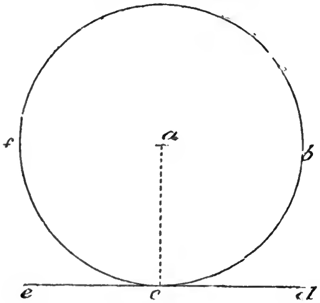


fig. 85.

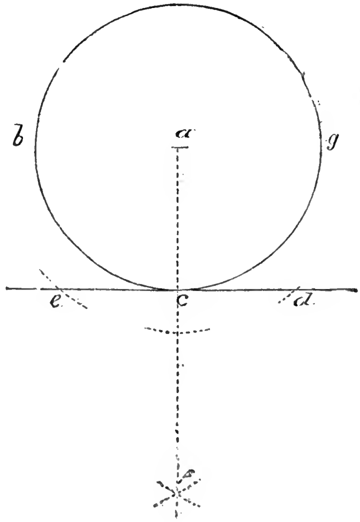


fig. 86.

A point without a circle being given, to draw a tangent through the point. Let *a b c*, fig. 87, be the circle, and *d* the point; join *a d*; from the point *b*, where it intersects the circle, draw a tangent, as *b f*; from *a*, with radius *a d*, describe a circle *d f h*; from *f* make *f h* = *f d*; join *h d*; it is the tangent required. In the preceding problems we have assumed the centres of the circles to have been given; in practice this may not always be the case, we therefore give methods of finding the centres of circles.

To find the centre of a given circle. Let *a b c* fig. 88, be a circle, of which the centre is required; draw any line *a b*, terminated by the circumference; bisect it in g, and draw $d\,c$ at right angles to $a\,b$; bisect $c\,d$ in f; and draw $f\,e$ at right angles to $c\,d$; the point f where they intersect is the centre of the circle.

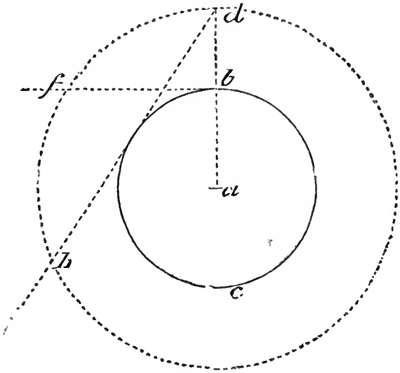


fig. 87.

Part of the circumference of a circle being given, to find the centre from which the remainder may be described. Let $a\,b\,c$, fig. 89, be the part given, and $a\,b\,c$ any three points therein; from a and b, with radius $a\,b$, describe arcs cutting in d, e; and from b, c, with $b\,c$, arcs cutting in g, h; through these draw lines cutting in m: it is the centre required.

Three points not in a straight line being given, to find a point which will be the centre of a circle passing through the points. Let a, b, c, fig. 90, be the points; from the points as centres, with radius less than the distance between them, describe circles cutting in e, f, g, d; through these draw lines cutting in m; it is the point required.—Meth. 2d. When the points are at a distance from each other, as a, b, e, fig. 91, join them by lines, bisect these in d, c; from these points erect perpendiculars cutting in g: it is the centre required. In cases where the points are nearly in a straight line, thus throwing the centre at such a distance from them that it will be difficult to describe the circle with compasses, the circumference may be described by the following means:—Place two thin rulers, $a\,b$, $b\,c$, fig. 93, their edges coinciding with the points; pass a pin through both to the point b, on which they may freely move; they must be restrained at this angle by a cross piece fastened to both; fix a pencil at the angle b, move the ruler so that their

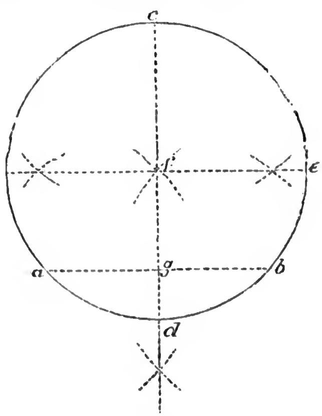


fig. 88.

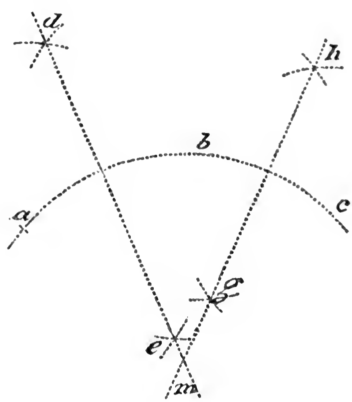


fig. 89.

edges will always coincide with a and c; the pin or pencil at b will trace the circle. If the whole circle is to be described, the legs $a\,b$, $b\,c$, must be of considerable length.—Meth. 3d. Points may be found through which to trace a circle, which will pass through three given points, as *a, b, c*, fig. 92. From *a*, through *b, c*, draw lines produced to *d, e;* from *a*, with any radius, describe part of a circle, as *d e;* from *e* with *d e*, lay off on this to *g*, and

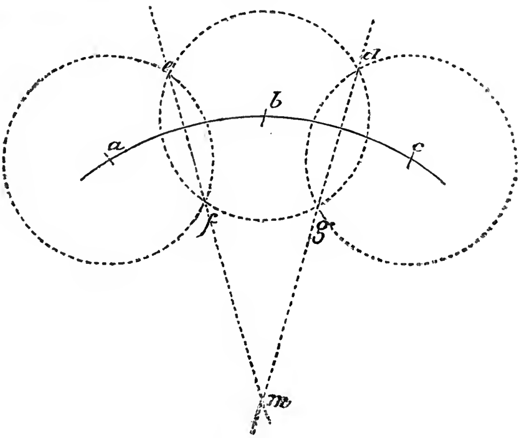


fig. 90.

so on; from these points draw to *a*; from point *c*, with distance *b c*, cut *g a* in *g;* from *g*, *a h* in *h*, from *h* the other line from *a;* these are all points in the circumference of a circle which will pass through *a, b, c*.

Having shewn the various methods of drawing lines parallel, &c., by means of construction, we now explain how these operations can be most rapidly effected, greatly facilitating complex constructions by means of the drawing-board and square. The former is shewn in fig. 47, *a b c d;* the edges are perfectly straight and even, those at the ends being at right angles to those of the sides, and *vice versa*. A convenient size for ordinary geometrical construction will be 16 inches long by 12 wide, $\frac{3}{4}$ inch thick; having cross pieces at the sides, to prevent warping. The form of the T square is seen in fig. 47, at *e e*, and is too well known to need further description; the blade *e e* should be as long as the length of the drawing-board. The square can be moved along the edges of the board without altering its position; this is effected by having a ledge on each side of the blade. All lines, as *m, n, o*, drawn parallel to the sides, *a d, b c*, are at right angles to the ends *b a, c d*, while those parallel to the end *s*, as *t s*, are at right angles to the sides. Hence arises a simple method of drawing lines parallel to one another. Thus, as the blade *e e* of the square is at right angles to the stock *f f*, it follows that if the blade is placed to have its edges parallel to the sides of the board, all lines drawn along it are not only parallel to the sides, but to one another, as *m, n, o;*

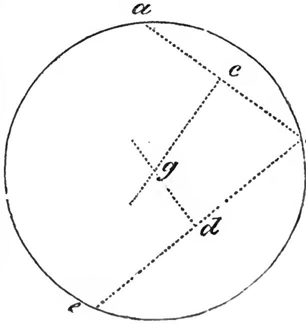


fig. 91.

if a line is to be drawn perpendicular to one of these lines, all that is required is to move the square into the position shewn at *e, e, e,* the blade will then be parallel to the ends, consequently lines drawn along its edge, as *s, t,* will be at right angles to those previously drawn, as *m, n, o.* Again, by placing the edge of the blade to coincide with the points from which lines are to be drawn, either parallel or perpendicular to each other, lines can be drawn as required. It is obvious, however, that when right lines are required to be drawn changed in their direction, it is necessary to move the square at each time; to obviate this, a simple contrivance shewn in fig. 20 is used; it is made of thin mahogany, its side *a b* at right angles to *b c*—hence, if the side *a b* coincides or lies in contact with the edge of the drawing square, all lines drawn along *b c* will be at right angles to the edge—the side *b c* must coincide with the point from which the perpendicular is to be drawn.

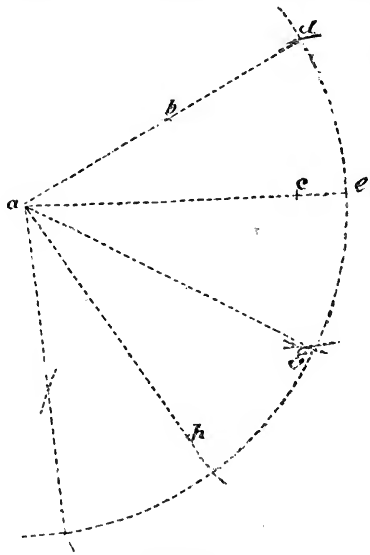


fig. 92.

In fig. 47, *x* shews the position of this simple instrument. The pupil will at once see the ease and rapidity with which lines can be drawn and figures constructed by the use of these contrivances. We shall now resume our problems, first noticing the various geometrical plane figures, and their modes of construction.

To construct an equilateral triangle. Let *a b,* fig. 94, be the length

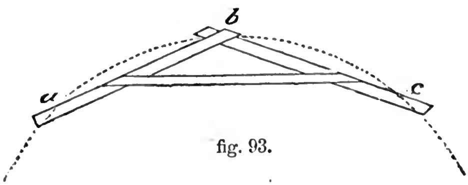


fig. 93.

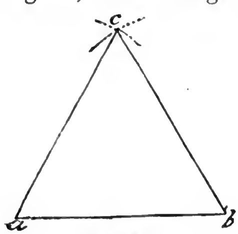


fig. 94.

of its side; from *a b,* with *a b,* describe arcs cutting *d* in *c,* join *a c, b c; a b c* is the triangle.

To construct an isosceles triangle, the length of the base and one of the sides being given. Let *a b* be the base, and *c d* the side; draw *e f,* fig. 95, $=a b$, from *e f,* with *c d,* describe arcs cutting in *g;* join *e g, f g; e f g* is the triangle required.

To construct a right-angled triangle, having the base and perpendicular given. Let *a b,* fig. 96, be the base, and *c d* the perpendicular; draw *e f* and make $e g = a b$; draw from *g* an indefinite line perpendicular to *e g;* with *c d* from *g,* cut *g h* in *h;* join *e h.*

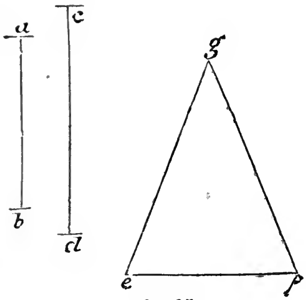


fig. 95.

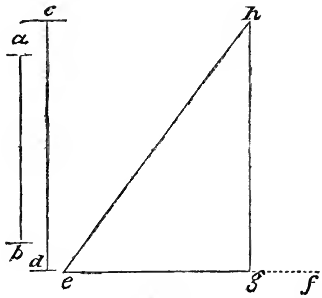


fig. 96.

To construct an obtuse-angled triangle, having the three sides given, as *a, b, c*, fig. 97. Draw *d e*=*c;* from *e* with *b* describe an arc; and from *d* with *a* another, cutting it in *f;* join *d f, e f.* Or the angle being given and two of the sides, it may be constructed as in fig. 71.

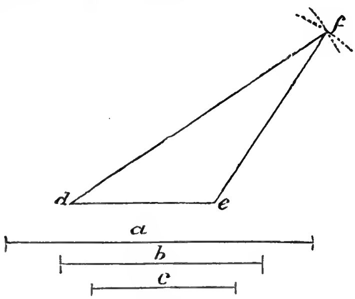


fig. 97.

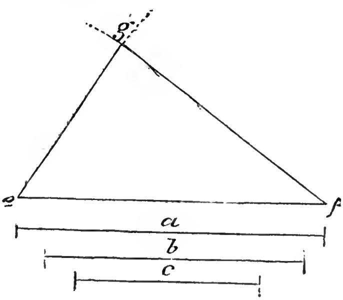
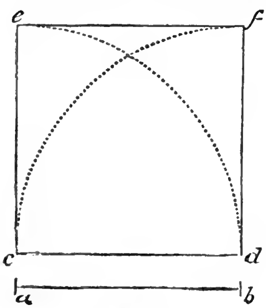


fig. 98.

To construct a scalene triangle, having the three sides a, b, c given. Draw *e f*, fig. 98 = *a;* from *e*, with side *c*, describe an arc; and from *f* with *b* cut this in *g;* join *e g, f g.*

To construct a square, the side being given. Let *a b* be the side; draw *c d* equal to this; with *a b*, from *c, d*, describe arcs; from *c, d* draw lines cutting these arcs perpendicular to *c d;* join *f e, c e, f d* (fig. 99).

To construct a parallelogram, when the length and breadth are given.



g. 99.

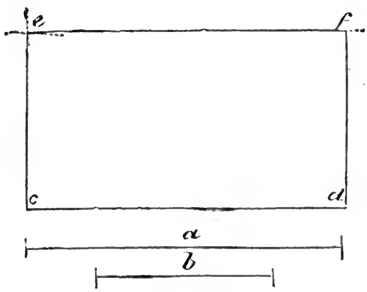


fig. 100.

Let a be the breadth and b, fig. 100, the length; make $cd=a$; from c, with radius b, describe an arc to e; raise the perpendicular ce, cutting the arc; from d, with radius b, describe an arc at f; from e, with a, cut this in f; join ef, fd.

To construct a rhomboid, the side and diagonal being given. Let a, fig. 101, be the breadth, b the length, and c the diagonal. Draw $de=b$; from d, e with a describe arcs to g, f; from d with c, cut that in f, at f; from f with distance b, cut that in g; join dg, gf, fe.

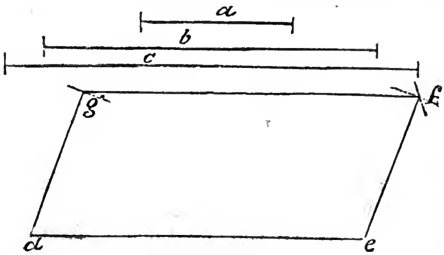


fig. 101.

To construct a rhombus, the side and angle being given. Let ab, fig. 102, be the side; draw cd equal to it, make the angle dce equal to the angle given, and draw an indefinite line from c to e; from c with ab, cut this in e; do the same from d, and from e cut this in f; join ed, fd.

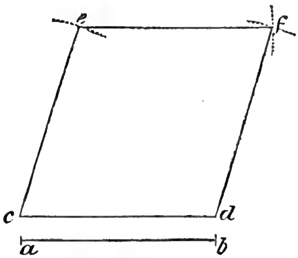


fig. 102.

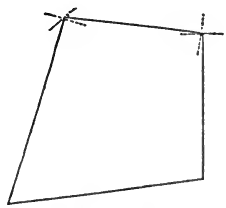


fig. 103.

The method of construction of a *trapezium* may be seen by the dotted arcs in fig. 103. It will be obvious to the pupil, that quadrilaterals, having angular sides, may be constructed by means of the protractor, scale of chords and equal parts, and the diagonal scale. Where these are used, one or more of the sides and angles must be given. Thus, to construct fig. 104, the sides and angles being all given, cd would first be drawn, then cb would be drawn at the proper angle; and ca cut off to the required size; ab would be drawn parallel to cd, and from d, da at the proper angle. The construction of figures having many sides and angles will be treated of under the head of Land Surveying, in a treatise of this series in the higher branches of Mathematics.

To construct a square on a given line, ab, fig. 105. From a and b, with radius ab, describe arcs to c, d; from the point e of intersection, with radius ea, describe a circle; with same radius from c, d, cut the circle in f and g; draw af, bg; from g, f, with radius of the circle, cut these lines in h, i; join hi: $abhi$ is the square required.

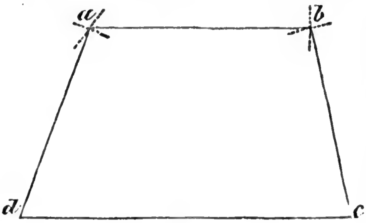


fig. 104.

To construct an equilateral and equiangular pentagon on a given line, a b, fig. 106. From *a* with *a b* describe the arc *b c*; draw the perpen-

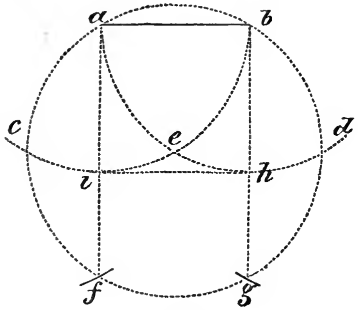


fig. 105.

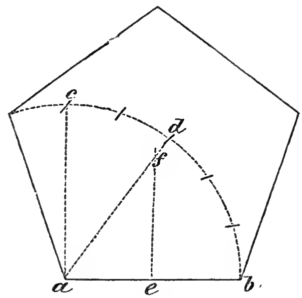


fig. 106.

dicular *a c*, divide *b c* into five equal parts, draw *a d* to the third of these from *b*; bisect *a b* in *e*; draw from this a perpendicular cutting *a d* in *f*; from *f* with *f b* describe a circle; lay *a b* five times round this, join the points.—Meth. 2d. Let *a b*, fig. 108, be the line; from *a b* describe arcs

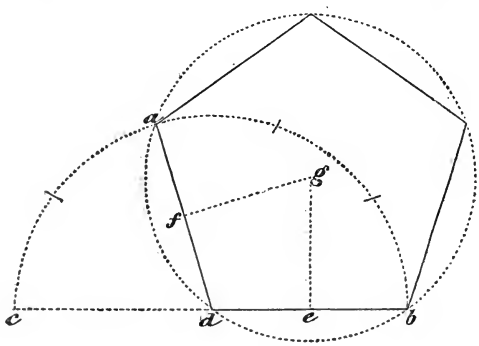


fig. 107.

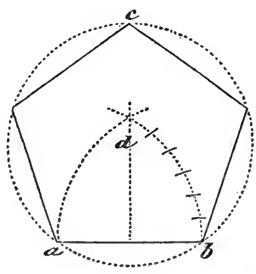


fig. 108.

cutting each other; drop from this a perpendicular; divide the arc from *b* into six equal parts, from the point of intersection lay one of these to *d* on the perpendicular; this is the centre of a circle, which will contain *a b* five times; *d b* is the radius.—Meth. 3d. Let *d b*, fig. 107, be the line; from *d* with *d b* describe a semicircle *b a c*, produce *d b* to *c*; divide this into five equal parts, through the third of these draw *d f a*; bisect *d a*, *d b*, in *f* and *e*;

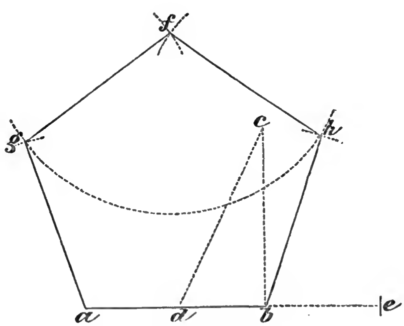


fig. 109.

from these draw perpendiculars cutting in *g*—it is the centre of a circle which will contain *d b* five times; the radius being=*g d.*—Meth. 4th. Let *a b*, fig. 110, be the line; from *a b* describe with *a b* the circles *c b d*,

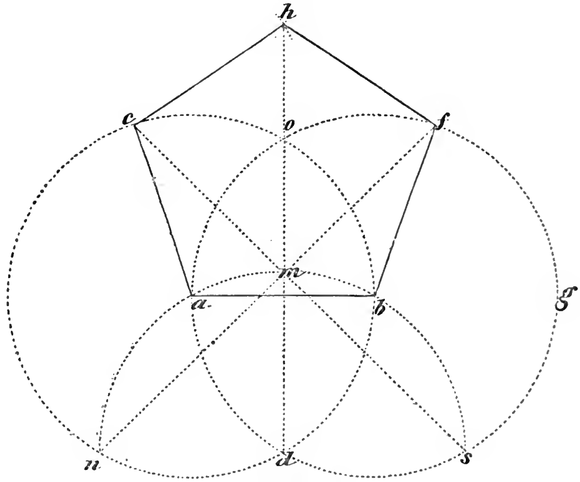


fig. 110.

a d f; from the point *d* draw through the points of intersection a line to *h*; from *d*, with radius *d a*, describe the semicircle *n m s*; from *s* and *n* draw through *m* to *c* and *f*; from *c* and *f*, with radius *a b*, describe arcs cutting in *h*; join *a c*, *c h*, *h f*, *f b*.—Meth. 5th. Let *a b*, fig. 109, be the line; at *b* draw *b c* perpendicular and equal to *a b*; bisect *a b* in *d*, join *c d*, from *d* with *d c* lay off to *e* on *a b* produced; from *a*, *b*, with distance *a e*, describe arcs cutting in *f*; from *f* with *a b*, describe another in *g*, *h*; from *a*, *b* with *a b*, cut this in *g*, *h*; join the points thus found.

A pentagon, as fig. 111, *being given, it is required to draw another similar to it.* Bisect *a b* in *c*; draw *c d* perpendicular to *a b*. Draw *e f*, fig. 112=*a b*; bisect it in *g*, draw *g h*, and make it equal to *c d*; with radius *a b*, from *e*, *f*, *h*, describe arcs cutting in *m*, *n*; join *e m*, *m h*, *h n*, *n f*.

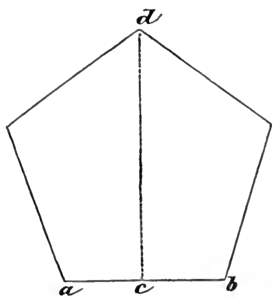


fig. 111

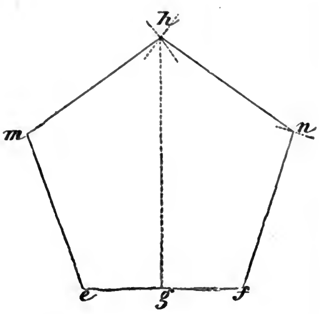


fig. 112.

An irregular pentagon, as fig. 113, *being given, to draw another equal and similar to it.* Draw the diagonals *a c, d b.* Draw any line *f g*, fig. 114, $= a\ b$; from *f* with radius *a c*, describe an arc; from *g* with *b c* cut this

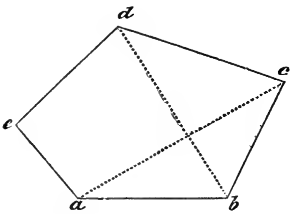


fig. 113.

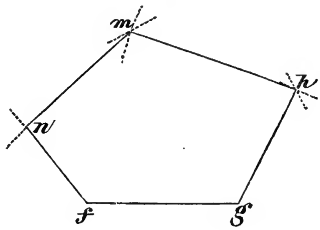


fig. 114.

in *h*, join *g h*; from *g* with *b d*, describe an arc, and from *h* with *a d*, cut this in *m*; from *m* with *d e*, describe an arc, and from *f* with *a e*, cut this in *n*; join *h m, m n, n f.*

To construct a regular hexagon. Let *a b*, fig. 115, be the line; from *a* and *b* describe arcs cutting in *e*; from *e* with radius *e b*, describe a circle; lay *a b* six times round the circle, to *d, e, f, g*; join the points thus found. —Meth. 2d. Let *a b*, fig. 116, be the line; from *a*, with *a b*, describe the

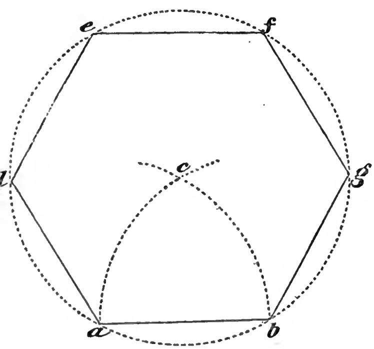


fig. 115.

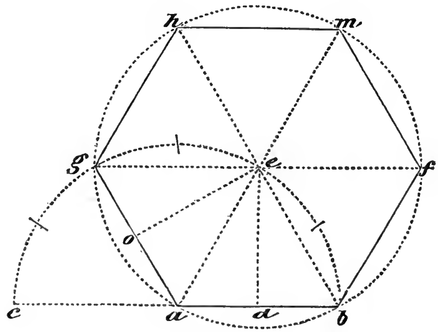


fig. 116.

semicircle *b e c*, on *a b* produced to *c*; divide this into six equal parts; draw *a g* to the fourth of these; bisect *a b, g a*, in *d* and *o*; draw perpendiculars from these cutting in *e*; from *e*, with radius *e a*, describe a circle; with *a b* from *g*, cut this in *h*, from *h* cut it in *m*, and from *m* in *f*; join these points.—Meth. 3d. Let *a b*, fig. 117, be the side; bisect it in *c*; draw *c e* perpendicular to *a b*; from *a* describe an arc with *a b*, cutting *c e* in *d*; through *d* draw *f d g* parallel to *a b*; from *d* lay off to *f, g* equal to *d b*; make $d e = d c$; through *e* draw *m n* parallel to *a b*; from *a, b* draw through *d*, cutting *e m n* in *m, n*; join the points in *m, f, n, g*, &c.—Meth. 4th. Let *a b*, fig. 118, be the side; bisect it in *c*, draw *c d*, and from *a* with *a b*, cut it in *d*; from *a* draw through *d* to *f*; from *d* with *d a* cut this in *f*; from *f* make *f g* parallel and equal to *a b*; from *f, g*, with *a b*, describe arcs in *m, n*; from *a b* cut these; join the points.

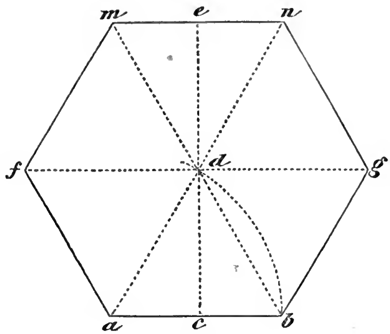


fig. 117.

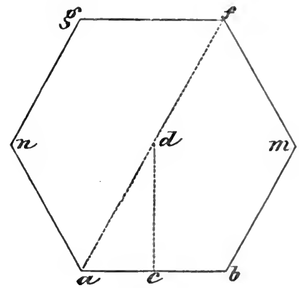


fig. 118.

A hexagon, as fig. 119, *being given, to draw another equal and similar to it.* Bisect $a\,b$, fig. 119, in c; draw $c\,d$, and join the opposite angles by a line through e. Draw $f\,g$ (fig. 120)$=a\,b$; bisect it in h, draw $h\,m=c\,d$;

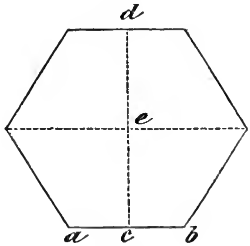
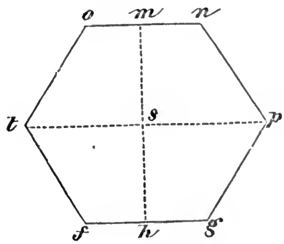


fig. 119.



g. 120.

bisect this in s, draw $t\ s\ p$ parallel to $f\,h\,g$; from m make $o\ n=f\,g$; from o, n with $f\,g$, cut $t\ s\ p$ in t and p; join the points. An irregular hexagon as that in fig. 33 may be drawn in the same way as figs. 113 and 114.

A side being given to construct a heptagon. Let $a\,b$, fig. 121, be the side; with this radius from a describe a semicircle $b\ g\ d$ on $a\ b$, produced to d; divide it into seven equal parts; through the fifth of these draw $a\,g$; bisect $a\ b$, $a\ g$ in c, e; erect perpendiculars from these points cutting in f; from f, with $f\,a$, describe a circle; lay $a\,b$ from g to $h\,m$ and $n\,o$; join the points. —Meth. 2d. Let $a\ b$, fig. 122, be the side; from b, with $a\ b$, describe an arc $a\ e$; bisect $a\,b$ in c; draw a perpendicular as $e\,d$; divide $a\,e$ into seven parts, lay one of these from e to d; d is the centre of a circle (the radius of which is $d\ a$), which will contain $a\ b$ seven times.

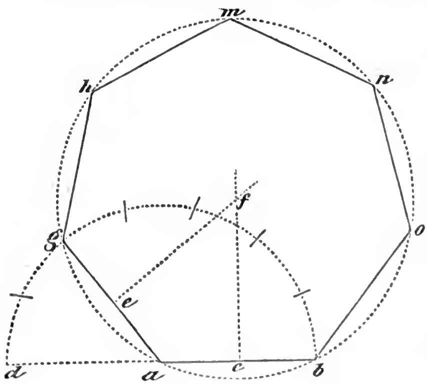


fig. 121.

A heptagon, as fig. 123, *being given, to construct an equal and similar one, as fig.* 124. Bisect $a\,b$, fig. 123; on c draw $c\,e$, join $d\,f$, make $a\,b$,

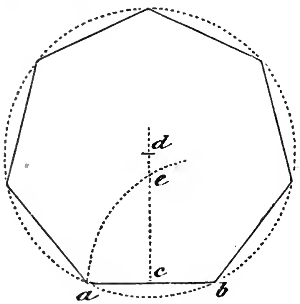


fig. 122.

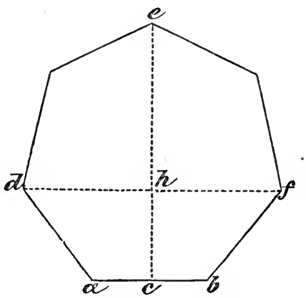


fig. 123.

fig. 124,$=a\ b$, fig. 123; bisect it in c, join $c\,f$; make $c\,m=c\,h$, and $m\,n=h\,f$, join $n\,n$; make $c\,f=c\,e$; with $a\,b$, from a, b, $n\,n$, f, describe arcs cutting each other; join the points thus found.

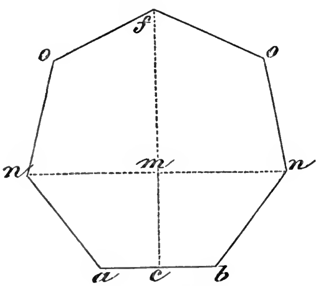


fig. 124.

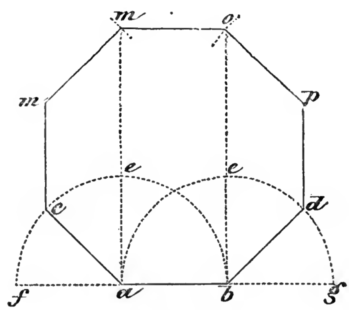


fig. 125.

A side being given, as a b, fig. 125, *to construct a regular octagon thereon.* With radius $a\,b$ from a, b, describe semicircles on $a\,b$ produced to f, g; divide these into four equal parts each; through the third of these draw $a\,c$, $b\,d$; from a, b, through e, e, the second points, draw to m, o; parallel to these, from c, d, draw to $m, p=a\,b$; from m, p, with $a\,b$, cut $a\,m$, $o\,b$ in m, o; join the points.—Meth. 2d. Produce the side $a\,b$, fig. 129, to d, c; from a, b, erect perpendiculars to m, n; divide $a\,b$ into four equal parts, lay three of these to c, d; from these draw lines parallel to $a\,m$; from a, b, with $a\,b$, cut these in h, g; make $h\,o$, $g\,o=a\,b$; and from these, with $a\,b$, cut $a\,m$, $b\,m$ in m, n; join the points.—Meth. 3d. A square, fig. 126, can be converted into an octagon, as follows: From a, b, c, d, draw diagonals; and from these points, with $b\,e$, where the diagonals intersect, describe arcs cutting the sides in certain points; join the points.

An octagon, as fig. 127, *being given, to construct an equal and similar one.* Bisect $a\,b$ in c, erect $c\,d$; join $a\,e$, $b\,e$; through f draw $f\,g$ parallel to $a\,b$; make $a\,b$, fig. 128$=a\,b$, fig. 127; bisect it in c, draw $c\,d$, and $a\,o$, $b\,o$, and through e, $g\,e\,f$; with $f\,g$, fig. 127, make $e\,g$, $e\,f$, equal; through these, draw lines parallel to *c d*; with *a e*, fig. 127, from *a*, *b*, cut *a o*, *b o*, in *o*, *o*; and from *a*, *b*, *o*, *o*, describe other arcs, cutting the lines *g*, *f*; join the points.

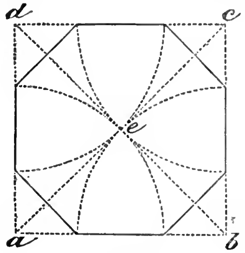


fig. 126.

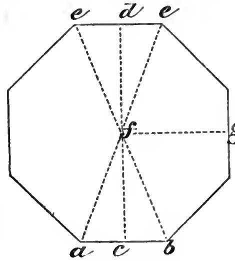


fig. 127.

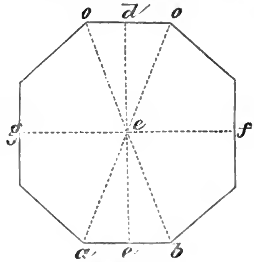


fig. 128.

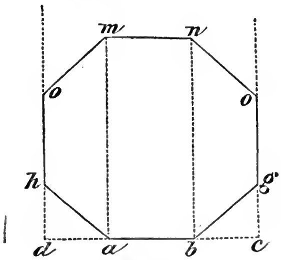


fig. 129.

To construct on a given line any polygon, having from six to twelve or twenty-four sides. Let *a b*, fig. 130, be the line; from *b*, with *a b*, describe an arc *a e*; bisect *a b* in *c*, and erect an indefinite perpendicular, as *c e*; divide the arc *a e* into six equal parts; from *e* transfer these to the line *e c*.

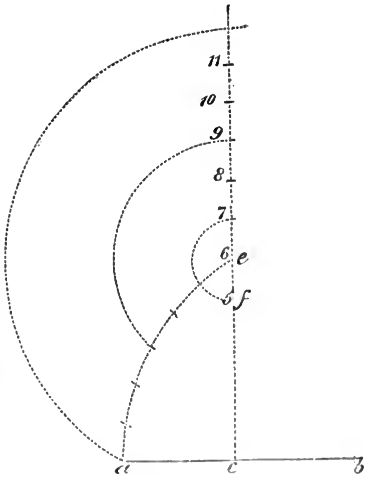


fig. 130.

To construct a hexagon. On *a b*, from *e*, with radius *e a*, describe a circle. This will contain *ab* six times. For a heptagon, octagon, nonagon (nine-sided figure), decagon (ten-sided), undecagon (eleven-sided), dodecagon (twelve-sided), the centre of the circle is respectively at the points 7, 8, 9, 10, 11, and 12. A polygon, having from twelve to twenty-four sides, can also be constructed by the same means, by dividing the arc into twelve equal parts, and proceed as above. In fig. 130, *f* is the centre of a circle, containing *a b* five times. The sides of a regular pentagon, hexagon, &c., can be found by means of the protractor. The rule is simple. Divide 360°, the number of degrees on the circumference of a circle, by the number of the sides of the desired polygon. This will give the angle at the centre of the circle in which, or about which, the figure is to be inscribed or described. If the figure is to be constructed on a given line, the angle found as above is to be subtracted from 180°; the angle thus found is that to be used. Thus, suppose a pentagon is to be inscribed in the circle, fig. 108, 360° divided by 5 gives 72°. From *d* the centre of the circle, draw a line, touching the circumference in *a*; lay the edge of the protractor to coincide with the line $d\,a$, and the central part with the centre d; make a line, drawn from d to $b=72°$; join $a\,b$; it is the side of the pentagon required. Suppose the pentagon is to be erected on the line $e\,f$, fig. 112. Subtract 72° from 180°, this leaves 108°; lay the protractor to coincide with $e\,f$; and the central point with point e; make a line $e\,m$ $=e\,f$, and at an angle of 108°, with $e\,f$; at m make $m\,h=e\,f$; and at an angle of 108°, with $e\,m$, and so on. All the other figures can be constructed by the rule given above.

We shall now proceed to problems, shewing the methods of inscribing and describing figures, within and without others.

To inscribe a circle within a triangle (fig. 131). Bisect the angles $a\,b\,c$, $a\,c\,b$, by lines cutting in d; from d draw to e perpendicular to $b\,c$; from d, with $d\,e$, describe the circle.

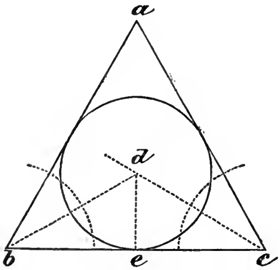


fig. 131.

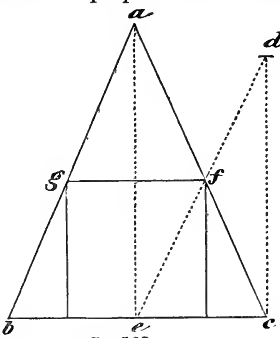


fig. 132.

To inscribe a square in a triangle (fig. 132). From c draw $c\,d$, perpendicular and equal to $c\,b$; bisect $b\,c$ in e, join $e\,d$; from where this cuts $a\,c$, as f, draw $f\,g$ parallel to $b\,c$; $f\,g$ is the side of the square.

To inscribe a pentagon in an equilateral triangle (fig. 133). Perpendicular to $b\,c$ draw an indefinite line $b\,d$; from b with $b\,c$, describe the arc $b\,c\,e$; divide $d\,c$ into five equal parts; lay one from d to e; join $b\,e$; bisect it in f; from b, with $b\,f$ describe the arc $f\,g$; join $f\,g$, produce it to h; make $b\,m=c\,h$; join $e\,a$ cutting $m\,g$ in n; from g, with $g\,n$, describe the arc $n\,n$, from these points, with same radius; cut $a\,b$, $a\,c$ in o, o; join the points.—Meth. 2d. Let $a\,b\,c$, fig. 134, be the triangle; bisect $b\,c$ in d, draw $d\,a$; divide $d\,b$ into six equal parts; from c lay off one of these to e; and from c and b three of them to g, h; join $d\,g$, $d\,h$; join $a\,e$, cutting $d\,g$ in m; from d, with $d\,m$, describe an arc cutting $d\,h$ in n; from m, n, with same radius, describe arcs cutting $b\,a$, $c\,a$, in o and s, join $o\,n$, $s\,m$.

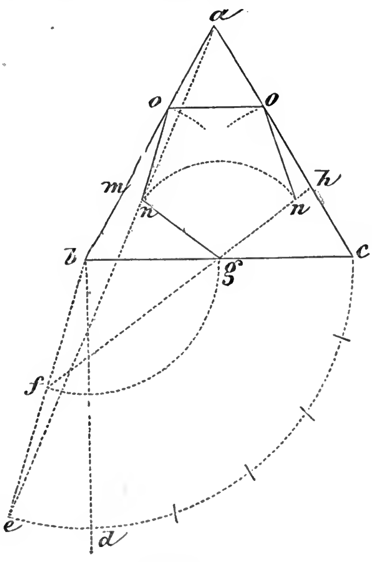


fig. 133.

To inscribe a square in a given square (fig. 135). Bisect *c d* in *e*; from *d* and *a*, with *d e*, describe arcs *e f*, *g h*; join the points thus obtained.

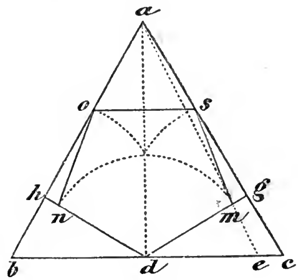


fig. 134.

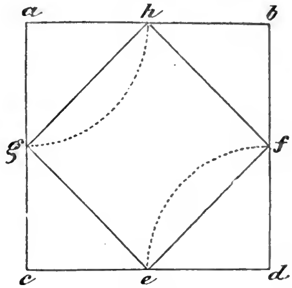


fig. 135.

To inscribe an equilateral triangle in a given square (fig. 136). Draw the diagonals *a d*, *b c*, cutting in *e*; from *d*, with *d e*, describe the arc *f e g*; join *f g*, *a f*, *a g*.

To inscribe an isosceles triangle of greatest dimensions in a given square (fig. 137). Bisect *a b* in *f*; join *c f*, *d f*.

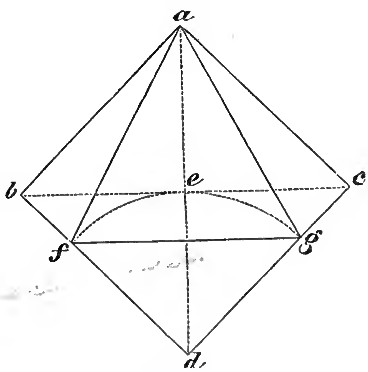


fig. 136.

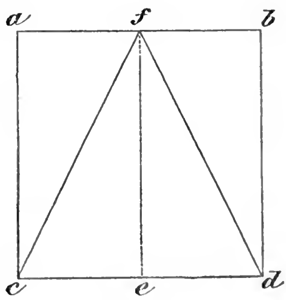


fig. 137.

To inscribe a circle within a square (fig. 138). Draw diagonals, cutting in *e*; from *e* parallel to *c d* draw *e f*; from *e*, with *e f*, describe the circle.

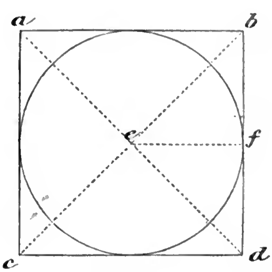


fig. 138.

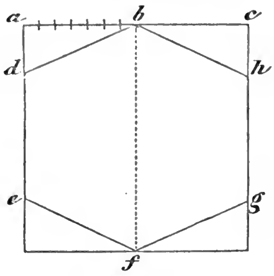


fig 139.

To inscribe a hexagon in a given square (fig. 139). Bisect the side *a c* into two parts in the point *b*; divide *a b* into seven equal parts; lay three of these from *a* to *d*; join *b d*; and with this distance lay off to *e* in the side *a d e;* from *e* to *f, g* and *h,* join the points.

To inscribe an octagon in a given square (fig. 140). Draw the diagonals, cutting in *e;* from the corners, with *b e* describe arcs; join the points thus found.

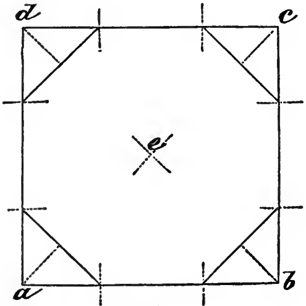


fig. 140.

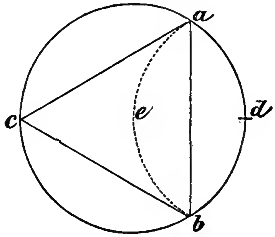


fig. 141.

To inscribe an equilateral triangle in a circle (fig. 141). From any point *d* in the circumference, with *d, e* (the centre), describe an arc cutting the circle in *a, b;* from *a, b,* with *a b,* describe an arc cutting in *c;* join *c a, c b, a b.*

To inscribe a square in a circle (fig. 142). Draw diameters at right angles to one another, cutting the circumference in four parts; join these.—Meth. 2d. Draw the diameters *a b, c d;* divide any two of these quadrants thus formed in *f* and *g;* from these draw *e g, f h* parallel to *dc;* join *ef, gh* (fig. 143).

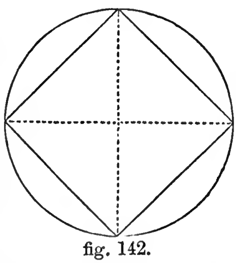


fig. 142.

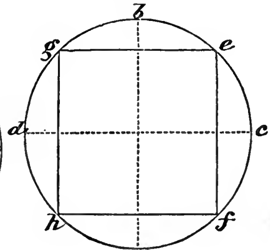


fig. 143.

In a given circle to inscribe a rectangle of greatest dimensions (fig. 144). Divide the diameter *a b* into four equal parts; through the first and third draw lines *d f, c e* at right angles to *a b;* join *c d, e f.*—Meth. 2d (fig. 145).

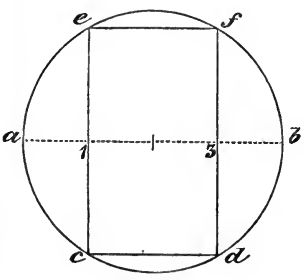


fig. 144.

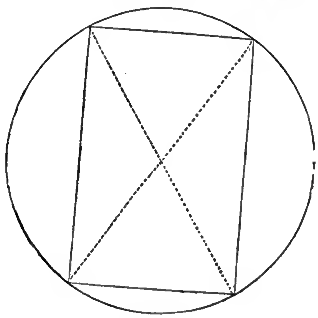


fig. 145.

Draw any two diameters; join the points where they cut the circumference.

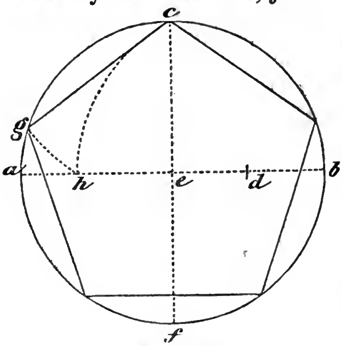


fig. 146.

To inscribe a pentagon in a given circle. Draw diameters intersecting in *e* (fig. 146); bisect *e b* in *d;* from *d*, with *d c*, describe the arc *c h ;* from *c*, with *c h*, describe an arc cutting the circle in *g;* join *c g*, it is the side of the pentagon required.—Meth. 2d (fig. 147). Draw the diameter *a b;* divide it into five equal parts; from *a*, *b*, with *a b*, describe arcs cutting in *d;* through the second of the points from *a*, draw from *d* to *c;* join *a c*, it is the side required.

To inscribe a hexagon in a given circle (fig. 148). The method last described is

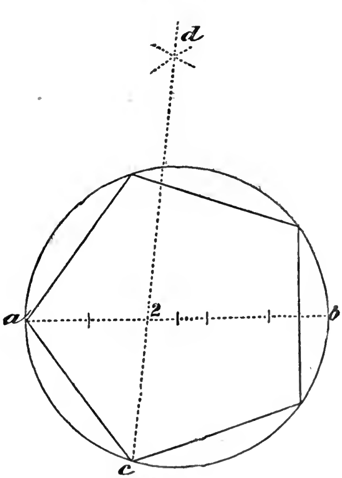


fig. 147.

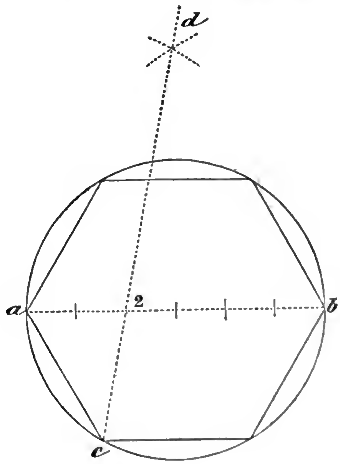


fig. 148.

applicable to this problem. The diameter being divided into six parts, *a c* is the side required.—Meth. 2d (fig. 149). Draw the diameter *a b* from

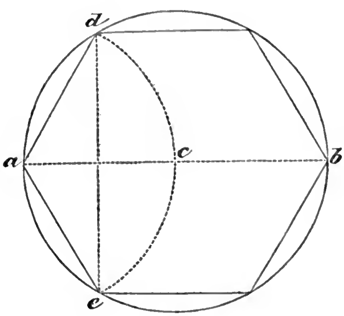


fig. 149.

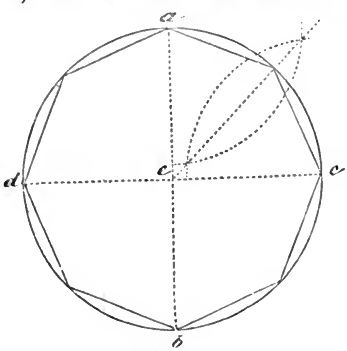


fig. 150.

a with *a c* (the centre of the circle); describe an arc cutting the circle in *d e;* join *a d,* it is the side required.

To inscribe an octagon in a given circle (fig. 150). Draw diameters intersecting in *e;* bisect each of the quadrants thus obtained; join the points.

To inscribe a dodecagon, or twelve-sided figure, in a circle (fig. 151). Draw diameters intersecting in *e;* with *a e,* from *a, b, c, d,* cut each quadrant in two points; join these.

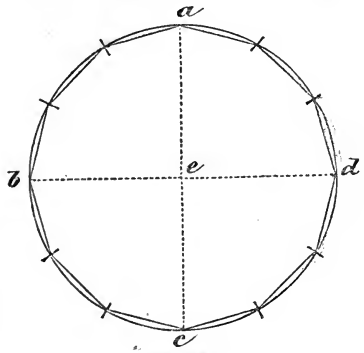


fig. 151.

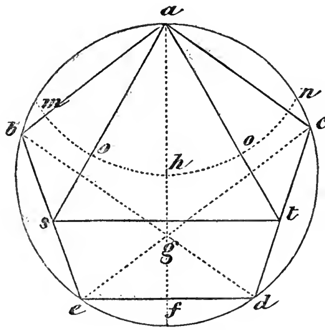


fig. 152.

To inscribe an equilateral triangle in a given pentagon (fig. 152). Join the opposite angles by lines *d b, e c,* cutting in *g;* join *a f* through *g;* lay off *f g* from *g* to *h;* from *h,* with *h a,* describe a circle about the pentagon; from *a,* with *a h,* describe the arc *m h n;* bisect *m h, h n,* in *o, o;* through these from *a* draw lines cutting *e b, d c* in *s* and *t;* join *s t.*

To inscribe a square in a pentagon (fig. 153). Join the angles *c, b;* from *c,* perpendicular and equal to *c b,* draw *c d* (from want of space this line is not given in full); join *a* and the extremity of *d;* from the point *e,* where it cuts *c e,* draw *e f* parallel to *b c;* *e f* is the side required.

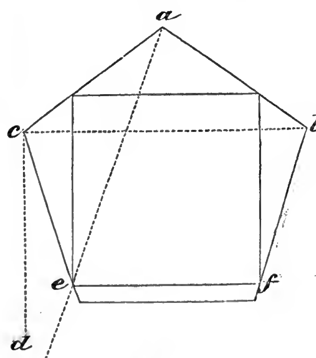


fig. 153.

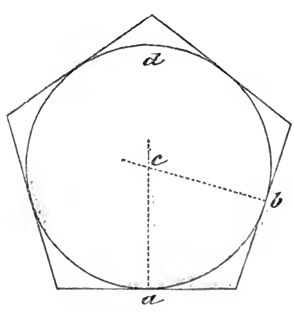


fig. 154.

To inscribe a circle in a pentagon (fig. 154). Bisect any two of the sides in *a* and *b;* draw perpendiculars from these intersecting in *c,* with *c a* from *c* describe *a b d.*

To inscribe a hexagon in a given pentagon (fig. 154). Inscribe a circle as above, and thereafter a hexagon in the circle.

To inscribe an equilateral triangle in a given hexagon (fig. 155). Bisect any two of the sides as *a b*, *c d* in *e*, *f*; join *e f*, from *e*, *f*, with *e f*, describe arcs cutting in *g*; join the points.

To describe a circle about a triangle (fig. 156). Bisect *a b*, *a c*, by lines cutting in *d*; from *d*, with *d b*, describe the circle.

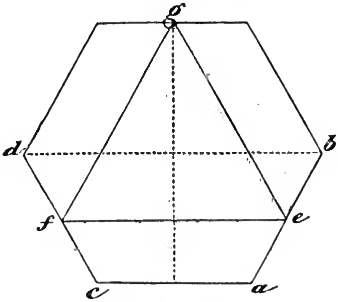


fig. 155.

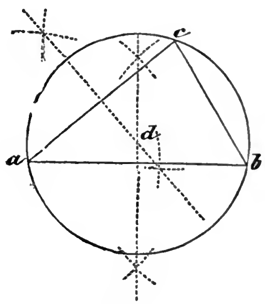


fig 156.

To describe a circle about a square (*g e h f*, fig. 143). Draw the diagonals; the part where they intersect is the centre of the circle.

To describe a triangle about a circle (fig. 157). Draw the diameter *a b*; from centre *c* draw *c d* perpendicular to *a b*; draw any line *e f*; from centre *d* lay off the length of base *e f*; from *e f*, touching the circle in *h*, *g*, draw lines to *m*.

To describe a square about a circle (fig. 158). Draw diameters cutting in *e*; with *a e*, from *a*, *b*, *c*, *d*, describe arcs cutting each other; join the points.

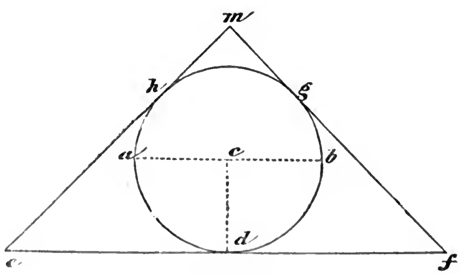


fig. 157.

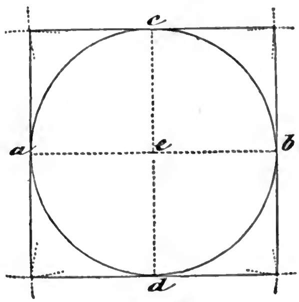


fig. 158.

To describe a square about a given circle (fig. 159). Draw two diameters intersecting at *i*, with the radius of the circle, from the points of the diameters *a b*, *d c*, describe arcs cutting in *f*, *g*, *h*, *e*; join these points.

To describe a pentagon about a circle (fig. 160). Inscribe in the circle a pentagon, by any of the rules already given; bisect the sides of this, and from the points draw lines cutting in *e*; from *e* draw to *b*; and through *a* draw a tangent *b a c* to the circle; from *e*, with *e b*, describe a circle; points are obtained where the radial lines from e cut this; join the points.

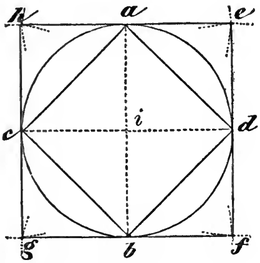


fig. 159.

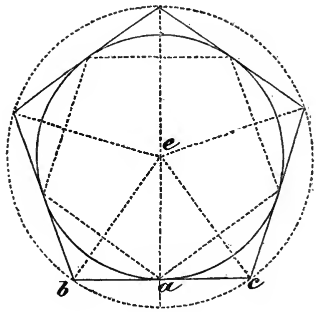


fig. 160.

To describe a pentagon about an equilateral triangle (fig. 161). From a and b, with any radius, describe arcs $f\,g$, $d\,k$; draw $a\,m$ perpendicular to $b\,c$; divide $m\,o$ into five parts; from o with four of these describe the arc $f\,t$; with $f\,t$ set off from k to d; join $a\,f\,d$; make $r\,g = o\,f$; through g draw $a\,g\,n = c\,f\,d$; from n, d, with $a\,d$, measure to s, s; join $d\,b\,s$, $n\,c\,s$, and $s\,s$.

To describe a pentagon about a square (fig. 162). Produce $c\,a$ to f; bisect $a\,b$ in e; draw the perpendicular $e\,g$; from a, c, d, with $a\,e$, draw the arcs $e\,f$, h, h; divide $e\,f$ into five equal parts; through the second of these draw $a\,g$; with one of them lay off from the sides $c\,a$, $b\,d$, in the arcs h, h; from c draw through h to m; produce $g\,a$ to meet this in m; two of the pentagonal sides are found.

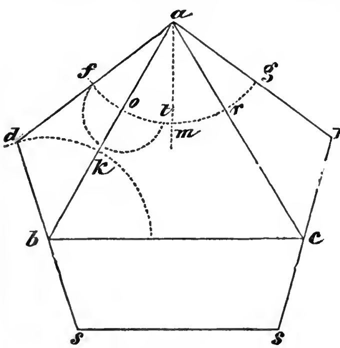


fig. 161.

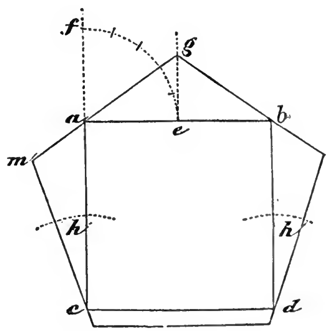


fig. 162.

To describe an octagon about a square (fig. 163). Draw diagonals, cutting in e; from e, with $e\,b$, describe a circle; bisect $c\,d$, $c\,a$, in f and g, from these draw lines through, meeting the circle; join the points.

To describe a hexagon about a hexagon (fig. 164). Produce $a\,b$, $c\,d$ to e; bisect $b\,e$, $d\,e$ in f, g; draw from b and d through these, cutting in h; from m, the centre of the given hexagon, with $a\,h$, describe a circle; bisect all the sides of the hexagon, as $a\,b$, $c\,d$; through the centre m from these draw lines touching the circle; join the points.

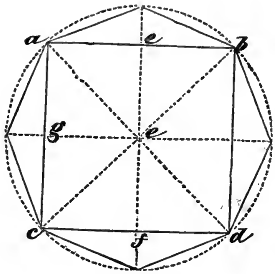


fig. 163.

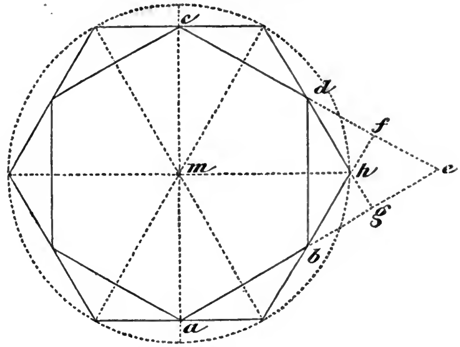


fig. 164.

To describe a square about an equilateral triangle (fig. 165). Bisect $b\,c$ in d; draw $d\,a$; produce $b\,c$; make $d\,e$, $d\,e$, equal to $d\,a$; join $e\,a$; from d, with $d\,c$, describe $c\,f\,b$; from f, through b, c, draw to h, g.

To inscribe four circles within a circle (fig. 166). Draw diagonals, cutting in e; join $a\,c$; from c, with $a\,c$, lay off on $c\,d$ to d; with $d\,c$, from a, b, c, d lay off in the diameters to g, h, t, f; with radius $f\,b$ describe from these points the four circles.

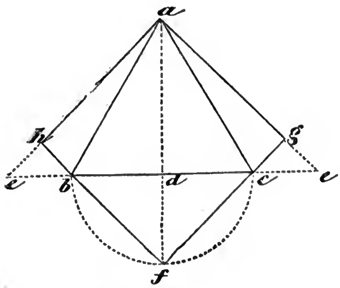


fig. 165.

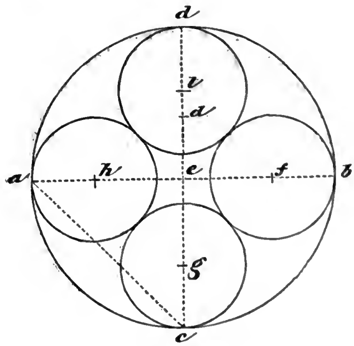


fig. 166.

To inscribe three circles within an equilateral triangle (fig. 167).

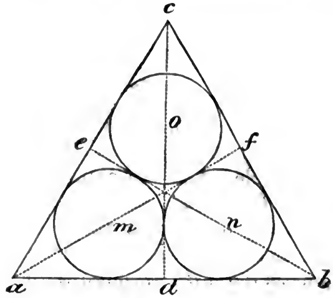


fig. 167.

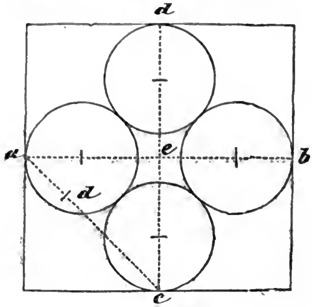


fig. 168.

Bisect the sides in *d, e, f,* and from these draw to the opposite angles; with *a d,* from *e, d, f,* lay off to *m, n, o*; describe from these the three circles.—*Note.* By joining the points *m, n, o* by lines, a triangle may be inscribed within the other.

To inscribe four circles within a square (fig. 168). Bisect the sides, and draw lines from the points, cutting in *e*; join *a c*; from *c*, with *c e*, cut *a c* in *d*; with *d a*, from *a, b, c, d,* lay off in the diameters; these are the centres of the circles of which *a d*=radius.

A triangle being given, to construct a parallelogram equal to it (fig. 169). From the apex *a* draw *a e* parallel to *b c*; from *a* draw a perpendicular to *d*; from *c* draw to *e* parallel to *a d.*—Meth. 2d. From *a* (fig. 170) draw *a e* parallel to *b d*; bisect *b d* in *c*; from *c* draw *c f,* the angle *d c f*=*d b a*; from *d* draw *d e* parallel to *c f.* This is the figure known as a rhomboid.

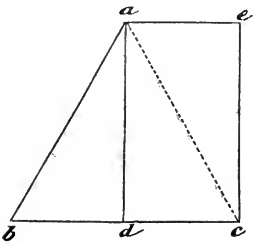


fig. 169.

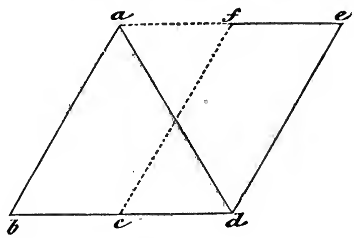


fig. 170.

To construct a parallelogram equal to a triangle (fig. 171). Draw the diagonal *a d,* produce *c d* to *e*; from *b* draw *b e* parallel to *a d*; join *b c, e c b*=*a b c d.*

To construct a square equal to two squares, of which the sides a, b *are given* (fig. 172). Draw *c d*=*b,* and *d e* at right angles to *c d*=*a*; join *c e,* it is the side of the square required.

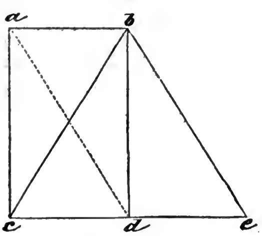


fig. 171.

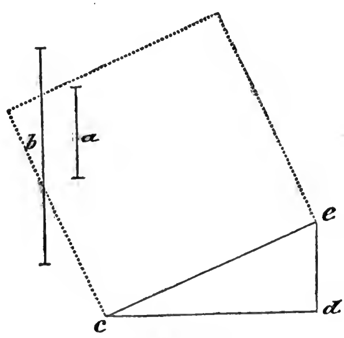


fig. 172.

To construct a square equal to a given rectangle (fig. 173). Produce the base *b c* to *e*; from *c* with *c d* describe the arc *e d,* bisect *b e* in *f,* from *f* with *f e* describe the semicircle *e h b*; produce *c d* to *h*; *c h* is the side of the square; *n m h c*=*a b c d.*

To construct a triangle to contain three times a given triangle. Let *a b c,* fig. 174, be the triangle. Produce *a b* to *d*, lay from *b* three times *a b* to *d*, join *c d*.

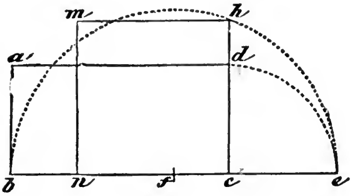


fig. 173.

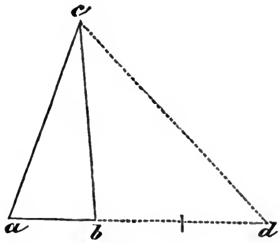


fig. 174.

To construct a triangle equal to a given angle a b c (fig. 175), *but of less height.* Let *d* be the point to form the apex of the required angle; produce *c b* to *e*, join *d b*; from *a* draw *a e* parallel to *d b*; join *d e*, *d e c*=*a b c*.

To draw any irregular polygon by means of the scales of equal parts, diagonal scales and protector, the sides and angles being given. Draw *a b*, fig. 176=the length given, say 250 feet, taken from the diagonal scale; make *b c*=150, and at an angle of 50° to *a b*; at an angle of 90° draw *c d*=175; make *d e*=180, and the angle 120°; join *e a*, it will be=217, and the angle 129° 30′.

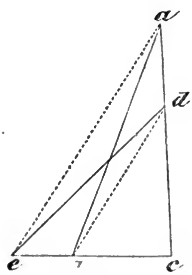


fig. 175.

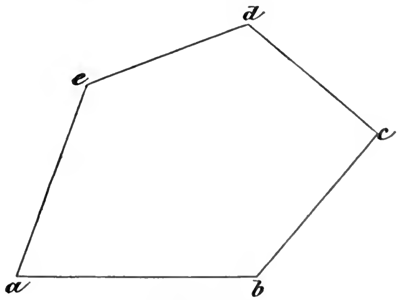


fig. 176.

To reduce a polygon to a quadrilateral. Produce *a e* (fig. 177) indefinitely; join *e c*; from *d* draw *d f* parallel to *c e*; join *c f*; *f a b c*=*e a b c d*.

A quadrilateral being given, to reduce it to a triangle (fig. 178). Produce *a b* indefinitely, join *d b*; from *c* draw *c e* parallel to *d b*; join *d e*.

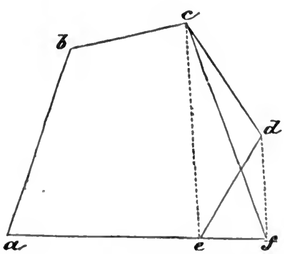


fig. 177.

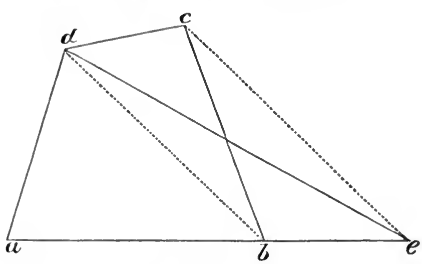


fig. 178.

An irregular figure being given, to construct another similar to it, but reduced or enlarged. Let the figure be reduced one-half; draw the diagonals, joining the opposite angles; bisect $a\ b$ (fig. 179) in g; from g draw a line parallel to $b\ c$, cutting $a\ c$ in h, $g\ h$ is $= b\ c$; from h draw to m parallel to $d\ c$; proceed till the figure is complete. If the figure had to be enlarged, $a\ b$ and all the diagonals should be produced, and lines drawn parallel to those given.

An irregular figure being given, to construct another equal and similar (fig. 180). From b draw $b\ o$ perpendicular to $a\ b$; and draw from the angles of the figure lines parallel to $a\ b$; draw $m\ n$ (fig. 181) $= a\ b$, draw $n\ o$ perpendicular to $m\ n$; take from b the height in $b\ o$ where the parallel lines cut it, and lay them off respectively to $n\ o$ from n; through the points thus obtained draw lines parallel to $m\ n$; from n with $b\ c$ cut the first parallel in 1; from 1, with $c\ d$, cut the third in 2; from 2, with $d\ e$, cut the fourth at o; from o, with $e\ f$, cut the fifth in s; from s, with $f\ g$, cut the second in v; from m, with $a\ g$, cut this in v.

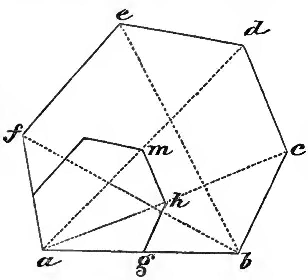


fig. 179.

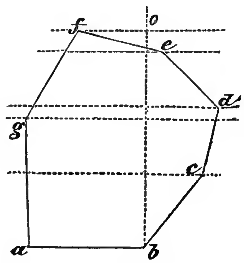


fig. 180.

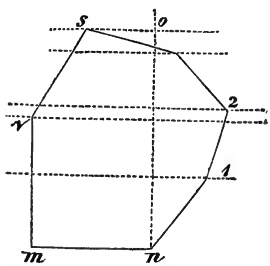


fig. 181.

An irregular figure being given, to construct another equal and similar, but in a reversed position (fig. 182). The method is similar to the above; the letters on the diagram, and that in fig. 183, will render much description unnecessary. From any part in $b\ c$ erect perpendiculars, make their position the same in both lines; with $c\ d$ from c (fig. 183) draw to the first parallel; by proceeding thus the figure will be constructed as desired. Figures having irregular sides can be copied, reduced, enlarged, or made equal, by means of squares, as in figs. 184 to 189. Suppose fig. 184 to be copied double the size. Draw any number of horizontal and parallel lines across the face of the diagram at equal distances from each other; at the

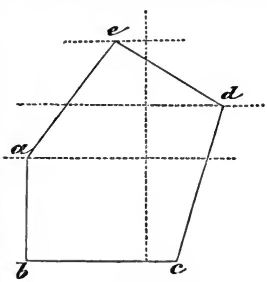


fig. 182.

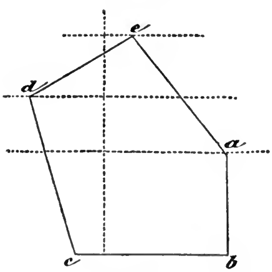


fig. 183.

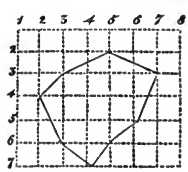


fig. 184.

same distance draw other lines perpendicular to the others. There will thus be described a series of squares, the boundary-lines of which will enclose the figure. By drawing the same number of lines perpendicular to one another, but at double the distance of those in fig. 184, a series of similar but enlarged squares will be obtained, as in fig. 185. The points at which the terminations of the figure in fig. 184 touch the lines, or are placed in the square, must be ascertained and transferred to corresponding points and situations in fig. 185. Fig. 189 is a similar one to fig. 188; twice larger, but, as will be observed, it is reversed; the angle at the top, in fig. 188, being in the lowest position in fig. 189. Fig. 187 is a similar figure to fig. 186, but enlarged as $1\frac{1}{2}$ to 1; the angle at the right hand in fig. 186 is placed at the left hand in fig. 187. These examples, aided by the annexed numbers, will shew the pupil the method of using a system of squares for reducing, enlarging, or drawing equal and similar figures, in transposed positions, or otherwise. We shall now proceed to the construction of the curves known as the 'conic sections.'

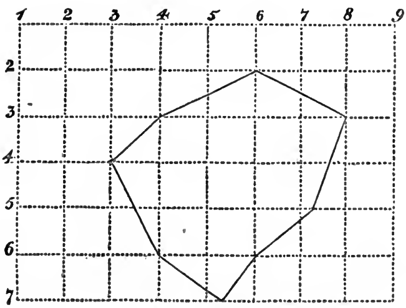


fig. 185.

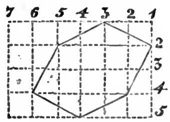


fig. 186.

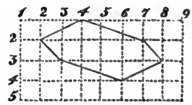


fig. 188.

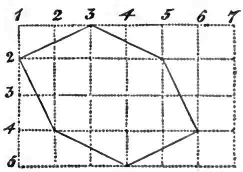


fig. 187.

To describe an ellipse in a given line (fig. 190). Divide *a b* into three equal parts; from *c*, *d*, with *c a*, describe two circles cutting in *e*; through the centre and the points of intersection draw lines as *c f*, *d e*; from the point of intersection take to *f* in the compasses; from the points, as *e*, describe parts of circles joining the small ones previously described, as *f f*.—Meth. 2d (fig. 191). Divide the line *a b* into four equal parts; from *c*, *d*, the first and third, describe with radius *a c* two circles; from *c d*, with *c d*, describe arcs cutting in *e*, on both sides

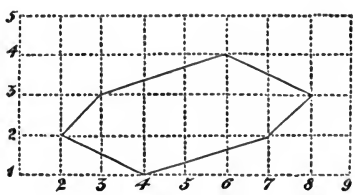


fig. 189.

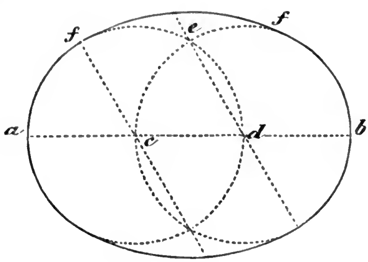


fig. 190.

of $a\ b$; from e draw through d to g with $e\ g$; from e describe parts of circles joining those previously drawn.—Meth. 3d. *The diameters being given* (fig. 192). Let $a'\ b'$ be the diameters; draw $a\ b = a'$; bisect it in e, draw $e\ a$, $d\ c =$ half of b', $d\ c$ will therefore equal b'. Take $c\ d$, and from d lay it on $a\ b$ to f; divide $f\ b$ into three equal parts; with two of these from e lay on $a\ b$ to g; make $e\ h = e\ g$; from h, g, with $h\ g$, describe arcs in m, n; from h, g, with $a\ h$, describe parts of circles a, b; from m draw through g, touching the circle described from g; from m, n describe arcs as in preceding problems.—Meth. 4th. Let $a\ b$, $c\ d$ (fig. 193) be the diameters. With $c\ e$ from b lay off to f; divide $f\ e$ into three equal parts; from f, with one of these, describe a semicircle to h; make $e\ g = e\ h$; proceed as in last problem.—Meth. 5th. An ellipse may be described without compasses, on a large scale, as follows:—Let $a\ b$ (fig. 194) be the length of proposed ellipse, and $c\ d$ half its breadth; bisect $a\ b$ in c, draw $c\ d$ perpendicular to it; with $a\ c$, from d, cut $a\ b$ in e and f, in d, e, f fix pins; fasten a cord round e, carry it round d, and fasten it firmly to f; take out the pin d, and substitute for it a pencil or tracer; keep the cord tight, and from d, towards a, move the tracer, and from d to b; half of the ellipse will be described; move the cord to the other side of the pins for the remaining half.

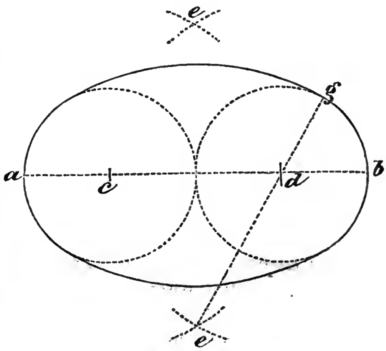


fig. 191.

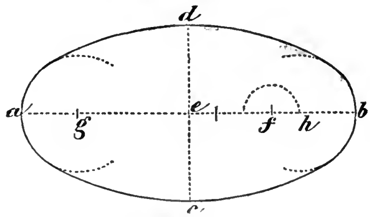


fig. 193.

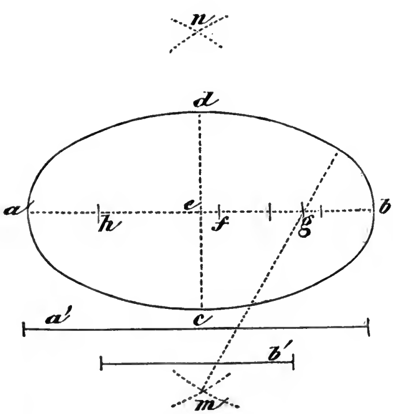


fig. 192.

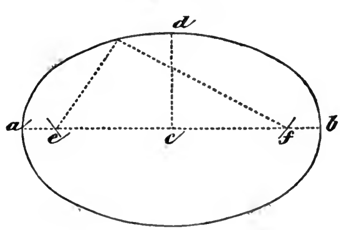


fig. 194.

To draw an ellipse round two squares (fig. 195). Let $a\ b\ c\ d$, $e\ f\ d\ c$ be the squares, draw the diagonals as in the diagram; from g and h, c and d, describe the parts of the circles, joining $a\ b$, $f\ e$, $f\ a$, $e\ b$.

To draw a tangent to an ellipse (fig. 196). Let c be the point of contact, and $a\,b$ the foci; from b draw a line through c; make $c\,d=c\,b$; join $d\,a$, bisect it in e; from e draw through c; $e\,c$ is the tangent.—Meth. 2d (fig. 197). From a, b, the foci of the ellipse, to the point of contact at c, set off in $c\,a$, $c\,d=c\,b$; from b draw through d; draw from c a line parallel to $b\,d$; it is the tangent required.

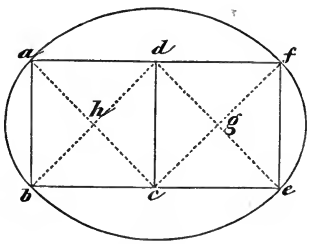


fig. 195.

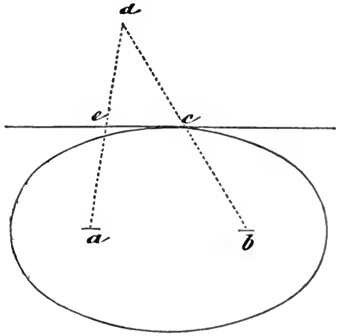


fig. 196.

An ellipse being given, to find its 'foci' and diameters (fig. 198). Draw any two parallel lines as from $a\,b$, $c\,d$; bisect them in e, e; draw $e\,e$, bisect it in f; f is the centre of the ellipse; from this, with any radius greater than half the supposed conjugate diameter, draw the circle $p\,b\,c$, cutting the ellipse in h, m; join $h\,m$, bisect it; through the point of bisection and f draw a line $o\,o$; this is the transverse diameter; through f perpendicular to $o\,o$ draw a line, meeting the ellipse; this is the conjugate diameter; bisect $f\,o$ in s; make $f\,s=f\,s$; s, s, on both sides the conjugate, are the foci.

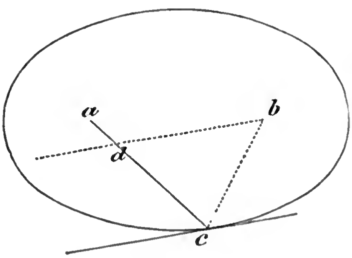


fig. 197.

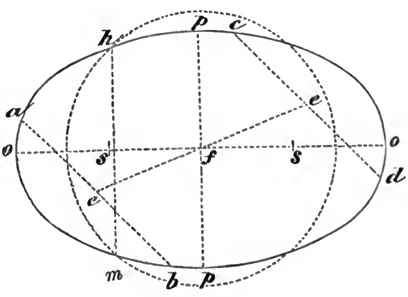


fig. 198.

To describe an ellipse on the large scale by means of points (fig. 199). Let $a\,b$, $c\,d$ be the two diameters; with $a\,e$, from c, lay on $c\,d$ to g; from any point m between $e\,g$, with $e\,g$, cut $e\,b$ in n; from m through n draw a line and make this from $n=e\,d$; the point thus found is in the curve of the ellipse: any number to complete the curve may thus be found.—Meth. 2d. Let $a\,b$, fig. 200, be half the transverse, and $b\,c$ half the conjugate diameter; draw *b c* at right angles to *a b*, and produce it indefinitely; from *b*, with *a b*, describe the quadrant. Divide *a b*, *b c* into the same

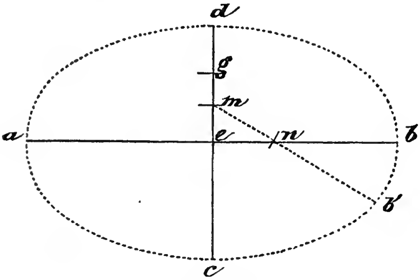


fig. 199.

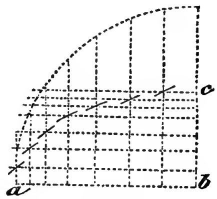


fig. 200.

number of equal parts; and from these draw lines parallel to *a b*, *b c*; through the points where the corresponding lines intersect as the first from *b*, with the first from *c*, draw a curve by hand—this is one quarter of the ellipse, the others may be produced in like manner.

The base c d *of a parabola and its abscissa* a b *being given, to find the curve* (fig. 201). From *c* and *d* draw lines to *e*, *f*; through *a*, parallel to

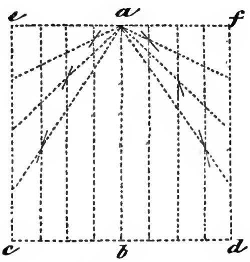


fig. 201.

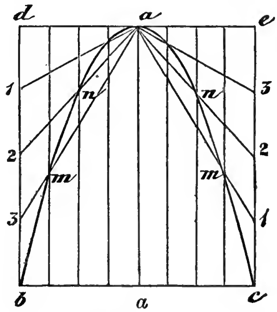


fig. 202.

b d, draw *e a f*. Divide *c b*, *b d*, each into any number of equal parts as four, also *c e*, *d f*. From the points in *c d* draw lines to *e f*, parallel to *c e*; and from those in *c e*, *d f* to the vertex *a*; through the points where the corresponding lines intersect, as the first from *c*, with the third from *e*, draw by the hand the curve required—the various points may be correspondingly numbered to facilitate the operation. Fig. 202 gives another diagram, shewing this construction; *a b*, *b c*, divided each into four parts, as also *c e*, *b*,—the points *n*, *m*, *n*, *m* are those through which the curve is drawn. In fig. 203 another method is shewn. Draw the line *a b*, *c d*; divide *a b* into five equal parts; through these draw lines to *d e*, *c f*; from the points on *d e* draw lines to *a*, and from *c*, through the points on *a b*, meeting those; through the points thus obtained draw the curve by hand.

A parabolic curve being given, to find its focus, directrix, and parameter (fig. 204). Draw any two parallel lines, *a b*, *c d*; bisect them in *e*, *e*; draw a line *e e* through these, this forms a diameter: at right angles to this draw

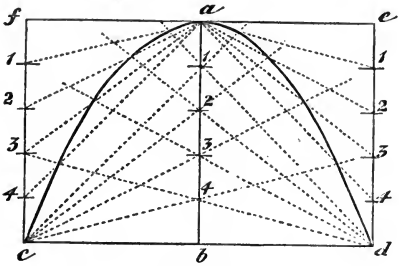


fig. 203.

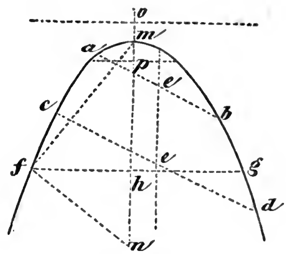


fig. 204.

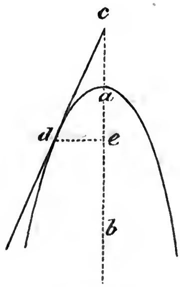


fig. 205.

any line *f h g*, bisect it in *h*; draw *h m o*; join *m f*; from *f*, at right angles to *m f*, draw a perpendicular cutting *m n* in *n*, divide *h n* into four equal parts: lay one of these from *m* to *p* and *o*: *p* is the focus; through this draw a line parallel to *f g*—it is the parameter—a line through *o* parallel to this is the directrix.

To draw a tangent to a given point in the curve of a parabola. Let *a* (fig. 205) be the vertex, the point of contact, and *c* the point where the tangent will intersect the parabola's axis produced. From *d* draw the semi-ordinate *d e* at right angles to *b e*, draw *a c*=*a e*; *d e* is the tangent.

To draw the curve of a hyperbola, the centre d (fig. 206), *the vertex and ordinate* d c *being given.* Draw *a b*; through the vertex draw *e f*, and from *a*, *b* parallel to *d c*, *a e*, *b f*; divide *a c*, *c b* into any number of equal parts as four, and draw from these to the centre *d*; divide *a e*, *f b* into the same number of equal parts as *a b*, namely four, and draw from these to *e* —through the points where the corresponding lines intersect draw the curve by hand.

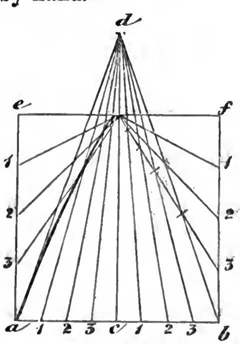


fig. 206.

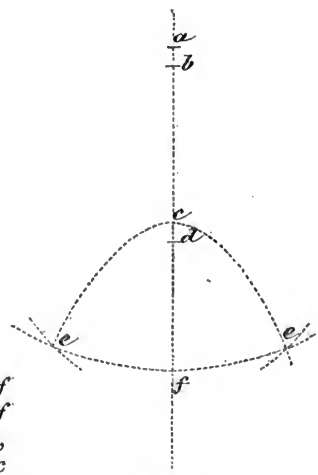


fig. 207.

To describe a hyperbola by means of points. Draw any indefinite line *a f* (fig. 207); set off on it the transverse, *b c*. Let *d* be the focus; equal to *d c* from *b* set off to *a*; from *a*, with any radius greater than *b a*, describe an arc; from the radius take the transverse $b\ c$, and with this difference as a second radius, from the centre d describe another arc, cutting the former one in $e\ e$. By this means any number of points may be found; the nearer they are the better.

To describe the curve 'cycloid.' Let $a\,b\,c\,d$ (fig. 208) be any circle; at right angles to $a\,b$ draw any line $b\,e$; make this equal to half of the circumference of the circle $a\,b\,c\,d$; this will be quickest done by dividing $a\,b$

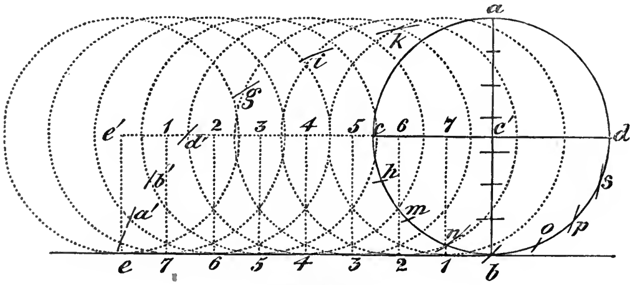


fig. 208.

into seven equal parts, and making $b\,e$ equal to eleven of these; the proportion the circumference of a circle bears to the diameter being as 22 to 7. Divide $b\,e$ into any number of equal parts, as eight, and number them as in the diagram; make $e\,e'$ at right angles to $b\,e$, and equal to $b\,c'$; draw $c'\,e'$, and divide it into the same number of parts as $b\,e$; from each of these parts as centres, with radius $b\,c$, describe circles; from the centres draw lines to the various points on $e\,b$. Divide half of the circle $d\,b\,c$ into as many parts as $b\,c$ is divided into; then with radius $c\,h$, from the point 7 on $b\,e$ cut the circle described from the point e; then with $c\,m$, from the point 6, cut the circle described from the point 1 on $c\,e$, in the point a'; in the same manner with the distances $c\,n$, $c\,b$, $c\,o$, $c\,p$, $c\,s$; from the various points in $a\,b$, cut the circles in the points b', d', g, e, i, and h; through the points thus found draw the curve.

To describe the curve 'the conchoid.' Draw any two lines, as $a\,b$, $g\,c$ (fig. 209) at right angles to each other; from b draw any number of straight

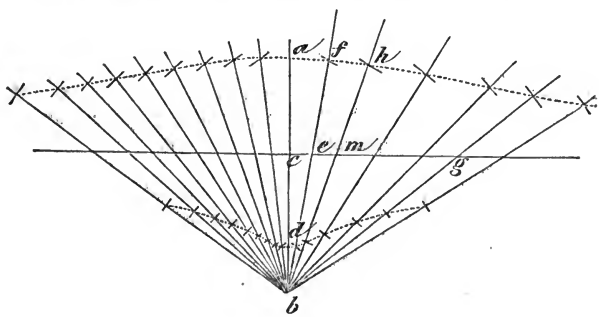


fig. 209.

lines, as $d\,e\,f$, $b\,m\,h$, $b\,g$; make on the line $a\,b$, $c\,d = c\,a$; and on each of the lines drawn from b, take $e\,d = e\,f$, $m\,h = a\,c$, and so on; through the points thus obtained draw the curves; the upper curve *f h* is called the 'superior conchoid,' the lower one the 'inferior conchoid.'

To describe the cissoid. Let *a b c* (fig. 210) be a circle, and *d e* any indefinite line touching it at *b*; from *a* draw any lines to points on the

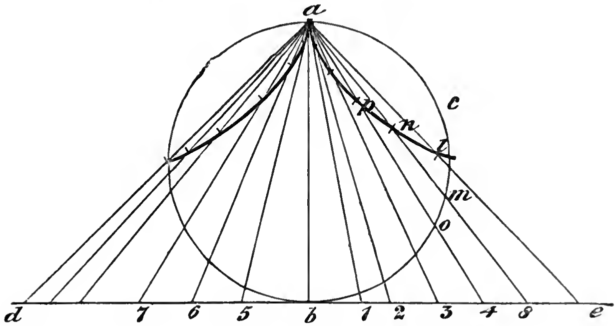


fig. 210.

line *d e*, as to 1, 2, 3, 4, 5, 6, 7, and so on; with the distance *a m* cut the line 8 *a* from 8 in *n*, and from 4, with *a o*, cut *a* 4 in *p*, and so on. Through the points thus found, on each side of *a b*, draw a curve as in the diagram.

To draw a spiral on a given line (fig. 211). Let *a b* be the distance between each convolution; divide *a b* in *c*; from *c*, with *c b*, describe the

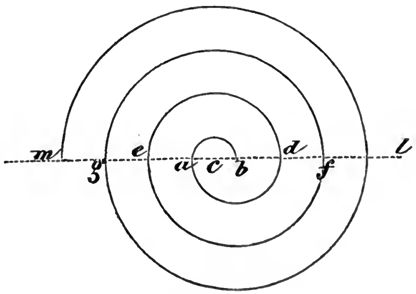


fig. 211.

semicircle *b a*; from *b*, with *a b*, the semicircle *a d*; from *c*, with *c d*, the semicircle *d e*; from *b*, with *b e*, to *f*; from *c*, with *c f*, to *g*; from *b*, with *b g*, to *l*; from *c*, with *c l*, to *m*; the spiral is complete.

Having thus fully explained the various methods of performing useful Geometrical Constructions, we shall shew the application of Geometry to Architectural Drawing.

GEOMETRY

APPLIED TO

ARCHITECTURAL DRAWING.

We shall first notice under this division of our work the methods of describing the various "mouldings" met with in architectural productions. We shall take them as nearly as possible in the order of their general sequence. The first we notice is the '*Fillet*,' shewn in fig. 212; this is so simple, that it requires no particular instructions as to the method of describing it.

fig. 212.

Fig. 213 is the '*Astragal*.' Let b = the breadth, draw a line $b\,d$; make c the centre, take half of b; and as radius from c describe the semicircle; draw the horizontal lines e, e.

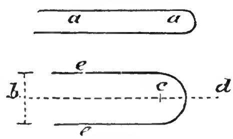


fig. 213.

Fig. 214 is the '*Torus*.' The method of describing it, the breadth being given, is the same as in last problem.

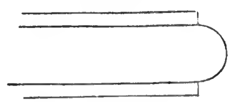


fig. 214.

Fig. 215 is the '*Scotia*.' Let $a\,a$ be the top line, and $b\,b$ the bottom one; from a drop a perpendicular to b; divide this into three equal parts: from the first of these, from a, draw any line $e\,d$ parallel to a or b; from the point of intersection c, with radius $c\,a$, describe the semicircle $c\,d$; from d, with $d\,e$, describe part of a circle, meeting the line $b\,b$; draw the fillets $b\,b$, $a\,a$.

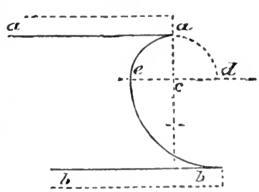


fig. 215.

Method 2d. Let $a\,a$, fig. 216, be the upper line, and $c\,c$ the lower; from a drop a perpendicular to c; divide $a\,c$ into 7 equal parts; through the third of these, from a, draw a line parallel to $a\,a$; from b, with $b\,a$, draw the semicircle $b\,d$; from d draw to e perpendicular to $b\,d$, produce $a\,a$ to e; from e draw through b a line meeting the semicircle $b\,d$ produced in m; from e as a centre, with $e\,m$ as radius, describe part of a circle to n.

Fig. 217 is the '*Echinus*,' '*Quarter round*,' or '*Ovolo*.' Let $a\,b$ be the two points, join them by a line $a\,b$; divide this into 7 equal parts, from b, with b 6, and from a with same radius describe arcs cutting in c; from c, with $c\,a$, describe the arc $a\,b$.

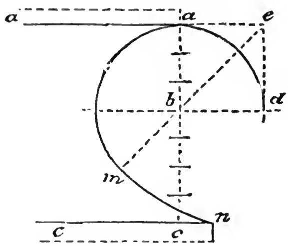


fig. 216.

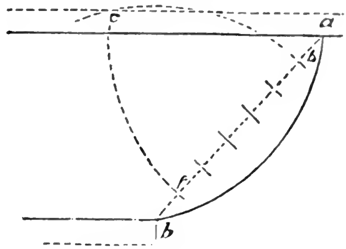


fig. 217.

Method 2d. Let *a b*, *c d*, fig. 218, be the two lines; draw *b d* perpendicular to *e d;* divide it into three equal parts; produce *c d* to *e*, and make *d e* equal two of the parts on *b d;* from *e* draw to *f;* join *d f;* from *d*, *f*, with any radius greater than half, describe arcs cutting in *g;* from *g*, with *g f*, describe the arc *f d*.

Method 3d. Let *a b*, *c d*, fig. 219, be the lines; divide *b d* into four equal parts, make *d e* equal three of these; draw *e f*, and proceed as in last problem.

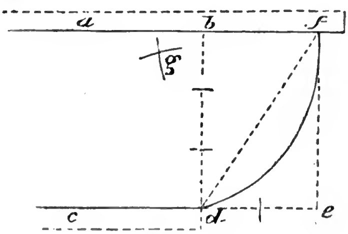


fig. 218.

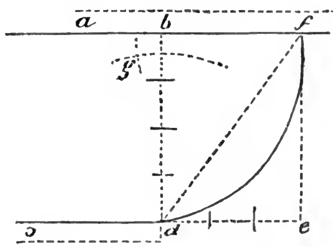


fig. 219.

Fig. 220 is the '*Cavetto*,' or '*hollow*.' To describe it. Let *a b*, *c d*, fig. 221, be the lines at top and bottom; from *b* draw to *d* perpendicular to *a b;* divide *b d* into three equal parts; from *d* lay on *d c* to *e* equal to two of these; join *b e;* from *e* and *b*, with radius greater than half *e b*, draw arcs cutting in *f;* from *f*, with *f b*, draw the arc *b e*.

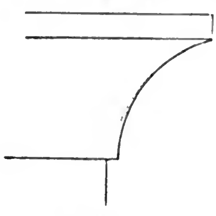


fig. 220.

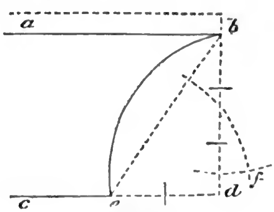


fig. 221.

Method 2d. Let *a b*, *c d*, fig. 222, be the two lines; divide the perpendicular into five equal parts; make *d e* equal to four of these, and proceed as in last problem.

Fig. 223 is the '*Apophygee*,' generally used to connect the shaft of a column with its base. To describe it. Let *a b*, fig. 224, be the line of base,

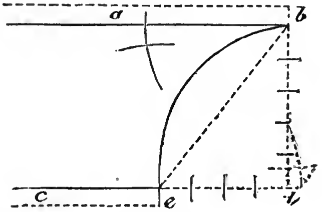


fig. 222.

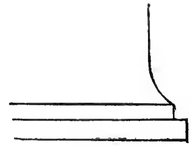


fig. 223.

and *c* that of the shaft; produce *c* to *d*; divide *a d* into four equal parts; lay five of these from *d* to *e*; join *e d*, bisect it by arcs cutting in *f*; from *f*, with *f a*, describe the arc *a e*.

Fig. 225 is the '*Cyma-recta*.' To describe it. Let *a b*, *c d*, be the lines: join *a d*, divide it into five equal parts; bisect the part *a e* (the point *e* is

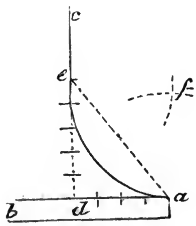


fig. 224.

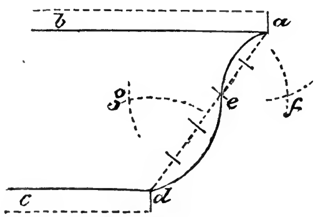


fig. 225.

the third from *d*) by arcs cutting in *f*; and the part *d e* by arcs in *g*. From *f*, with *f a*, describe the arc *a e*; and from *g*, with *g d*, an arc *e d*; the moulding is complete.

Method 2d. Let *a b*, *c d*, fig. 226, be the lines, drop a perpendicular to *e*; produce *c d* to *e*; make *d e*=*e b*; join *d b*, divide it into twelve parts; from *d* and *e* (the sixth of these), with radii *d* 5, *e* 1, describe arcs cutting in *f*; from *e* and *b*, with radii *e* 11, *b* 7, arcs cutting in *g*; from *f* and *g* as centres, with radii *f d*, *g b*, describe arcs meeting in the point *e*.

Fig. 227 is the '*Cyma-reversa*.' To construct it. Let *a b*, *c d* be the lines; produce *c d* to *e*, and drop a perpendicular from *b*; from *e*, with *e b*, describe an arc cutting *c e* in *d*; join *d b*, bisect it in the point *n*; from *d* and *n*, with radius greater than half *d n*, describe arcs; from the point of

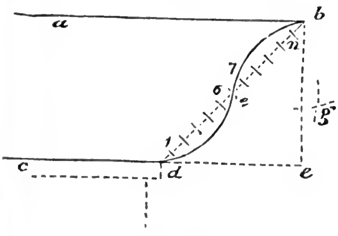


fig. 226.

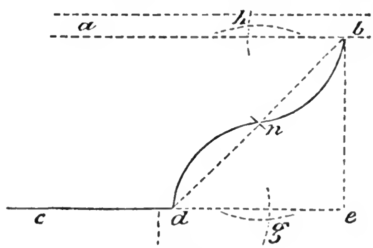


fig. 227.

intersection as centre describe an arc *d n;* from *n* and *b*, with same radius, describe arcs cutting in *h;* from *h*, with *h b*, describe an arc meeting the arc *d n* in *n*.

Fig. 228 is the '*Ogee.*' To construct it. Let *a b*, *c d* be the lines; join *b d*, divide it into four equal parts; through the third of these from *d*, as *e*, draw a line parallel to *a b*. With the distance *e b*, from *e*, lay on *e f* to *h;* from *h*, with same distance, describe a semicircle to *o;* draw *h o* parallel to *e b*, cutting the semicircle described from *h* in the point *o;* join *o d*, bisect it by arcs meeting in *g;* from *g*, with *g d*, describe the arc *o d*.

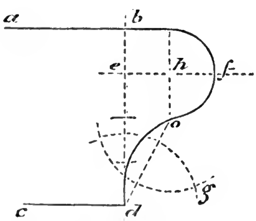


fig. 228.

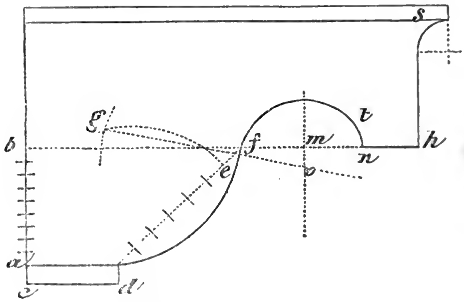


fig. 229.

We now proceed to give examples of various *Mouldings*, with the method of describing them. Draw the line *a b*, divide it into nine equal parts; from *b* draw to *h*, at right angles to (fig. 229) *a b;* take any point *f* for the termination of the quarter round, from the end of the fillet *c d;* join *f d*, divide it into seven equal parts; from 1 and 6, with 1-6 as radius, describe arcs cutting in *g;* from *g*, with same radius, describe the quarter round; from *f* make *f n* equal to ten of the parts in *a b;* bisect *n f* in *m;* draw a line through *m* parallel to *a b*. From *g*, through the point where the arc 6 *g* intersects *f b*, draw the line *g f o;* make *h n* equal to four and a half parts of *a b;* from *o* as a centre, with *o f* as radius, describe an arc to *t;* from *m*, with radius *m n*, describe another meeting this. This moulding is met with in the Tuscan order.*

To describe the moulding in fig. 230. Draw any two lines cutting into *c;* with *c b* as radius, describe a

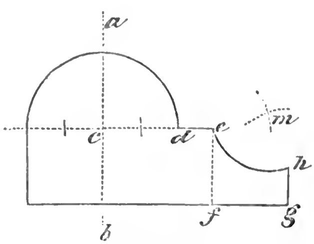


fig. 230.

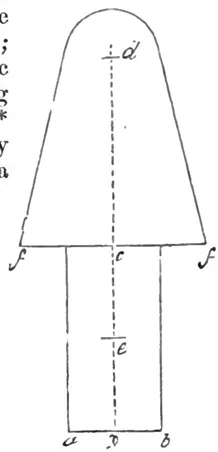


fig. 231.

* See the work in the present series on "Architectural, Engineering, and Mechanica Drawing."

semicircle *c a d*; divide *c d* into two equal parts; make *d e* equal to one of these; drop a perpendicular from *e* to *f*; make *f g* equal to *c d*, and *g h* to *d e*; from *e* and *h*, with radius greater than half the distance between them, describe arcs cutting in *m*—*m* is the centre of the arc *e h*.

To describe the moulding in fig. 231. Draw any line *d g*; divide *g d* into two equal parts at *c*; divide *c g* also at *e*; make *c f*, *c f* equal to *c e*; bisect *c f*, and make *g b*, *g a*, equal to it; from *a* and *b* draw to *f c f*, perpendicular to *a g b*; from *d* describe the semicircle with radius *g b*; join the points *f f* with the extremities of this.

To describe the moulding in fig. 232. Draw the line *a d*; make *a b* equal to *b c*; bisect *c b* in *e*; draw through *c* and *b* lines *f f*, *s s* at right angles to *d a*; make *b f*, *s c* equal to *b e*; bisect *b f*, *b f*, in *m*, *m*; join *m n*, *m n*. The remainder of the moulding will be easily drawn from inspection of the diagram.

To describe the moulding in fig. 233. Draw *a b*, and divide it into six equal parts; through the fourth of these draw a line *c d* at right angles to *a b*; bisect the distance between 2 and 3 in the point *e*; from 4, with 4 *e*, describe the arc *d e*; from the point 1 draw 1 *f* perpendicular to *a b*, and make it equal to *a e*; from *f* as centre, with *f* 1, describe an arc; from *d*, with *d e*, describe a second arc, and from the point 4, with 4, 5, the arc *c* 5; the three arcs joining will describe the curve as in the diagram.

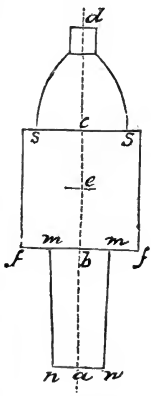


fig. 232.

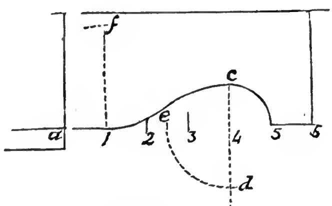


fig. 233.

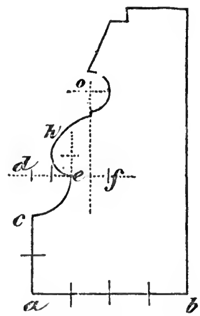


fig. 234.

To describe the moulding in fig. 234. Draw *a b*, divide it into four equal parts; make *a c* equal to two of these, and *c d* equal to one; through *d* draw *d f* parallel to *a b*; from *d*, with *d c*, describe the arc *c e*; make *e f* equal to *e d*; from the centre, above *e*, describe the part of the circle to *h*; from *f*, with *f h*, describe the curve meeting the semicircle described from *o*.

To describe the moulding in fig. 235. Draw *d e f*; and the semicircle *a e*, with radius *d e*; divide *d e* into five equal parts; make *e f* equal to one of these; make *d b* equal to twice *d e*; from *f* draw a perpendicular, meeting *c b* produced.

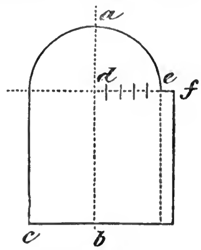


fig. 235.

To draw the moulding in fig. 236. Draw *a b*, divide it into five equal parts; make *c d* equal to four of these; through *d* draw *d f* parallel with *a b*; from *d*, with *d c*, draw the arc *c e*; make *e f* equal to *d e*; divide *e f* into five parts; make the line above *f* equal to one of these; draw *f g* equal to six of these; from *g*, with radius *d e*, describe the arc; bisect *g f*, and lay the distance to *h* —it is the centre of the curve, meeting the semicircle described from *m*; join *n o*, *o s*.

To describe the moulding in fig. 237. Divide *a b*

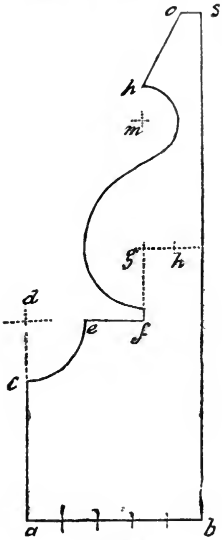


fig. 236.

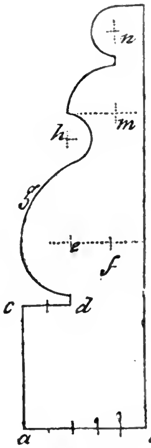


fig. 237.

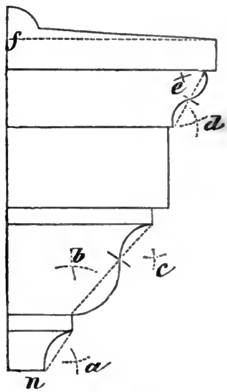


fig. 238.

into five equal parts; make *a c* equal to *b a*; make *c d* parallel to *a b*, and equal to two parts; from *e*, with *c d*, describe the arc; *f*, *h*, *m*, *n*, are the centres from which the other arcs are described.

The mouldings in fig. 238 may be drawn easily by inspecting the figure; *a*, *b*, *c*, *d*, *e*, and *f*, are the centres of the curves; the measurement for the height of fillet must be taken from the base *n*, on the line *n f*.

In drawing the mouldings in fig. 239 the base *b* must first be drawn, then the line *a b* at right angles to it; the respective depths of the mould-

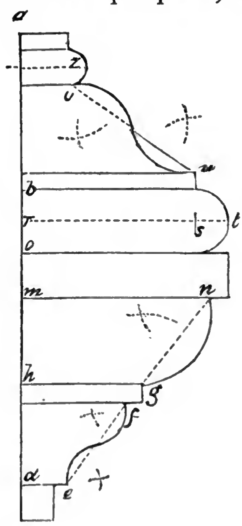


fig. 239.

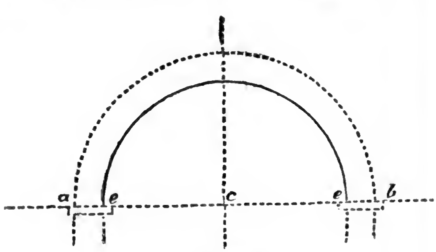


fig. 240.

ings must be laid down on this line, as *d, h, m, o,* and *p*; *t, t,* 2, are the centre-lines of the torus *s* and 2; *e f* is a "cyma reversa;" *g n* the quarter round; *w v* the "cyma recta."

We shall now proceed to give illustrations of the different varieties of *Arches,* with explanations as to describing the curves geometrically; the first we shall notice is the

Semicircular Saxon arch (fig. 240). Draw the line *c*, and perpendicular to it *a b*; from *c* lay off to *e e*, and with *c e* describe the semicircle.

To describe the Norman or horse-shoe arch (fig. 241). Draw the line *e b*, and perpendicular to it another *b a*; from *b* lay off to *d*, and from *d*, with *b e*, describe the arch; draw perpendicular lines joining the extremities of the arch with the line *e b e*.

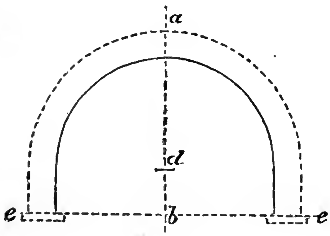


fig. 241.

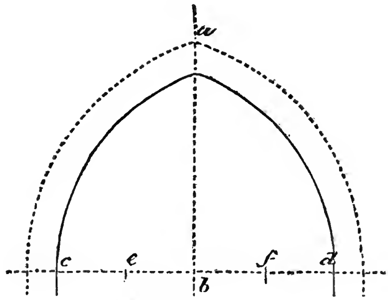


fig. 242.

To describe the pointed horse-shoe arch (fig. 242). Draw the lines *c b*, *b a* perpendicular to one another; divide *c b*, *b d* each into two equal parts at *e, f*; from *e*, with *e d*, describe an arc, and from *f*, with *f c*, another, both meeting in *a*.

To describe the equilateral arch, or early English arch (fig. 243). Draw *c e*, *m n* at right angles to each other; make *m e*=*m c*; from *e, c*, with radius *e c*, describe arcs meeting in *h*.

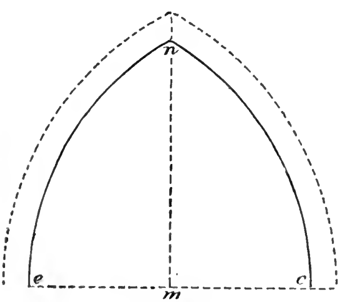


fig. 243.

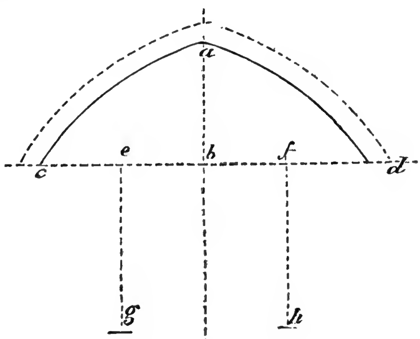


fig. 244.

To describe the early English arch, given in fig. 244. Draw the lines *a b*, *c d* at right angles; divide *c b*, *b d* into two equal parts at *e* and *f*; from these points draw lines to *g, h* perpendicular to *c d*, and make *e g*, *f h* equal to *e f;* from *g* and *h* as centres, with radius *g d,* or *h c,* describe arcs meeting in *a.*

To describe the lancet arch in fig. 245. Draw *c h, f d,* at right angles. Let *a b* be the breadth, and divide it into three equal parts; lay four of these from *a b* to *h;* from *a, b,* with *a b,* lay to *d* and *f;* from these as centres, with radius *d b, f a,* describe arcs cutting in *h; o, o* are centres, from which the dotted arcs are put in.

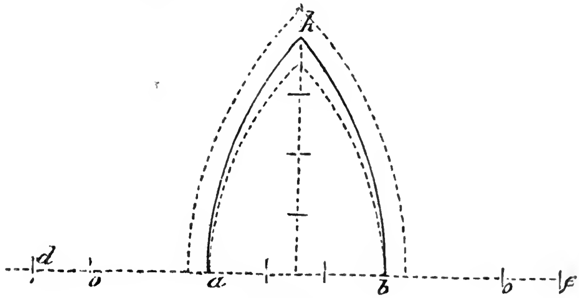


fig. 245.

To describe the 'semi-elliptical arch' in fig. 246. Let *a b* be the breadth and *g f* its height; divide *a g, g b* into two equal parts at *d* and *c;* from *d, c,* with *d c* as radius, describe arcs cutting in *g;* from *c, d,* with radius *c b,* describe parts of circles; from *g* draw through *c, d* to *m, n;* from *g,* with radius *g n* or *g m,* describe part of circle joining *m n.*

To describe the elliptical arch in fig. 247. Draw the line *a b,* divide it

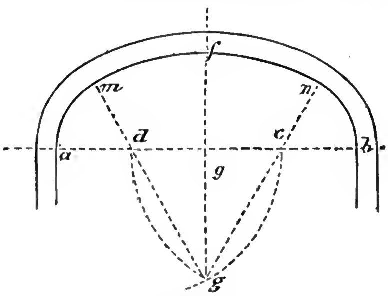


fig. 246.

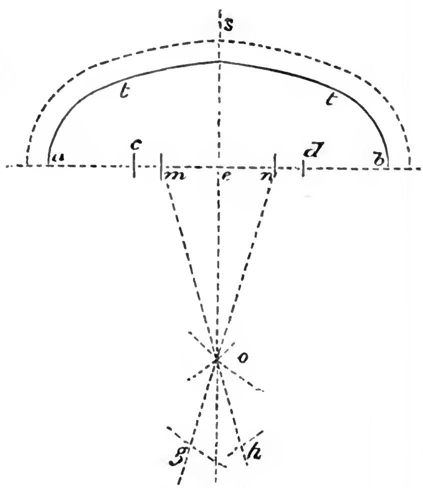


fig. 247.

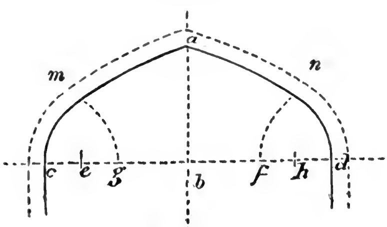


fig. 248.

in the point *e*, and draw a line perpendicular to *a b* through this; divide *e a*, *e b* into two equal parts at *c*, *d*; from *a*, *b*, with radius *a d* or *b c*, describe arcs cutting the line *e* produced; from *d*, *c*, with radius *d b*, describe parts of circles to *t*, *t*; divide *a e*, *e b* into three equal parts, and lay one of these from *e* to *m*, *n*; from *m*, *n*, through *o*, draw lines to *g*, *h*; from *a*, *b*, with *a b*, cut these in *g*, *h*; from the points *g*, *h*, with radius *g t*, describe arcs joining *t*, *t*.

To describe another form of arch in the same style. Draw *c d*, *a b*, fig. 248, at right angles; divide *c b*, *b d* into two equal parts at *g* and *f*; divide *g c*, *f d* into equal parts at *h*, *e*; from *g*, *f*, with radius *g c*, describe arcs or parts of circles to *m*, *n*; from *c*, *d*, with radius *c h* or *d e*, describe arcs below *c d*; then with *c d* as radius, from *g* and *f* cut these; from *o*, *o*, with *o m*, *o n*, describe arcs meeting in *a*.

To describe another form. Draw *a b*, *e m*, fig. 249, at right angles; divide *a m*, *b m* into four equal parts; from *c* and *d* (the first of these from *a*, *b*), with radius *a b*, describe parts of circles to *t* and *s*; from *c*, *d*, with *c d*, describe arcs cutting the perpendicular drawn through *m* in *f*; from *d*, *c* through *f* draw lines to *g* and *h*; with *a b*, from *c* and *d*, cut those lines in *g*, *h*; from *g*, *h*, with *g s* or *g t*, describe arcs cutting in *e*.

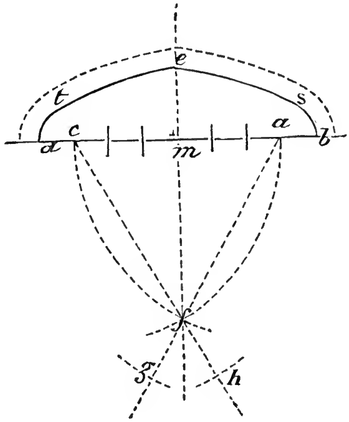


fig. 249.

We shall now proceed to describe the method of constructing arches used as canopies for niches, &c.

To draw the form in fig. 250. Make *a b*, *c d* at right angles; divide *a d*, *d b* into five equal parts; lay one of these from *d* to *e e*; let *c d* be the height of the arch; through *c* draw *f c g* parallel to *a b*; from *e*, *e*, with radius *e b*, describe parts of circles to *m*, *n*; join *a c*, *b c*; bisect *c n*, *c m* (from where the lines *a c*, *b c* cut the circles described from *e*, *e*) in *o*; draw lines through the points of intersection of the bisecting circle, meeting *c g f* in *f* and *g*; from *f* and *g*, with radius *g n*, describe parts of circles joining *c m*, *c n*.

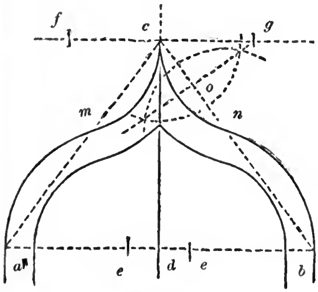


fig. 250.

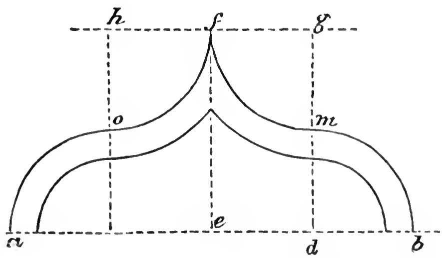


fig. 251.

To describe the form in fig. 251. Let *a b* be the breadth, and *e f* the height of the canopy arch, equal to half *a b*; draw lines *a b*, *e f* at right angles; divide *a e*, *e b* into two equal parts at *c*, *d*; from these points draw lines parallel to *e f*, meeting a line drawn through *f* parallel to *a b*; from *c*, *d*, with *d b*, describe quadrants to *m*, *o*; from *g*, *h*, with same radius, describe other quadrants joining *o f*, *m f*.

To describe the form in fig. 252. Let *c d* be the width, and *a b* the height; draw *a b* perpendicular to *c d*, and join *c b*, *d b* (only one half of the diagram has the constructive lines). Divide *a d*, *a c* into two equal parts in *g* and *h*; from *g*, *h*, with radius *g d*, describe arcs cutting *c b* in *o*; bisect *o b* in *m*; draw *h b s* parallel to *c d*, and through the intersection of the bisecting circles between *o b*; draw a line cutting *h b* in *h*; *h* is the centre of the circle, joining *o b*; divide *g d*, *c h* into three equal parts; from *d*, *c* lay off to *f*, *f*; with *f d* lay from *a* in *a b* to *t*; from *h*, *g* and *t*, with radius *d f*, describe the circles as in the diagram.

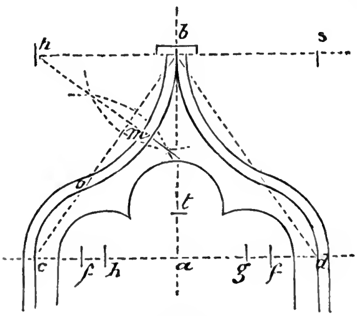


fig. 252.

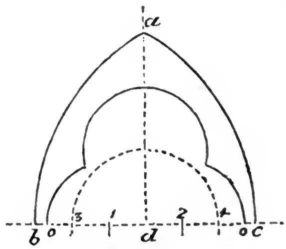


fig. 253.

To describe the example in fig. 253. Let *c b* be the breadth; from *c*, *b*, with *c b* as radius, describe arcs cutting in *a*; join *c a*, *b a*, and draw *a d* at right angles to *c d*; divide *b c*, *b d* into three equal parts; from *d* with *d* 3 describe a semicircle cutting *a b* in *m*, the point 3. Bisect *a c*, *c b* in the points *e*, *e*; through the points of intersection of the bisecting circles draw lines cutting the line *c d* in the points *o*, *o*; from the divisions 1, 1, on the line *c d*, and the division 3 on the line *a b*, with radius 1 *o*, describe arcs meeting in *g* and *h*.

To describe the arch in fig. 254. Draw the lines *a b*, *c d* at right angles; divide *a d*, *a c* into two equal parts at *e*, *e*; from *e*, *e*, with radius *e e*, describe arcs cutting *b a* produced in *f*; from *f*, through *e e*, draw lines to *g*, *g*; from *e*, *e*, with *e e*, describe arcs to *g*, *g*; join *g b*; bisect it in the point *m*; from *a*, through *m*, draw a line meeting a line perpendicular from *c* in *o*; from *o*, with radius *o g*, describe the arc *g b*; *p* is the corresponding centre to *o*.

To describe the arch in fig. 255. Draw *a b*, *b c* 4, at right angles; divide *b* 4 into four equal parts; bisect 1, 2 in *d*, and 2, 3 in *c*; from *c*, with *c* 3, describe the arc as in the diagram; make *b e* equal to two of the parts in *b c*; draw *e h* parallel to *b d*; join *d h*; by a line perpendicular to *b c* form *c h*; *h* is the centre of the arc meeting *a b*, and that described from *c* as a centre.

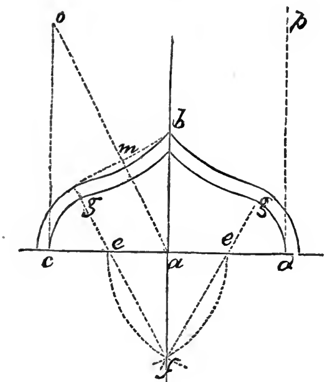


fig. 254.

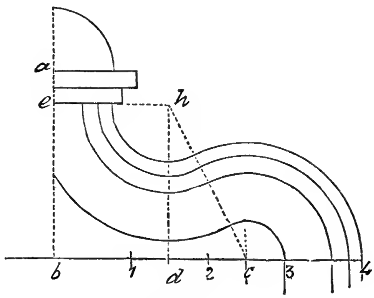


fig. 255.

To describe the arch in fig. 256. Let *a b* be the breadth; draw *c h* at right angles to this; divide *a b* into five equal parts; in *c n* draw the line *n m* parallel to *a b*, and at a distance from *a* equal to two of the parts in *a b*; make *n o*, *o m*, equal to four of these; the points 1 and 4 in *a b*, and *n m*, are the centres from which the various arcs are described.

The arch in fig. 257 is described from the centres *e*, *d* and *f*.

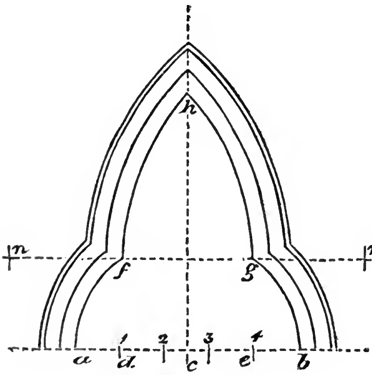


fig. 256.

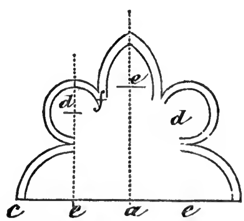


fig. 257.

To describe the arched window opening in fig. 258. Describe an equilateral triangle *a b c*; *a*, *b*, *c* are the points from which the arcs are described.

In fig. 259 is shewn *the method of describing the internal tracery-work.* Draw, as before, the equilateral triangle, and the outline curve; bisect *a c*, *b e*, *a b*, in the points *e*, *f*, *g*; from the point *e*, with radius *a e*, describe arcs to *m*, *n* from *a* and *b*; from *f* and *g*, with same radius, other arcs meeting in *n* and *m*, and *n*, from *a*, *b*, and *c*.

To describe the arch in fig. 260. Draw a line *b c*, bisect it and draw perpendicular to it a line from *a*; make the point *a* distant from the line *b c* equal to half *b c*; bisect *a b*, *a c*, in *e*, *e*; with *b e* as radius from *b*, *c* and *a*,

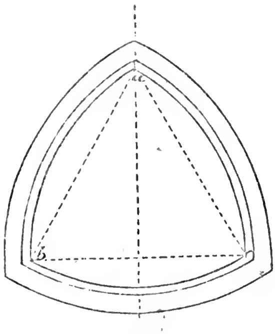


fig. 258.

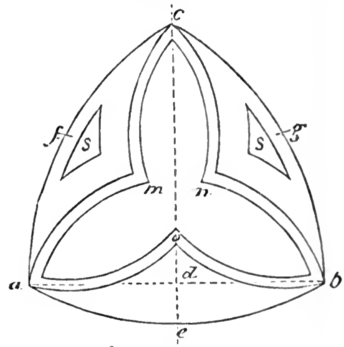


fig. 259.

describe the arcs as in the diagram, and the curves of the sunk pannels *d, d.*

To describe the arch in fig. 261. Draw *e f,* and at right angles to it the line *g;* on *g* make a square *a b c d;* from *a* and *b* describe with radius *a b* arcs meeting in *m;* bisect any side of the square *a b c d,* and with the distance obtained as radius, from *a, b, c, d,* and *m,* as centres, describe the arcs in the diagram.

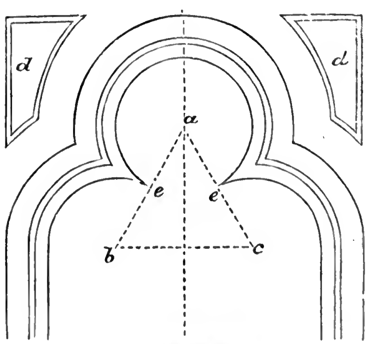


fig. 260.

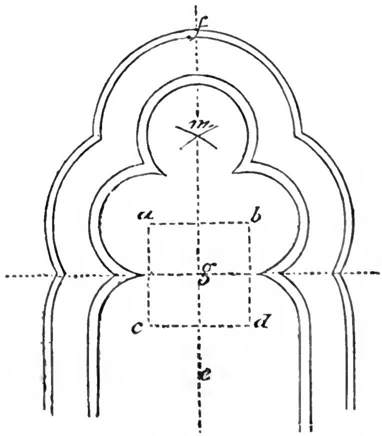


fig. 261.

To draw the intersecting arches in fig. 262. Draw the line *e f;* let *c d*

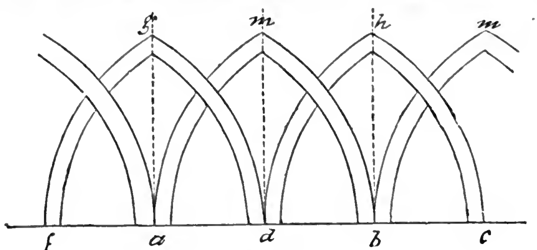


fig. 262.

be the breadth of an arch; divide it in *b*, draw *b h;* make *d a* equal to *d b*, and draw *a g; b h, a g* are the centre-lines of two of the arches; *d m* is the centre-line of the third.

To draw the intersecting arches in 263. *b b* are the centre-lines of the two arches; *f f* those of the others; *c c, d d, o o,* are the centres of the respective arches. An inspection of the diagram will sufficiently illustrate the method of drawing them as given.

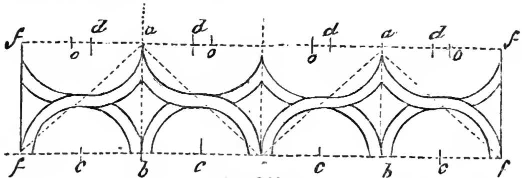


fig. 263.

To draw the Trefoil as in fig. 264. The equilateral triangle *a b c* is first

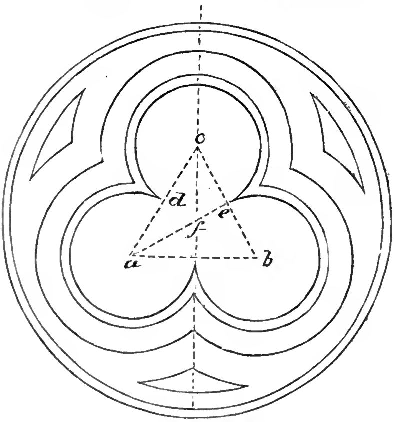


fig. 264.

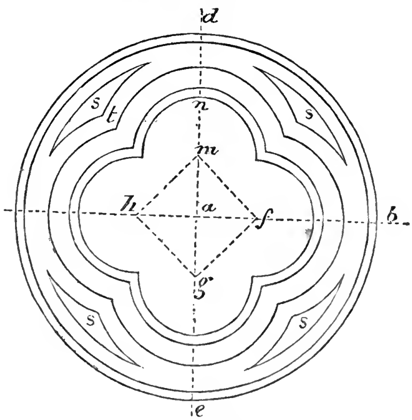


fig. 265.

drawn, and the angle *b a c* bisected; a line drawn from *a* to *e*, cutting the line *c f*, gives the centre of the surrounding circles; *a b* and *c* are the centres of the trefoil curves.

The Quatrefoil in fig. 265 is described from the corners *h m, f g* of a square; *a* is the centre of the surrounding circles, found by the intersection of the diagonals, *a b, c d,* of the square; the curves *s s s s*, are drawn from the centre *a;* while those meeting in *t t t t*, are described from the centres *h, m, f* and *g*.

The 'Cinquefoil' ornament, in fig. 266, is described from the

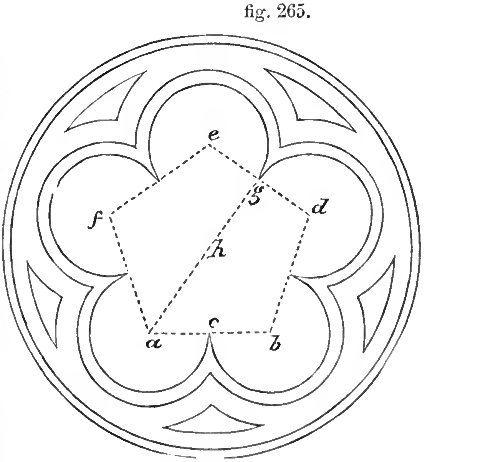


fig. 266.

corners of a pentagon, *a, b, d, e, f,* by dividing *e d* equally on the point *g*, and drawing a line from *a* to it, cutting the perpendicular *e c* in *h;* the centre *h* of the surrounding circles is obtained.

The Ornament in fig. 267 is described as follows: Draw *a b, o d,* at right angles; divide *a c, c b,* into parts at *e, f;* draw lines parallel to *c d* from *f* and *e;* with *f c* or *c e* lay from *f* and *e* to *g* and *h;* from these points as centres, with radius *g c,* describe parts of circles; divide *o d* into four equal parts; from *m,* the third of these, with radius *g c,* describe arcs meeting the lines produced from *f e* as in *n,* and the circles described from *g* and *h;* join *d n;* through *d,* parallel to *a b,* draw a line to *c;* bisect the line *d n,* and through the intersections of the bisecting arcs draw a line to *c; c* is the centre of the arc joining *d n.*

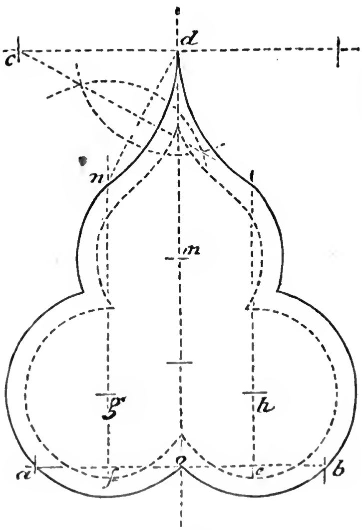


fig. 267.

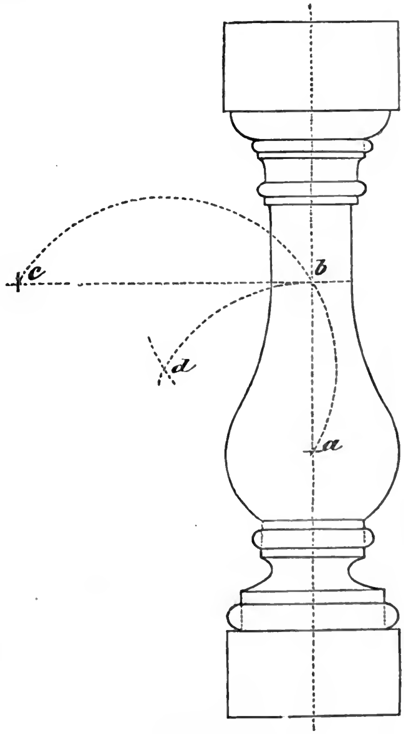


fig. 268.

In fig. 268 we give the *drawing of a Baluster.* *a* is the centre of the lower curves; the centres of the upper curves are found by drawing a line *c b;* from *a* and *b* describe arcs cutting in *d;* from *d,* with radius *d a,* describe an arc cutting the line *c d* in *c; c* is the centre of the curve.

Part of the Baluster (the central portion) shewn in fig. 269, is drawn in a similar manner, as may be seen on inspection; the centre-line is *a b;* the other centres are *c, c, e* and *d.*

The *Ornament* in fig. 270 will be easily drawn by the assistance of the centres marked.

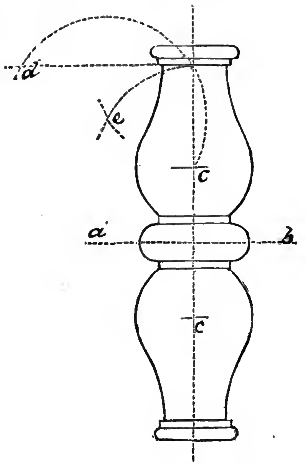


fig. 269.

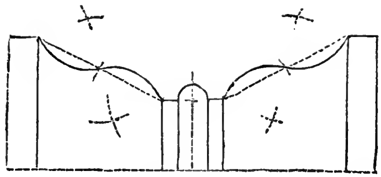


fig. 270.

We now proceed to give examples of *Vases*, with the mode of describing their contour or outline.

In the example, fig. 271, draw a centre-line *b h*, the base *a b*, *c c*, the fillet *d*, and the occult line *f f*, *g g*; *f f*, *e e* are the centres of the circles of the base; join *g h*; bisect it by the line *i i*, cutting *g g* in *k*, *k*; from *k*, with radius *k h*, describe arcs *g*, *h*; on the line *n n* the centres of part of the cap are found. In fig. 272 we give an enlarged view of the top portion of this vase. Draw *a b*; through *e* draw *c e c*; make *d c* equal *d e*; *c c*, *d d* are the centres for describing the base; *o* and *n* are the centres for the top.

In the form of Vase given in fig. 273, the centres for the base *a a* are on the line *c b c*; and at *h h*, on the lines *f f*, *i i*, *m m*, and *n n*. In fig. 274 we give an enlarged view of the upper part of 273. The centres *d e*

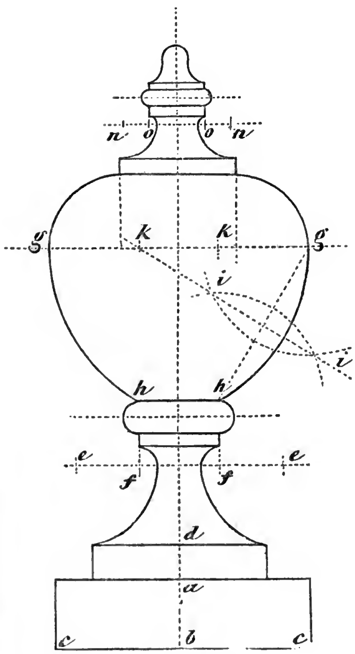


fig. 271.

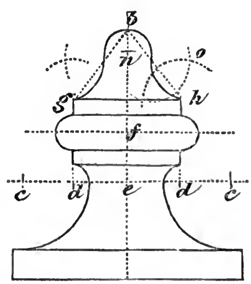


fig. 272.

are found by producing perpendiculars from *o o* to *d* and *e*, cut by lines drawn through the points of intersection of the bisecting circles of the lines *b o*, *c o*; the centre of the top circle at *h a* is found by bisecting lines *c a*, *b a*, and producing the lines of bisection, meeting the perpendicular from *a*.

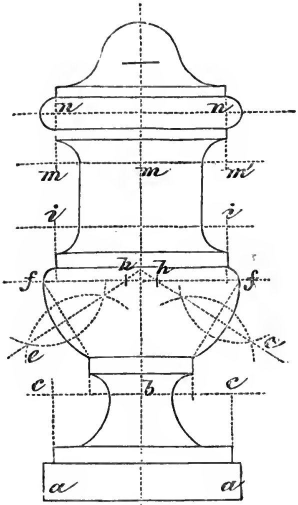


fig. 273.

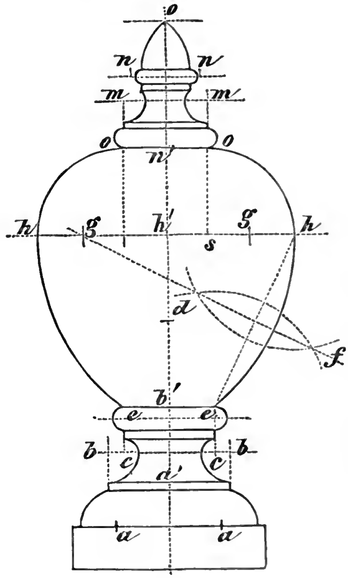


fig. 275.

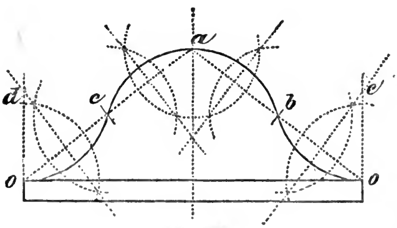


fig. 274.

The form of Vase in fig. 275 is described as follows: Make the points *a a* distant from the ends equal to the height of the fillet forming the base; *a a* are the centres of the arcs; *b, b* and *c, c* are the centres of the top part of the base; *e, e* are the centres for describing the arcs of the torus; make *b′ d* = to *a a′*; and lay off from *b′ h′* and *n′*; through *h′* draw *h h′ h*; join *e h*, bisect it by a line *f d* produced, meeting *h h* in *g*; *g* is the centre of the arc *h e*; the arcs *h o*, *h o* are described from the centres *s*; *m m*, *n n*, are the centres for describing the curve of the upper part.

The form of Vase in fig. 276 is described as follows: Draw *a o*; form the base *a a*; make *b c* equal *a b*; and from *c* lay off three times *a b* to *b′*; bisect the last part in *f*; through *f* draw *g f g* parallel to *a a*; from *h, h* describe the arcs to *e, e*; join *d e*, *d e*, bisect them by lines produced, cutting *g f g* in *g, g*; these are the centres of the arcs *d e*, *d e*; make *b′ n* equal to *b b′*, and draw *n m* and *i i*; *m′*, *m* are the centres from which the arcs *s s* and *o o* are described; *i i* the arcs *t t*, and *n′* the arcs *o v*.

In fig. 277 the upper part of a Vase is given: *n n*, *a a*, *b b*, *c c*, and *m*, are the centres from which the curves are described. In fig. 278 the base of a vase is given: *a b* is the centre-line; *c c* the centres for the 'torus' *c c c*, and *f f* for that at *f e f*; produce *f f* to *h h*, and *c c* to *d d*, meeting the line drawn through *g* parallel to *c c c*; *h, h* and *d, d* are the centres of the curves.

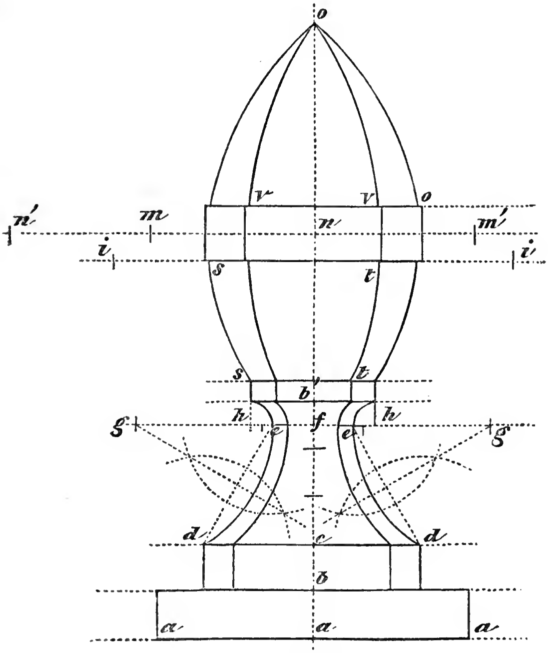


fig. 276.

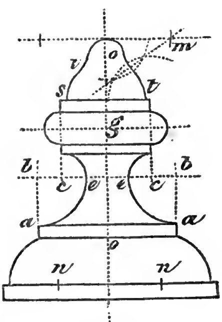


fig. 277.

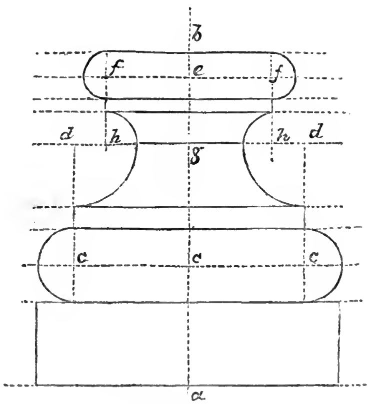


fig. 278.

To describe the part of the hand-rail of a stair shewn in fig. 279. Draw *a b*, and at right angles to it, through the points *c*, *d* and *e*; from *c* lay off to *g g*, and from these describe curves to *f f* and from *h h*; from *f*, *f*, with *f f*, describe arcs meeting in *a*; with *a b* from *a* describe the part of the circle joining the arcs from *g g*.

The manner of describing the 'flutes' or hollows in the shaft of a column is shewn in fig. 280. Let *b a c* or *d e f* be the diameter of the shaft at its base; describe a semicircle *b h c*. Suppose there are to be 24 flutes in the shaft; divide *b h c* into 12 (half) equal parts; bisect each of these parts, and from the points as centres describe small semicircles, as in the diagram, or merely mark the points of division, as *n n*; parallel to *a e*, from the points, draw lines, as *c d*, *b f*; 1, 2, 3, 4, 5, shew the divisions between the flutes, lessening in breadth as they approach the outside line; thus giving the appearance of roundness or distance. When the shaft tapers towards the top, the diameter at the upper extremity is taken and divided as above described.

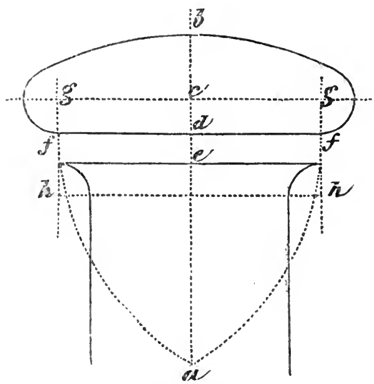


fig. 279.

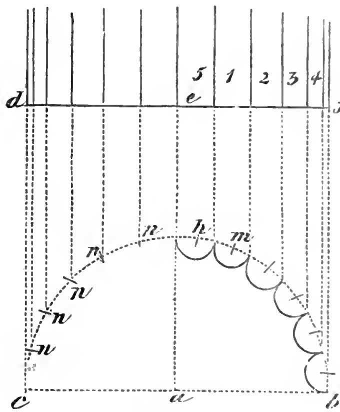


fig. 280.

In fig. 281 *the method of drawing the hollows in cases where each is divided from the other by a narrow band or fillet* is given. *a b* is the semi-diameter of shaft; *c d* the line on which the semicircle is drawn; *n n n* is the breadth of the fillets.

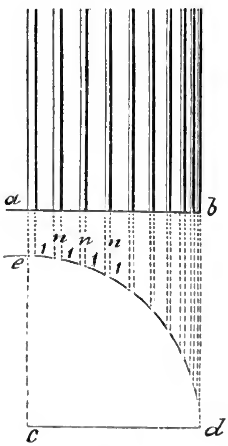


fig. 281.

To describe the spiral scroll of the termination of a hand-rail for a stair, as in fig. 282. On the line *a* draw a square, and divide it as in 283. From *a* describe the circle *n b c*; then from the point 1 (see fig. 283) describe the curve to *e*, from 2, from *e* to *d*; from the point 3, from *d* to *c*; from 4, from *e* to *f*; from 5, from *f* to *g*; from 6, *g h*. Suppose the breadth of rail to be *h p*; then from the point 6 draw the curve *p o*; from point 7, *o* to *n*.

Fig. 284 *gives another method of drawing a scroll to the termination of a hand-rail.* From *b* draw a circle *a c*; divide its circumference into eight equal parts, and draw the radial lines; draw the circle *b d*; join *a c*; from *a* describe the arc *d e*, meeting *a c* in *e*; divide *d e* into eight equal parts; from *a* through these draw lines meeting *b c* in the points *f*, *g*, &c.,; from *b* as a centre, with *b f* as radius, describe a circle cutting the radial line *b p* in *p*; from *b*, with *b g*, the radial line *b q* in *q*; with *b h*, the line *b r* in *r*; *b m*, *b s* in *s*; *b n*, *b t* in *t*; *b o*, *b o* in *o*, and so on. Then, with *b a* as radius, describe from *a* and *p* arcs meeting in the point 1; with *p b* as radius from *p* and *q*, arcs meeting in the point 2; with *q b* as radius, from *q* and *r*, arcs cutting in the point 3, and so on, producing points 4, 5, 6, 7, 8. From the point 2, with radius 2 *a*, describe the arc *a p*, from 3, with 3 *p*, the arc *p q*; from 4, with 4 *q*, the arc *q r*, and so on.

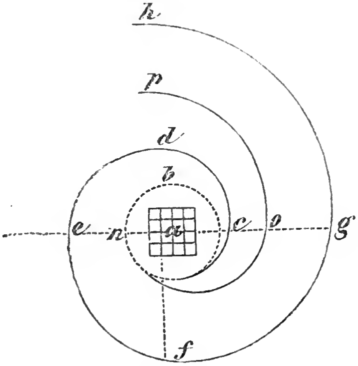


fig. 282.

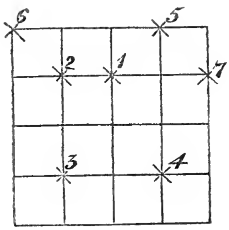


fig. 283.

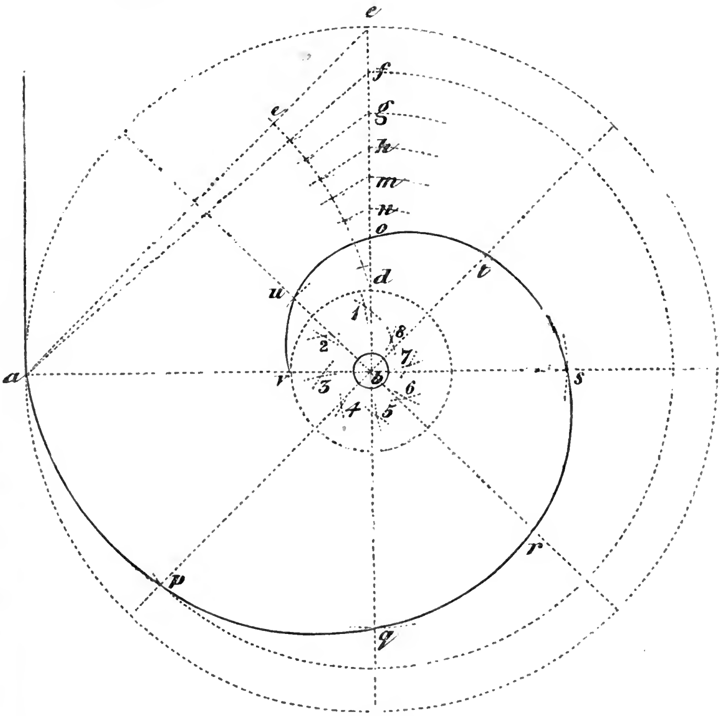


fig. 284.

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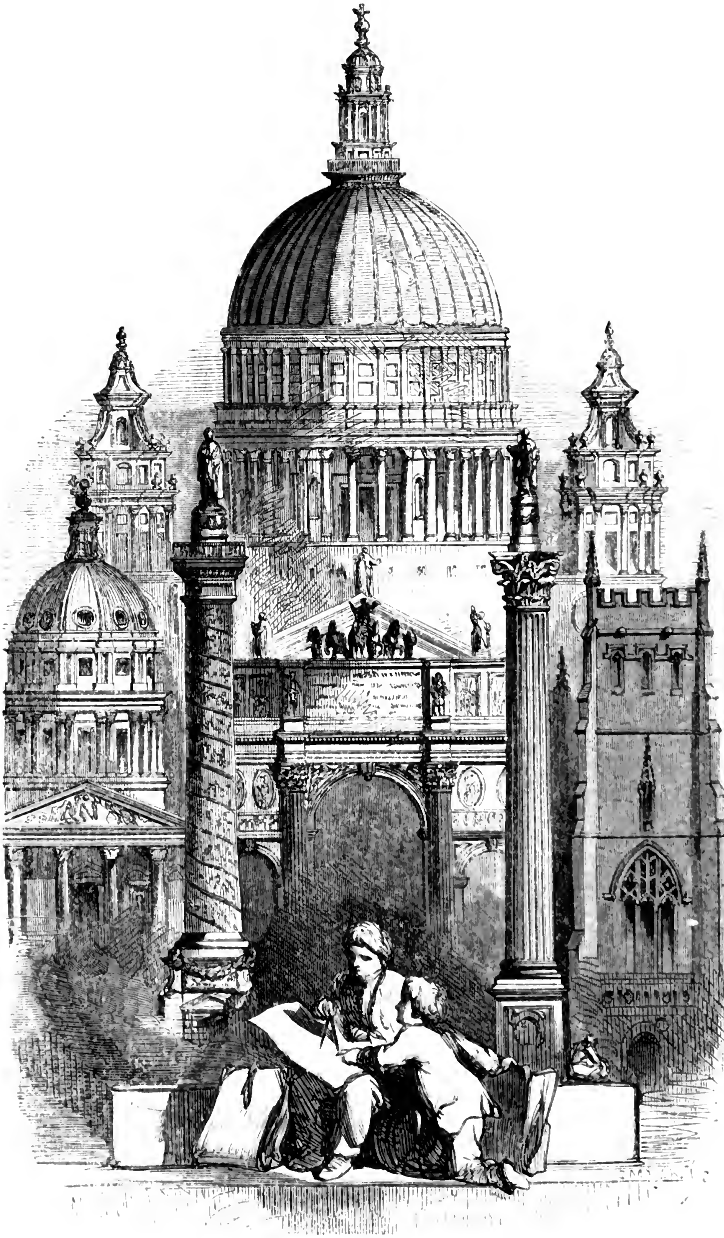

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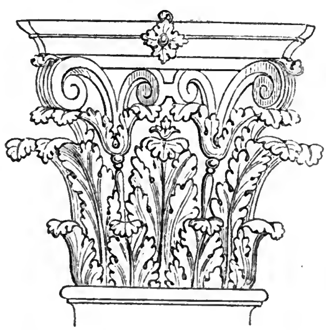

BY ROBERT SCOTT BURN,

EDITOR OF THE "ILLUSTRATED DRAWING-BOOK," "MECHANICS AND MECHANISM," "PRACTICAL GEOMETRY," "STEAM-ENGINE, ITS HISTORY AND MECHANISM," ETC.

SECOND EDITION, REVISED.

LONDON: WARD AND LOCK, 158, FLEET STREET.

1856.

LONDON:
PRINTED BY PETTER AND GALPIN, PLAYHOUSE YARD,
ADJOINING THE "TIMES" OFFICE.

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DRAWING-BOOK.

INTRODUCTION.

In the work on *Practical Geometry*, in the Series of Educational Books of which this treatise forms a part, we have given simple definitions and constructions of the various forms and figures which may be said to constitute the foundation of all drawing. We have there endeavoured to show that a knowledge of geometrical construction is necessary, before a thorough appreciation of the principles of outline sketching can be obtained, and a ready facility acquired in performing its operations. However much this position may be controverted as regards its application to an art which is generally looked upon as independent of, rather than dependent on, strict and formal rules, there can be no doubt, we think, that it holds with all completeness in reference to that which it is now our duty to illustrate and describe. In fact, so much do the various branches treated of in the following pages depend upon a knowledge of geometry, that many class them under the generic title of "geometrical drawing." Those commencing the study of these arts—so useful to the architect and the mechanic—without this knowledge of geometry, will be disappointed as to their speedy proficiency, and will labour under great disadvantages, from not understanding the principles upon which the constructions are founded.

In carrying out the objects of the present work, we purpose strictly to adhere to the plan followed in *The Illustrated Drawing-Book*, of adopting a series of progressive lessons, leading the pupil from the consideration of simple examples up to those more complicated in their construction. So that the simple steps are well understood, the more difficult ones will be easily mastered by the pupil who attends to the various gradations of examples. We have endeavoured, as far as the discursive nature of the subject has admitted, to preserve a distinct classification of objects, and a unity in the examples, so as to make the pupil thoroughly conversant with one department before proceeding to the consideration of another. Where this has been departed from, and an apparent mixing up of examples has resulted, considerations involving obvious advantages have suggested the change. On the whole, however, we trust that the classification so desirable has in some measure been obtained.

Although aware that architectural and mechanical drawing has for some time taken its place in many scholastic establishments as a branch of ordinary education, we are nevertheless anxious to see it still more extensively adopted. We conceive it likely to be of more general use—even to those who may not at all contemplate following up any of the professions to which it is more specially useful—than may at first sight be acknowledged. Apart from the habit of method, which, if it does not create, it will at least foster and encourage, we see many advantages accruing to those desirous of having a knowledge of science by an acquaintance with its practice. And there are few, we think, in these days of practical science, who are not likely to be interested in its progress. Geometrical drawing—taking the term in its widest sense—is an art which will enable those acquainted with its principles to understand a scientific exposition with greater readiness than those can do who are ignorant of it. To convince the reader of the truth of this, we have only to remind him, that few expositions of improvements or inventions in practical science, in its widest range, are ever made without the aid of sketches,—these ranging from the simple diagram up to the more complicated drawing; and the ready understanding of these is open only to those acquainted with drawing. This consideration should, we think, weigh very forcibly with those who are doubtful of the propriety of following the example of so many educational establishments, in introducing geometrical drawing as an ordinary branch of education. To those desirous of following out the profession of architect, engineer, or mechanic, an acquaintance with the art is as indispensable as a knowledge of sketching from nature or objects is to the artist or painter. Without it, the practical man, however ingenious, will inevitably fail in perfecting, unaided, his ideas with that facility available to the accomplished draughtsman. Its usefulness in the workshop, moreover, is no less conspicuous than in the study or bureau, in enabling the inventor or improver to communicate his ideas clearly and readily to the workman. To the latter also it is equally important and indispensable,—we mean to those who are desirous of raising themselves above the level of the mere operative, the handler of the hammer or the mallet. In short, to him who, in the exercise of his important avocations as architect or engineer, wishes to render himself independent of extraneous assistance in planning and working out his original ideas, and capable of communicating their results to others with facility, a knowledge of the art is absolutely indispensable. To those who have at all considered the subject, further comment on its value to the practical man is altogether unnecessary.

One cause probably of the art not being so generally adopted in educational establishments, is the extreme paucity of books treating exclusively on the subject; and of those calculated to serve as guides, the price is nearly prohibitive, at least to the generality of purchasers. A work taking up all the departments of the subject, treating them *methodically* and *fully*, yet issued at a price absolutely within the reach of all, has long been a desideratum; which we venture to hope the present volume may possess some claim to having supplied. As to its *method,* we have followed the same plan which, adopted in the *Illustrated Drawing-Book,* met with a considerable amount of success. If we have failed to attain in this the same clearness of exposition and attractiveness of illustration, this may be attributed, in some degree, to the nature of its subjects, which are not in themselves so attractive as those contained in the above work. At all events, we may lay claim to a strong desire to make it, in all its departments, as attractive and useful as possible. As respects the *fulness* or completeness of the work, a mere glance at its pages will show that, even should fault be found with the method of the lessons, none can be alleged on the score of the meagreness of their illustrations. The present volume is strictly a "drawing-book," showing how drawings—whether architectural, engineering, or mechanical—may be copied and laid down. The æsthetic principles and technical rules which *dictate* the proportions, the style, and the methods of planning structures—whether these be architectural or mechanical—are not treated upon, excepting in some few instances. These rules and principles, we conceive, belong to more strictly professional treatises. A work which is contemplated in this series—on "Ornamental and Architectural Design"—will, in one department, provide a guide to the pupil, desirous of going into the principles of one art, of which we here give lessons useful in delineating its examples. A work giving a clear exposition of the principles and practice of the other departments, namely, "Civil and Mechanical Engineering," is yet a desideratum among educational books. Should it be thought advisable, such a treatise may probably be included in the present series.

R. S. B.

May, 1853.

PREFACE TO THE SECOND EDITION.

THE Author feels gratified that the demand for another Edition of this Work has enabled him, by a careful revisal of every example, to render the description by which it is elucidated as clear and explicit as possible, and to expunge many errors and crudities which encumbered the first issue. Various improvements in the plan of the book have been suggested to him, some of which he has endeavoured to embody in the present issue. The majority of these, however, are more intimately connected with the department of a work to which frequent reference is made in this volume, namely, that on "Ornamental and Architectural Design," and the utility of which is adverted to in the Introduction above given. This work was suggested to the Author during the preparation of the present volume, some years ago; and since that period he has had numerous evidences afforded him of its probable utility in an educational course. From these the work is considered a desideratum, which it is deemed desirable to supply. For this purpose, the Publishers of the present volume have kindly entrusted its preparation to the Author; and it is hoped that in a short time it will be ready for publication. The treatise is intended to embody a variety of examples in the different styles of *Ornamentation*, and of the methods by which they are drawn; together with notes, historical, æsthetical, and practical, on *Architectural Design;* the whole having an immediate aim to their application to the general purposes of utility, as well as being calculated to afford a variety of useful information to the general reader.

R. S. B.

March, 1856.

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DRAWING BOOK.

ARCHITECTURAL DRAWING.

In this department the first lessons will be those which require for their construction nothing but the arrangement and combination of right or straight lines. It is scarcely necessary here to state, that the instruments requisite for the various operations are the same as those required for the constructions described in the *Illustrated Practical Geometry*, the 'drawing-board,' 'square,' and 'triangle,' these being absolutely indispensable. As this work is strictly designed to be a sequel to that on Geometry, we beg to refer the reader thereto for a description of these, and the readiest methods of using them.

Example 1. *To draw the portion of 'hipped roof' shown in fig.* 1.

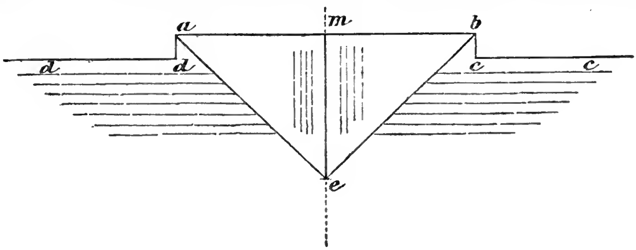


fig. 1.

On the drawing-paper, properly fastened to the board, mark any point *a*; parallel to the side of the drawing-board, draw from this point any line, and make it equal to *a b*. Bisect this in the point *m*; at right angles to *a b* draw from this point a line to *e*, and make this equal to *m e* in the copy. Join *e a*, *e b*. At right angles to *a b*, from these points draw to *c d*, making the length of these equal to *b c* in the copy. Draw the lines *c c*, *d d*, parallel to *a b*. The example given in fig. 1 will thus be copied. The pupil should be very careful to take the measurements in his 'compasses,' or 'dividers,' equal to those in the copy.

Example 2. *To draw the part plan of the wall of a house, showing the projection of one side of fireplace, with the internal flue, in fig.* 2. Divide the thickness of the wall *g′ g* by the centre line *a b*, bisect *f e*, and draw at right angles to *a b* a line *c m d n n'*. These lines are to be drawn on the copy in *light pencil lines*, as also the line *g* produced to *d* and *h*. These preliminary operations being performed on the paper on the drawing-board on which the copy is to be made, draw any lines *a b*, *c n*, corresponding to those made on the copy in fig. 2. From the point *c* of intersection, with the measurement *c n'* taken from copy, lay off from *c* to *n'*; with distance *n' f*, from copy, lay off on a line drawn through *n'* at right angles to *c n'*, to the points *e* and *f*; from *e* draw a line at right angles to *e f* to the point *g*, and make it equal to *e g*; do the same at *f*, and make the line equal to *f v*. Lines drawn from *g* and *v*, parallel to *a b*, will represent the internal line of wall; the external, or external line *g* 1, will be put in by measuring its distance on the copy from the centre line *a b*, and transferring it to the paper on the board, and thus drawing the line *g* 1 parallel to *a b*. The next portion to be copied is the internal flue. Take the measurement *d n* from the copy, and transfer it to the corresponding line on the board; in like manner put the measurement *n m*; with *n o* or *m s*, on lines drawn at right angles to *c n'*, measure to *s*, *o*, and join the points *s o*, *s o*; the example is completed. Another method of copying this figure may be adopted as follows:—Assume on the paper on which the drawing is to be made any point *e* fig. 2; parallel to the side of the board draw a line *g e*, and make it equal to the line *g e* in the copy. At right angles to this draw *e f*, and make it equal to *e f*; from *f*, parallel to *e g*, draw *f v*; from *g* and *v* draw lines, as in the copy, parallel to *f e*; parallel to these, and at the proper distance, put the line *g* 1. With the distance *n n'* from *e* lay on the line *e g*, and through this point draw a line *o n o*, parallel to *f e*. At the point *m*, the distance of which from the point *n* is easily obtained from the copy, draw another line *s m s*; from the line *g e* measure to the line *s o*, and transfer it to the board; parallel to *g e* draw *s o*, meeting the lines *m s*, *n o*. Measure the breadth of the flue from *o* to *o*, transfer it to the board, and join the upper ends of the lines *m s*, *o n*, by a line *s o*. We have here shown two methods, chiefly to enable the pupil, by a ready exercise of his reasoning powers, to decide as to the quickest method of copying any figure presented to him.

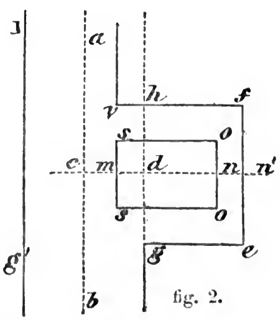


fig. 2.

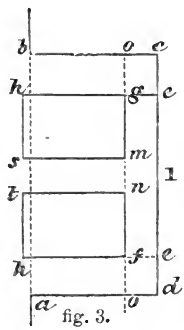


fig. 3.

EXAMPLE 3. *To draw one jamb with two internal flues.* Let *a b*, fig. 3, be the internal line of wall, *a b c d* the outline of jamb. Produce the sides *h g*, *h f*, to meet the line *c d*, in the points *e e*, and *m g*, *n f*, to meet *b c*, *a d* at the points *o*, *o*. Having fastened the paper properly on the board, and proceeded with the copy as directed above, the produced lines being marked in light pencil lines, the first operation is to draw any line, as *a b*, on the most convenient part of the paper on the board on which the drawing is to be copied. From *a* measure to *b;* and from these points, at right angles to *a b*, draw lines to *c* and *d;* make *b c, a d*, equal to the corresponding lines in the copy; join *d c*. Next take from the copy the measurement from *d* to *e* (the point found by producing *h f*), and lay it from the point *d* in the board on the line *d c*. Do the same from *c* to *e;* parallel to *b c* draw lines *e h, e h;* measure next the distance from *d* to *o*, and transfer it on *a d, b c*, to *o o;* parallel to *a b* draw a line *o o*. From *g* and *f* measure to *h h;* transfer these, and from the points obtained draw a line *hh* parallel to *o o*. With distance *h s*, or *n f*, measure from *h* to *s*, from *g* to *m*, from *n* to *f*, and from *t* to *h;* join the points. In inking the lines, the points *b c, d a, h g, s m, t n, h f*, will be their terminations. In the examples given in the figures the lines not dotted show the complete design.

EXAMPLE 4. *To draw the outlines of an ordinary sash window.* Make any line *c d* on the paper on the board equal to the corresponding line in the copy, fig. 4. At the points *c d* draw lines perpendicular to *c d* of an indefinite length. With the measurement *c a*, from the copy, cut the lines *c a, d b*, in *a, b;* join *a b*. Divide the line *c d* into three equal parts in the points *n, n;* parallel to *a c*, from these draw lines meeting *a b*. Divide the line *a c* into four equal parts in the points *m, e, g;* parallel to *a b*, from these draw lines meeting *b d* in *m′, f, h*. The parallelogram *a b d c* is divided into twelve lesser ones, representing each a pane of glass.

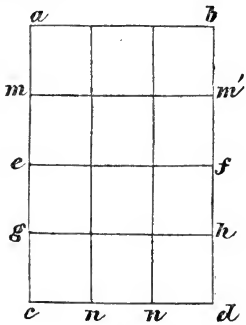


fig. 4.

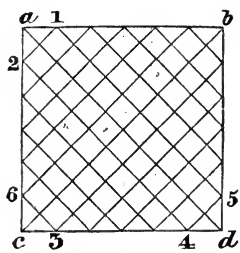


fig. 5.

EXAMPLE 5. *To draw the diagonal lines representing the panes in a rustic window, fig.* 5. Draw *c d*, making it equal to *c d* in the copy; *c d* is the side of the square *a b d c*, which describe. Divide the sides *c d, a c*, each into six equal parts; join the corresponding points, as 1, 2, 4, 5, 3, 6.

EXAMPLE 6. *To draw the central pilaster in fig.* 6. Divide in the copy the line *a b* into two equal parts at *c*, and through this, at right angles to *a b*, draw the line *c c;* bisect the part *o o* by a line *s f s*. On the paper on which the drawing is to be made, draw any line representing *c c*, and another at right angles to the first, representing *a b* in the copy, fig. 6. The intersection of these two lines will give the position of the point *c*. Take from the copy the measurement *c f;* transfer it from *c* to *f;* draw parallel to *ab* through this point a line, representing the line *s f s* in the copy. With *a c* from *c* lay off on *a b* to *a*, *b*; draw indefinite lines from these points perpendicular to *a b*; measure *a d*, *b e* equal to *a d* in the copy; join *e d*. With measurement *f t*, lay off from *f* to *t* and *u*, and on the line *c c* as many times as necessary; through these several points draw lines parallel to *a b*; these will be the centre lines of the parts corresponding to *o o*. With *a f* from the points of intersection of these with the line *c c*, lay off equal to *o o*; through the points draw lines parallel to *a b*; produce *a b* to *g g*. The terminations of the parts equal to *o o* will thus be formed, as represented in fig. 6. In the copy, as in fig. 4, produce the internal lines *h h*, to meet the line *a b* in *m n*; from *c*, with *c m* lay off on *a b* to *m*, *n*, and parallel to *c c* from these points, draw lines *m h*, *n h*. These lines will terminate the alternate internal portions. Another method of copying this figure will be as follows:—Draw any line *a b*, and at right angles to it another, *b g*; the point where they meet will correspond to the point *b* in the copy, and thus a datum point will be obtained from which to take measurements. With *b a* from the copy, set off *a b* parallel to *d e*; from *a* draw *d g*; make *a d*, *b e* each equal to the corresponding lines in the copy; join *d e*. From *e* measure to the line above it, and transfer it to the paper on the board; from the same point measure to the next line; and so on in succession. Transfer these measurements to the corresponding points on the paper on the board, and through the points obtained draw lines parallel to *a b*; these will form the under and upper lines of the parts *o o*. The lines representing the boundary-lines of the alternate inner portions can be obtained by measuring from *e* or *d* to the lines as *m h*, *n h*, in the copy, and transferring them; thereafter through the points obtained drawing lines at the parts required parallel to *b g*.

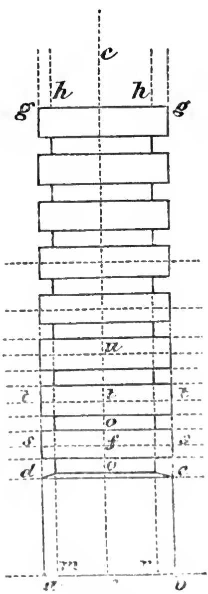


fig. 6.

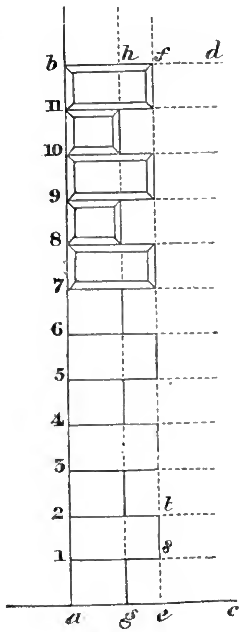


fig. 7.

EXAMPLE 7. *To draw the quoins of a house in fig.* 7. Produce in the copy the external line *f* to meet the base line *a g* produced in *e;* next, on the paper on the board draw any lines *a c, a b,* at right angles to each other; then the point of intersection will correspond to the point *a* in the copy. Measure the distance *a g* from the copy, and transfer it to the board; do the same with *a e.* From these points draw lines parallel to *a b,* as *g h, f e.* The line *a b* will represent the corner line of house, the line *g h* the internal line of quoins, and *e f* the external. Suppose *a b* to be the height on which the quoins are to be disposed, make *a b* on the board equal to *a b* in the copy; and on the supposition that there are to be twelve quoins in *a b,* divide *a b* into twelve equal portions, and through the points thus obtained draw lines parallel to *a c,* as *b h, f d,* 1*s,* 2*t.* Finish as in the copy. Another method is as follows:—Draw lines *a c, a b* as before; measure from *a* to *g,* and draw from this a line parallel to *a b;* measure from *a* to 1, and draw through the point a line 1 *s*; measure 1 *s,* transfer it to the paper on the board; measure *s t,* and draw it at right angles to *a e;* join *t* 2 by a line parallel to *a e.* The first quoin 1 *s, t* 2 will then be drawn, and afford datum points from which to finish the others; thus the line *s t* produced towards *f* will give the external line of all the others; and the distance *a* 1, transferred in succession to the line *a b,* will mark the horizontal distances.

EXAMPLE 8. *To draw the figure in fig.* 8, which represents the plan of the roof of an outbuilding, or external addition, projecting from the main wall *f n s.* The dotted line *c d* must be first drawn in the copy, dividing

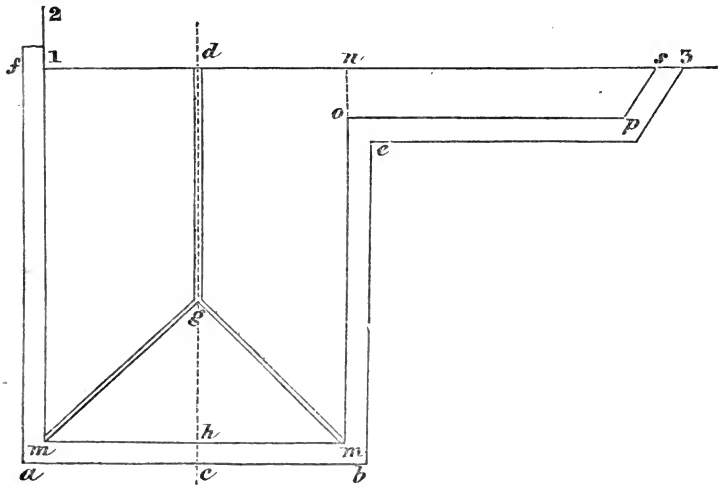


fig. 8.

a b into two parts at *c;* next, on the paper on the board draw any two lines at right angles corresponding to those in the copy, as *c d, f d n s.* To avoid unnecessary repetition, we wish the reader to understand that, when we give directions to measure any part or distance, as "measure from *c* to *b* and *a*," we mean that the distance *c b* is first to be taken from the copy in the figure, and transferred to the corresponding point on the board—thus ascertaining the position of the points *b*, *a* corresponding to those in the copy. The copy, as in the figures, is, in all instances, the only source from which measurements are to be taken: nothing in this species of drawing is to be left to the eye,—all must be tested by the instruments. Inaccuracy of measurement in any one point will inevitably result in throwing the whole drawing wrong. Thus, for instance, supposing the distance *a* 1, in fig. 7, was taken with the smallest possible error in measurement—say too much—it would be found that the distance would not go twelve times between *a b*, but would go beyond *b* to a much greater distance than would be supposed. Where an erroneous measurement is to be transferred from one point to another in succession, the original error increases in a remarkably quick ratio. But to proceed with the consideration of the construction of figure 8. Measure from *c* to *b* and *a*, and draw *a c b d;* from *a b* parallel to *c d* draw lines to *f* and *e;* measure from *c* to *h;* through *h* draw a line parallel to *a b;* from *h* measure to *m, m.* Or these points may be obtained by measuring from the lines *a f, b e.* From *m, m* draw lines parallel to *c d* to 1 *n;* from *n* measure to *o*, and parallel to 1 3 draw a line to *p*. Measure from *n* to *s;* join *s p*. From *c* measure to *g;* draw the lines *g d*, and join *g m, g m.* A line from 3 parallel to *s p*, joining a line from *e* parallel to *o p*, will complete the figure.

EXAMPLE 9. *To draw the plan of part of roof in fig.* 9. Bisect in the copy the line between *c c* in the point *b*, and draw *a b*. On the board draw any line *a b* corresponding to *a b* in the copy, and, at right angles to

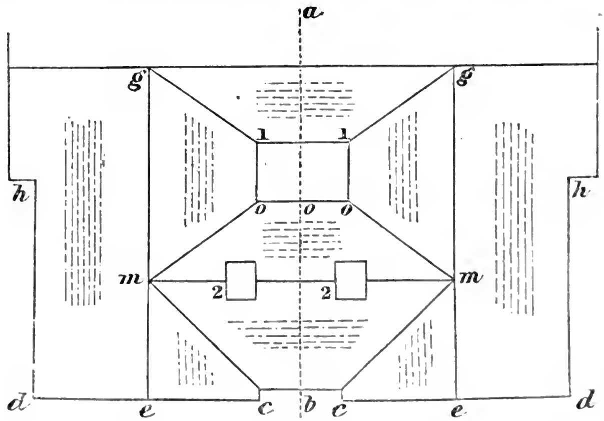


fig. 9.

it, another, representing the lines *c d, d e, c d.* At *c, c* drop the perpendiculars, as in the copy, and join them by a line parallel to *c d*. From *c* measure to *d*, and parallel to *a b* draw lines *d h, d h;* measure from *d* to *h*. From *c* measure to *e*, and parallel to *a b* draw *e g, e g;* measure from *e* to *g*, and draw a line *g g* parallel to *c d*. On *e g, e g,* measure to *m m;* draw *m m* parallel to *c d*. From *b* measure to *o*, and put in the lines *o o*, 1 1; join *o* 1, *o* 1: this represents the cistern in the roof for rain water. Join *g* 1, *g* 1, *m o, m o,* these representing the sloping lines of roof. From *m* measure to 2, and put in the plan of chimney flues.—(*See figs.* 1, 2.)

EXAMPLE 10. *To draw the window in fig.* 10. Bisect in the copy *a b* in *c*, and draw a line *c f;* draw lines on the board corresponding to *a b, c f.* From *c* measure to *a* and *b*, and draw lines *a e, b e.* From *c* measure to *n, d, m, s, h,* and *f*, and through all these points draw lines parallel to *a b*,—that drawn through *d* deciding the length of the lines *e e.* From *n* measure to *n n,* a distance equal to half *n n* in the copy. Do the same at the points *f* and *m* to *m m, g g.* Parallel to *f c* from *n, n* draw to *i, i,* and join *h i, h i.* From *g, g* parallel to *c f* draw to *m, m.* From *d* lay off to *o o*, and from these draw lines to *m m*, parallel to *c f*, meeting the line *m m;* join these with the point *s* by lines parallel to *h i, h i.* From *i* measure to *k'*, and make *k'k* at right angles to *o i.* At right angles to *k'k* make *k p;* from *p* measure to *r*, and draw *r t* parallel to *k' k.* Measure *t x*, and put in the line 1 1.

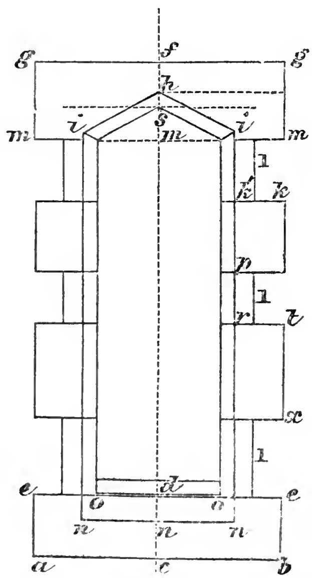


fig. 10.

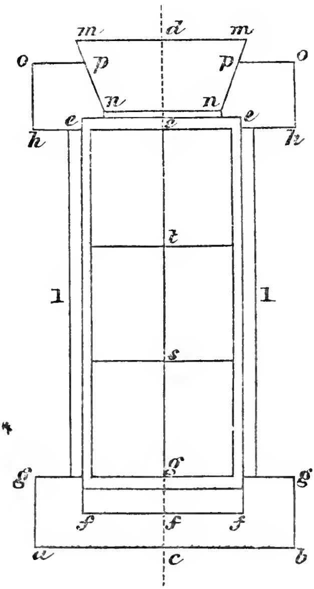


fig. 11.

EXAMPLE 11. *To draw the window in fig.* 11. Bisect *a b* in *c* in the copy, and draw *c d.* On the board draw any two lines corresponding to *a b, c d* in the copy; measure from *c* to *a* and *b*, and draw from these points to *g g* lines parallel to *c d;* measure to *g g*, and join *g g g.* From *c* measure to *e* and *d* and *f:* through these draw lines parallel to *a b.* From *f* measure to *f f*, and from *e* to *e e;* join *f e, f e* by lines parallel to *c d.* From *e* measure to *h, h* and to *n, n;* from *d* measure to *m, m*, and join *m n, m n.* From *h h* parallel to *c d* draw lines to *o o;* measure *h o*, and parallel to *h h* draw lines from *o o* meeting *m n, m n.* Draw the parallelogram within *e e, f f*, and from *c* measure to *s* and *t*, and through these draw lines parallel to *a b;* these represent the divisions of the glass. Put in the lines 1 1 parallel to *c d*, joining *g g, h h:* the drawing is complete.

EXAMPLE 12. *To draw the form of window in fig.* 12. Draw the centre-line *c c*, as in preceding examples. Corresponding to the lines *a b, c c* draw two on the board. From *c* measure to *a b*, and from the same point to *f, m*, and *c*; through *c* draw a line parallel to *a b*, as *e e*, and through *f, f f*, and *m, g g*. Measure from *f* to *f, f*, and from *m* to *g, g*; join *g f, g f*. From *c* measure to *x*, and join *g x, g x*. Parallel to *a b* put in the lines *d d, h v, h v*. From *v, h*, parallel to *g f*, draw lines to meet *g, g*, and from the points *o, o* lines to meet these, parallel to *g x*. From *e* measure to *n*, and put in *n t, n t*; put in the square *s s s s* by lines parallel to *m o, g x*. Draw the external 'dressings' by the method described in fig. 10.

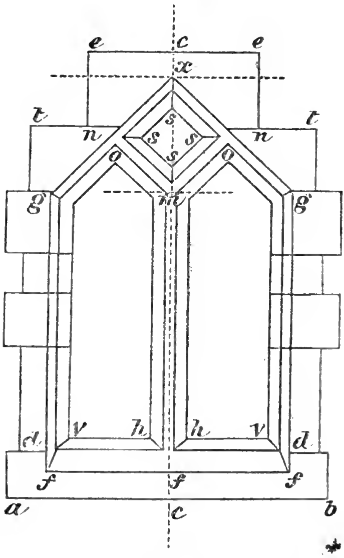


fig 12.

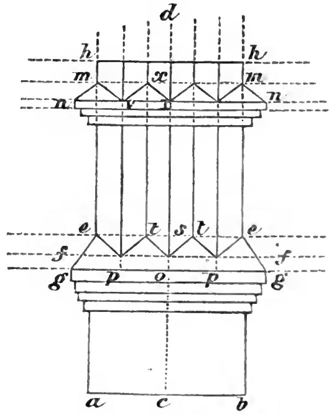


fig. 13.

Example 13. *To draw the chimney-shaft in fig.* 13. Bisect the line *a b*, draw a line *d o c* through this; draw corresponding lines to *a b, c d* on the board; measure from *c* to *o, s, x*, and *h h*; measure from *o* to *g g*, and put in the part *g g*, as well as those receding parts under it. Through *s* draw a dotted or *occult* line* *e s e*, divide *o g, o g* into two parts at *p p*, with the half of *o p*, from *s* lay off four times to *e e*, on both sides of the line *c d*, join *g e*, and from *t, t* lines meeting *f f*. Produce the lines *e p t* and *s* beyond the line *h h*; measure from 1 to *n, n*, join *n m, n m, v x*, and *x* 1, and put in the remaining portion as by preceding lessons.

Example 14. *To draw the steps of a staircase as in fig.* 14. Let *d g* be the height from one line of floor to the other, represented by the upper and under lines; and *c d* the distance in which the steps are to fall. The height of each step is 7 inches, technically called a 'riser;' the breadth being usually 9 inches; this part on which the foot rests is called the 'tread.' The measurements in the figure are taken from a scale one-fourth of an inch to the foot. Suppose the width *c d* to be 6 feet, allowing 9 inches for the tread, this will give eight divisions; divide *c d* therefore into eight equal parts, and from these points draw lines perpendicular to *c d*. Taking the

* For definition of the various kinds of lines see *Illustrated Practical Geometry.*

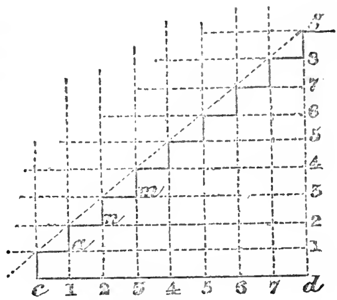


fig. 14.

height $d\,g$, from one landing to another, to be 5 feet 3 inches, this will give nine divisions of 7 inches each; divide $d\,g$, therefore, into nine equal parts, and from the points thus obtained draw lines parallel to $c\,d$. From the intersection of the line 1 on $c\,d$, and 1 on $a\,b$ at a, draw to the point of intersection of 2 the line from 1, with that from 2 on $d\,g$; from the point n, the intersection of the lines 2 2, draw a line meeting the intersection of the vertical line 2 with the horizontal 3. The intersection of the lines 3 3 gives the point of next step, and so on, each time proceeding nearer the line $a\,g$.

EXAMPLE 15. *To delineate the plan of the stairs in the preceding lesson.* The distance $a\,b$, fig. 15, corresponds to $d\,g$ in fig. 14; the breadth $a\,b$ being that between the side walls or balustrades. The height $a\,b$ is divided into 9 equal parts, each part representing a step. If a line be drawn from the point 9, fig. 14, to the left-hand top corner of the front step at c, it will be found to touch the corners of all the steps; this forms the foundation for another method of delineating the profile of the steps in a staircase, as described in

EXAMPLE 16. Let 1 2, fig. 16, be the breadth, and 2 b the height from one landing to another, as before; draw the line 1 3, and join b 3. From b on the perpendicular b 2, mark off to c a distance equal to the height of one

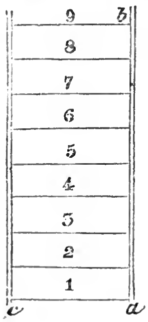


fig. 15.

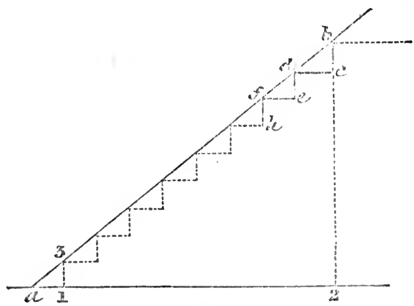


fig. 16.

riser equal to a 1 3. From c draw a line exactly parallel to a 2, or perpendicular to b 2, meeting the diagonal line b 3 in d; from d drop a perpendicular $d\,e$, equal 7 inches, or $b\,c$; from e draw parallel to $c\,d$ a line meeting b 3 as before; from f drop a perpendicular to h, and proceed thus till finished. Great care must be taken to draw the lines truly parallel to the proper lines; also to drop the perpendiculars, as $d\,e$, exactly from the point where the horizontal lines, as $c\,d$, join the diagonal b 3. The least deviation from accuracy in the beginning will inevitably result in throwing the operations towards the end far wrong. The lines should be drawn very finely, so that the exact points of intersection will be easily observable. The method shown in fig. 14 will be least liable to error. We give the two methods, as affording opportunities of extended practice to the pupil, and as suggestive of plans he may himself adopt.

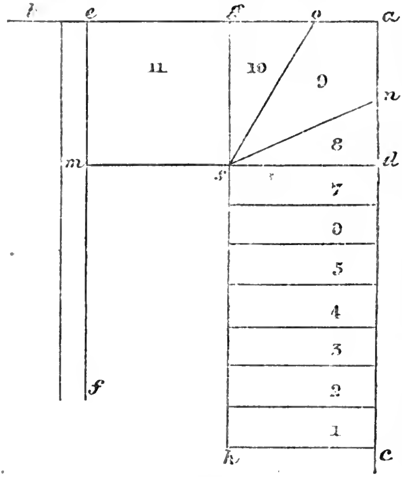


fig. 17.

EXAMPLE 17. *To delineate the plan of a staircase having 'returns,' by which the direction of the steps is changed.* Assume any point in fig. 17, as *a;* draw *a b;* perpendicular to it draw *a c*. Measure from *a* to *e* and *g*, draw from these points *e f*, *g h* parallel to *a c;* from *a* measure to *d*, and draw *d m* parallel to *a b;* measure from *d* to *c*, and draw the line 1; divide *d c* into seven equal parts. From *d* measure to *n*, and from *a* to *o;* join *s n*, *s o*. We give another lesson similar to this in

EXAMPLE 18. Draw *a b*, *b d* at right angles to one another; from *b* measure to *c* and *e*, and draw *e h*, *c h* at right angles to *b d*, *b a*. Divide *e d* into two equal parts, and *c a* into seven. Measure from *c* to *f*, and from *b* to *g;* join *h f*, *h g*.

EXAMPLE 19 shows plan of cellar-steps having a return at head which is entered from *p*, and another at foot entered from *s*. A party-wall is between the two houses, the steps of the adjoining house being shown in dotted lines.

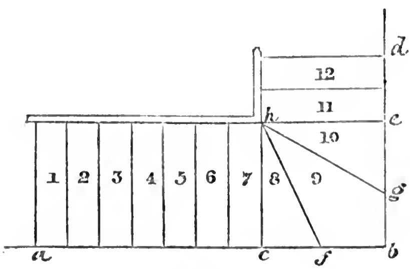


fig. 18.

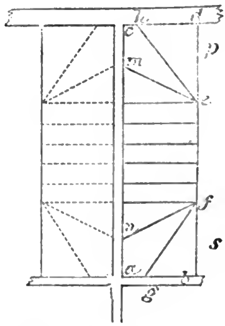


fig. 19.

Draw *a c*, *a b* at right angles; from *a* measure to *c;* draw *c d*, representing the inside line of external wall, parallel to *a b*. From *a* and *c* measure off the thickness of party-wall, dividing the two staircases, and draw a line *d b* parallel to *a c*. From *d* and *b* measure to *e* and *f;* from these points draw lines parallel to *a b*. From *c* measure to *m*, and from *a* to *n;* join *e m*, *n f*. Measure from *d* to *h*, and from *b* to *g;* join *f g*, *e h*. Divide the distance between *e f* into as many equal parts as in the drawing; from these points draw lines parallel to *a b;* these represent the steps in the stair parallel to the party-wall.

EXAMPLE 20. In fig. 20 we give a sectional vertical sketch, showing a flight of stairs *c*, reaching to the first landing-place *d'*, from the ground-floor *a b*, with return steps *e*, leading to the first-floor *f*; the landing-place *d*, counts as one step, a step *d'*, rising into the room of which *d'd* is the door; *a a* is the door of a room on the ground-floor, *g g* of one on the first-floor. The ground-plan of this is shown in

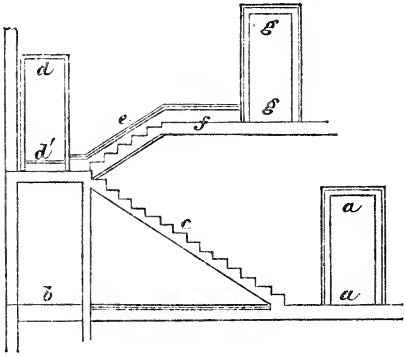


fig. 20.

EXAMPLE 21, fig. 21, the letters of reference in which correspond with those of fig. 20. The first flight, *c c*, is drawn in full lines, the return being dotted. The chamber or first-floor plan is shown in

EXAMPLE 22, fig. 22. The steps of the first flight are shown in full to where the landing reaches and the banisters begin; the dotted lines represent the steps, which are hid by the flooring-boards of the chamber floor.

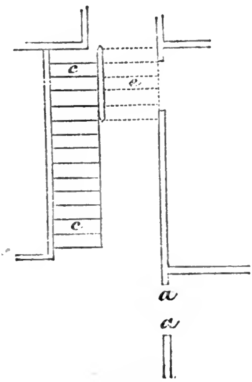


fig. 21.

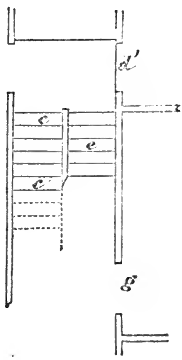


fig. 22.

We now proceed to the consideration of lessons in which a combination of straight and circular lines are met with. The first lesson is given in

EXAMPLE 23, fig. 23. Let *a b* be the ground-line of a house, and with part of the circular-headed window of apartment in basement seen above it; divide the width into two equal parts at *c*, draw *c d* perpendicular to *a b*.

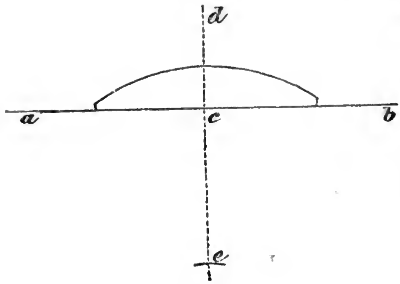


fig. 23.

Draw lines on the board corresponding to *a b*, *c d;* the centre of the curve will be found somewhere on the line *d e*. By trial on the copy, it will be found to be at *e ;* measure from *c* to *e*, and from *e* as centre, with *e d* as radius, draw the curve, joining the short perpendicular lines from *a b*. The centre from which the part of the circle in the copy is described can easily be found by adopting any of the methods described in *Practical Geometry*, one of which is here shown in fig. 25.

EXAMPLE 24.. *To draw the circular-headed fire-place in fig.* 24. Let *a b* be the width, bisect it in *c*, draw *c d* perpendicular to *a b;* draw corresponding lines to *a b*, *c d* on the board ; measure from *c* to *a*, *b*, from these draw lines perpendicular to *a b*, and equal to *a f*. From *c* as a centre, with *c f* as radius, describe the arch *f d e*. Measure from *a* and *b* to *h*, *h* to get the width of jambs, and perpendicular to *a b* draw *h m*, *h m;* measure to *m*, and draw *m n* parallel to *a b ;* measure to *o*, and parallel to *c d* draw lines *o o*, *o o*.

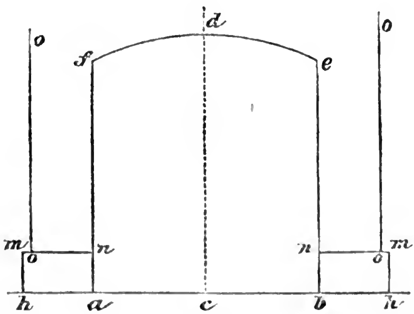


fig. 24.

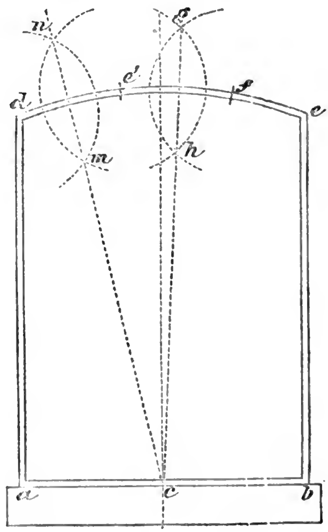


fig. 25.

EXAMPLE 25. *To draw the circular-headed window in fig.* 25. Let *a b* be the width, bisect it in *c*, draw *c g* perpendicular to *a b*. From *a*, *b* parallel to *c g* draw lines to *d* and *e*, the termination of the curve. To find the centre from which the curve *d f e* is described, take any points *e'* and *f* in the copy, and from these points, with radius greater than half the distance between them, describe arcs cutting in *g*, *h*. From *d* and *e'* in like manner describe arcs cutting in *n m*; through *n m*, *g h* draw lines meeting in *c*; *c* is the centre from which the curve is described. The centre may be found also by trial on the line *c d*, as described in fig. 23. The sketch may be copied by transferring the various points found, to the paper on the board, proceeding as in the foregoing lessons.

EXAMPLE 26. *To draw part of cellar-plan of house in fig. 26, showing walls, top of 'copper,' and flue of furnace connected therewith.* The sketch *without any of the dotted lines* is supposed to be given to copy from. By trial in the copy find the centre of the circle, which will be at *o*; from *o* draw a perpendicular to *a b*, parallel to *a s*, and another line at right angles to this, as *o e*, touching the line *c a* in the point *e*. On the paper on the board draw any two lines intersecting each other at right angles, the point of intersection at *o* will represent the point *o* of the copy. Measure from *o* to *d*, and from *o* to *e*; draw at these points lines at right angles, meeting in the point *a*. From *a* measure to *b*, draw *b f* parallel to *d o*; in the copy

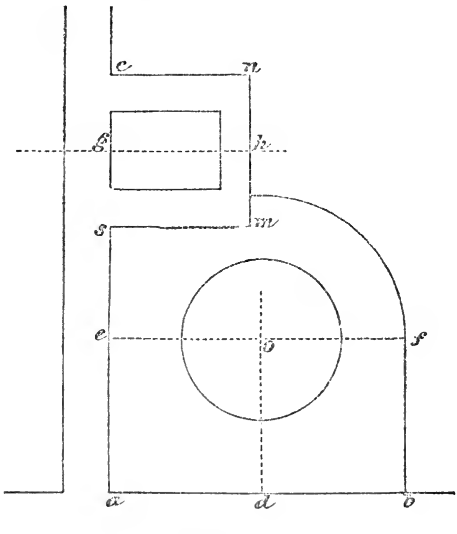


fig. 26.

bisect the side *n m* of the flue, and draw the line *g h* at right angles to *m n*. From *h* measure to *m*, *n*, and from these points draw lines meeting *c a* in *c*, *s*. From *o*, with proper radius, describe the circle, and from same point with *o f* describe part of a circle, joining *f* with side of flue *m n*. Another method of copying this may be adopted. Draw any two lines *c a*, *a b* at right angles, meeting in *a*; from *a* measure to *s*, at right angles draw from this point a line and measure *s m*; from *m* parallel to *c a* draw a line *m n*; from *n* parallel to *s m* draw a line meeting *c a* in *c*. The internal flue can be put in, as shown in fig. 2. From *a* measure to *b*, draw *b f*. Find by trial the centre of the circle, measure the distance of this from the two sides, *a s*, *a b*, transfer these to the board, and describe the circle as before.

Example 27. *To draw the walls and cellar-flues given in fig.* 27. In the copy continue the line *d* across *a*, the line *g g* across *f*, *t t* across *m*. By trial find the centres of the circles *p*, *p*, join them by a line *p o p*. On the board draw any line *a b*, representing the centre line of the wall *f m*, and at right angles to it another *d d*. From *a* measure to *e* and *c*, *c*, from these draw lines forming a parallelogram, as in the copy. From *a* measure to *f*, and through *f* draw a line parallel to *d d*; from *f* measure to *g g*, put in *h*, *h*, and join *g*, *h* by lines perpendicular to *g g*. From *a* measure to *o*; draw a line

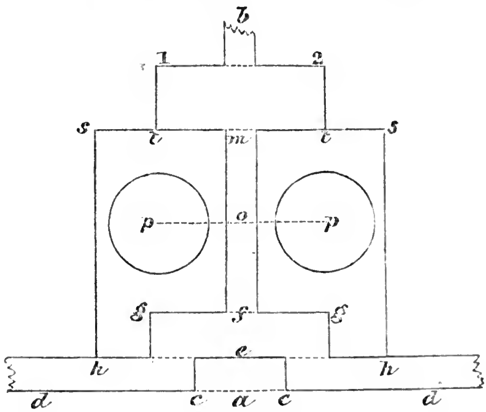


fig. 27.

through this parallel to *d d*; from *o* measure to *p p*; these points are the centres of the circles. From *a* measure to *m*; draw a line as before, and measure to *s*, *s*. From *m* measure to *t*, *t*, and draw lines to 1, 2; put in the thickness of the wall *m f*.

Example 28. *To draw the 'bull's eye' in fig.* 28. Bisect *e e* in *d*, *f f* in *d*, and from these draw lines intersecting at *a*. On the board draw lines corresponding to these. From *a*, with *a h* as radius, describe the circle *a h*. From *a* measure on the four radial lines to *d d*, from *d* measure to *e*, *e*, &c.; join *e d e*. From the points where the circle *a h* cuts these lines, measure from *h* to *m*; join *f m*; do this at all the radial lines. From *a*, with *a s* as radius, describe the parts of a circle joining the key-stones, as *t t*, &c. From *a*, with *a h*, describe in like manner a circle, as *m o*. From *a* measure to *c*, *c*, and from *c* to *b*; from *a*, with radius *a b*, describe parts of a circle, joining both ends of the lines *c*, *c*; finish as in the sketch.

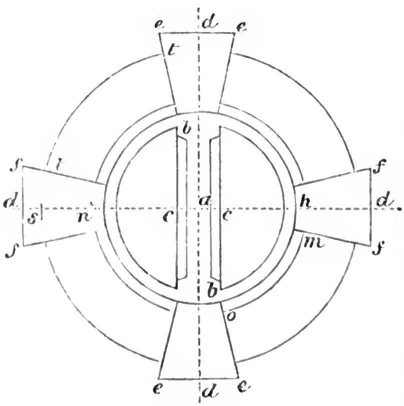


fig. 28.

EXAMPLE 29. *To draw the bracket of a cornice in fig.* 29. Let *a a* be the line of wall; from *a* draw *a b* perpendicular to *a a*. Measure from *b* to *c*, and draw *b c*. Measure from *a* to the point 5, and draw from it a short line

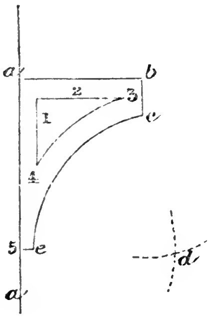


fig. 29.

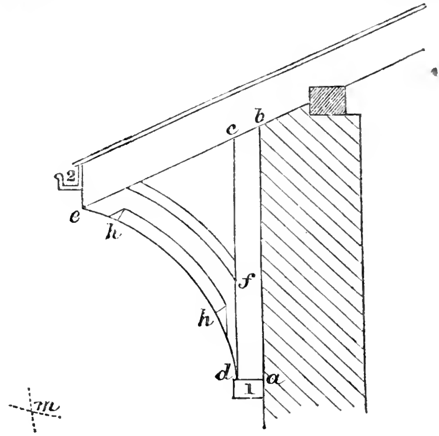


fig. 30.

perpendicular to *a a*, as in the diagram. From *a b* measure to 2, and from *a a* to 1; from these draw indefinite lines. Measure from 5 to *e*. Measure from the line *b c* to the point 3. By trial find the centre of the circle *c e* in the copy, as *d*, and transfer it to the board; join by an arc *c e*.

EXAMPLE 30. *To draw another form of bracket-cornice.* Draw a line *a b*, put in the part *a d* 1. Draw *c d* parallel to *a b*. From *a* measure to *b*, and from *d* to *c*. By drawing a line exactly through these points, the angle of the line of roof *e c b* will be obtained. From *c* measure to *e*; by trial find in the copy the centre from which the curve *e d* is described, as *m*; with the radius thus found, from the points *d* and *e* on the board, describe arcs cutting in *m*; with same distance still in the compasses, from this point describe a curve joining *d e*. From *d* and *e* measure to *h h*, and put the other arcs in as shown.

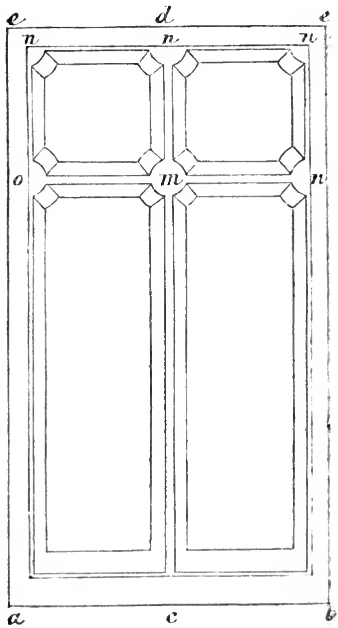


fig. 31.

EXAMPLE 31. *To draw the window in fig.* 31. Draw two lines, *a b*, *c d* at right angles to one another, intersecting in the point *c*. Measure from *c* to *a* and *b*, and also to *d*; through *d* draw a line *e d e* parallel to *a b*; measure from *d* to *e*, *e*; join *a e*, *b e*. Measure from *c* to *m*, and draw through this a line parallel to *a b*; measure also to *n*, and draw *nn*. From *m* measure on both sides the distance *m o*; *m n* also from *n* to *n*, *n*; these points are the centres of the circles shown in the sketch, the method of putting in of which is still further elucidated by

Example 32. Let the line *c d*, fig. 32, correspond to *o m n* in fig. 31, *a b* to *n m*, and *f e* to *n n*. From the point of intersection of these lines with *c d*, describe the circles as in the drawing. On each side of *c d* draw the

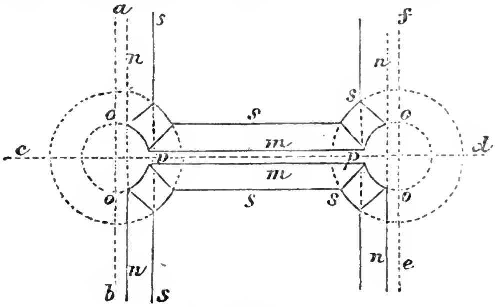


fig. 32.

lines *m*, *m*; and parallel to same lines, lines *s*, *s* touching the circles. From *f e*, *a b*, lay off to *n n* lines equal to *m*; and from *m*, to *s s* equal to the distance of the line *m s* from *c d*; join *p s* and the points corresponding.

Example 33. *To draw the basement arch below the principal entrance to a house, as in fig.* 33. Draw the line *a b*, and at right angles to it a line from *c*, the centre of *a b*. Measure from *c* to *a* and *b*. From same point,

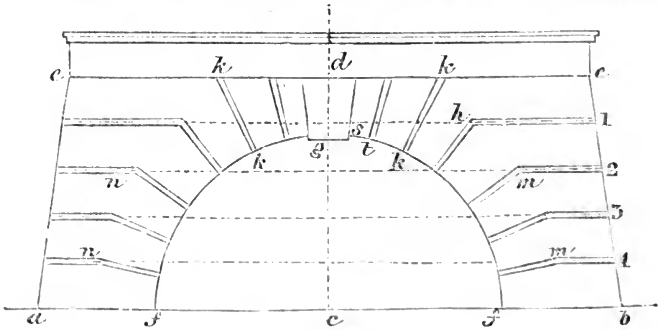


fig. 33.

with *c f* as radius, describe the semicircle *f f*. From *c* measure to *d*, draw a line through this parallel to *a b*. Measure from *d* to *e*, *e*; join *a e*, *b e*; put in the key-stone *d g*. Divide *b e* into five equal parts, and from these points, parallel to *a b*, draw lines through *d c* to the line *a e*. From *s* measure to *t*, and draw lines on each side the key-stone *d g*, parallel to its sides. From *t* measure to *k*. Divide *k f* into five equal parts. From *i* measure to *h*; from *c*, with *c h*, describe a dotted semicircle passing through the points *n n*, *h m m*; this will give the termination of the lines drawn from the points on *b e*. Join these with lines to the points found in the part of the circle *k f*.

EXAMPLE 34. *To describe the ornament (part of a verandah) in fig.* 34. Let *a b* be the breadth; bisect it in *c*, draw *c d* at right angles to *a b*. Draw on the board lines corresponding to these; the line *c d* will be that on which the centres of the complete circles are found. From *c* measure to *a* and *b*; draw *a f*, *b e*; the centres of the parts of circles *within the complete ones* will be found on these lines. At any distance on *a b* draw a line *g m h* parallel

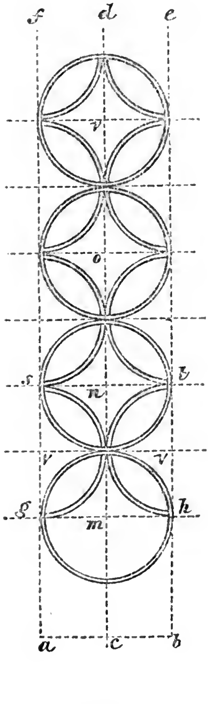


fig. 34.

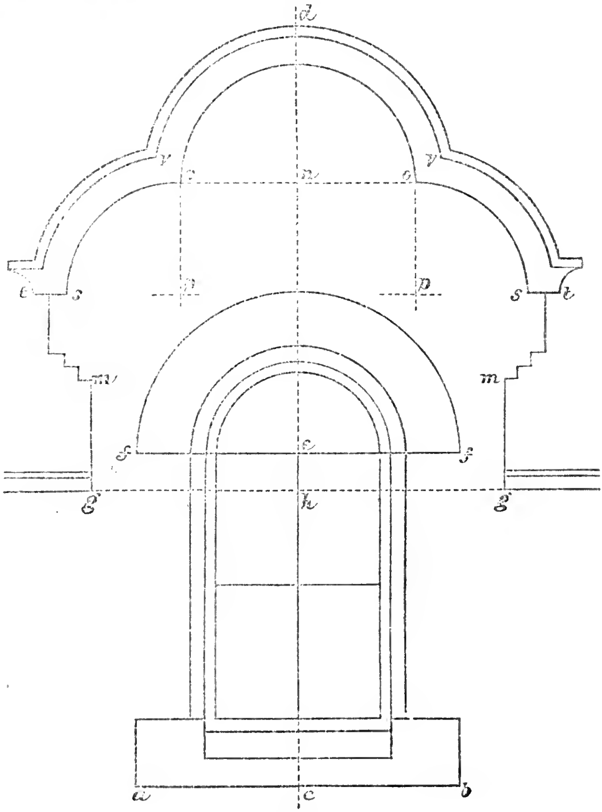


fig. 35.

to *a b*. With *a c*, from the point *m*, describe a circle *g m h*. With *g h*, the diameter of the outer circle, lay off on *c d* from the point *m* to the points *n* and *o*. Through these draw lines parallel to *a b*, as *s n t*. From *n*, with radius *a c*, describe a circle *s n t*. Through the point where the two circles touch, draw a line *v v* parallel to *a b*, cutting *a f*, *b e*. With radius *a*, *c*, from *v*, *v*, describe semicircles as in the sketch. The centres of the remaining circles will easily be found from the foregoing instructions.

EXAMPLE 35. *To draw the window in fig.* 35. Bisect *a b* in *c*; draw *c d*; join *g g* and *o o* by dotted lines as in the copy. On the board draw lines corresponding to *a b*, *c d*. From *c* measure to *a*, *b*, and put in the cill *a c b*, as described in fig. 10. From *c* measure to *h*, *e*, and *n*. From *h* measure to *g g*, and from these points draw lines parallel to *c d;* draw *g m, g m.* From *e* with *e f* describe the semicircle; and from *n*, with *n o, o n o.* Perpendicular to *o n o* draw lines to *p, p;* with the radius of the circle *o n o* measure to *p, p;* from these points with same radius describe the quadrants *o s, o s.* From *s* draw *s t* parallel to *a b.* Finish the circles as in the copy. The method of putting in the part from *g* to *v* will be more fully described in

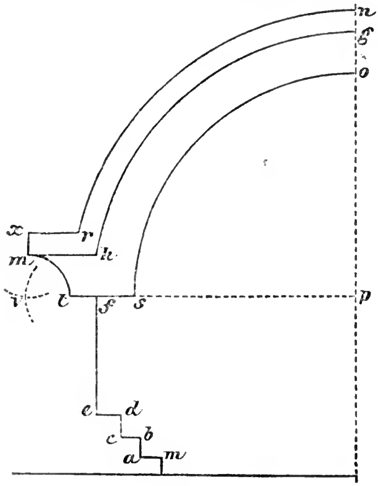


fig. 36.

EXAMPLE 36. Let *m, p* in fig. 36 represent similar points in fig. 35, *s o* the inner circle, and *s t* the horizontal line at termination of dripstone. From the point *m* draw *a m* parallel to *t s p;* at *a* draw *a b* equal and perpendicular to *a m;* from *b, b c;* from *c, c d;* and from *d, d e;* all equal to *a m*, and at right angles to one another. Join *e* to *t s* by a line parallel to *p n*, as *e f.* Let *g o* be the distance of the circle *g h* from *s o;* from *p*, with *p g*, describe a quadrant to *h*, making the point *h* distant from the line *s t* equal to *g o.* In like manner describe *n r.* From *h* and *r* draw lines *h m, r x* parallel to *s t.* From the points *m′ t*, with radius greater than half the distance, describe arcs meeting in *v;* from *v*, with same radius, describe the arc *m t;* join *x m.*

EXAMPLE 37. *To draw the Elizabethan gable in fig. 37.* Divide *a b* in the point *c;* draw *c d.* Corresponding to these draw lines on the board. From *c* measure to *a*, and put in the part below, as in the sketch. From *c*

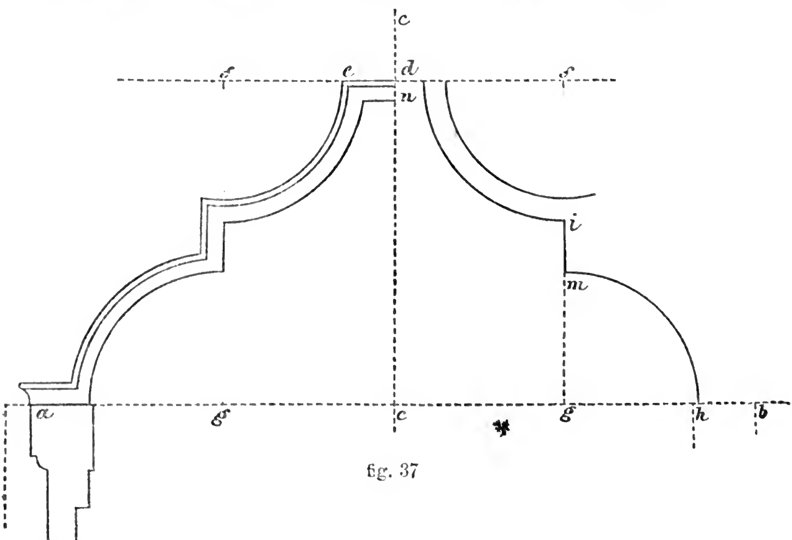


fig. 37

measure to *d*, and draw *f d f* parallel to *a b*. From *d* measure to *e e* and *f f*; from *c* measure to *g*, and from *g*, with *g h*, describe the quadrant *h m*. From *m* draw *m i* parallel to *c d*; from *f*, with radius *f n*, describe the arc meeting the line *i*. Finish as in the part to the left of the sketch.

EXAMPLE 38. *To describe the flutes and fillets in fig.* 38. Let *ab* be the diameter of column, bisect it in *c*; draw *c d*. Draw on the board lines corresponding to these, and from the point *c*, with *c b*, describe the semicircle *a d b*, representing half of the column. Bisect the quadrant *a d* in the point

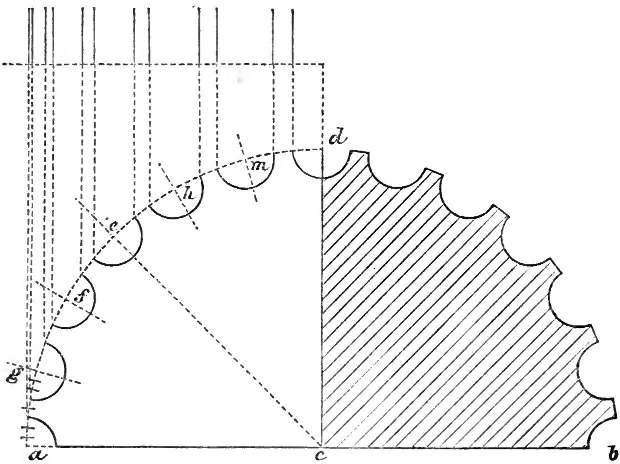


fig. 38.

e, and divide the arcs *a e*, *e d*, by points *g, f, h, m*. Mark the position of these by radial lines from *c*, as in the copy. Divide the part *a g* into eight equal parts; and with three of these as radius, from the points in the quadrant, as *g, f*, &c., describe semicircles. Six parts will thus be given to each flute, and two to each fillet: and the column will have twenty-four flutes.

EXAMPLE 39. *To describe the flutes in a Doric column without the fillets, as in fig.* 39. Proceed, as in last example, by dividing the quadrant *b e c* into

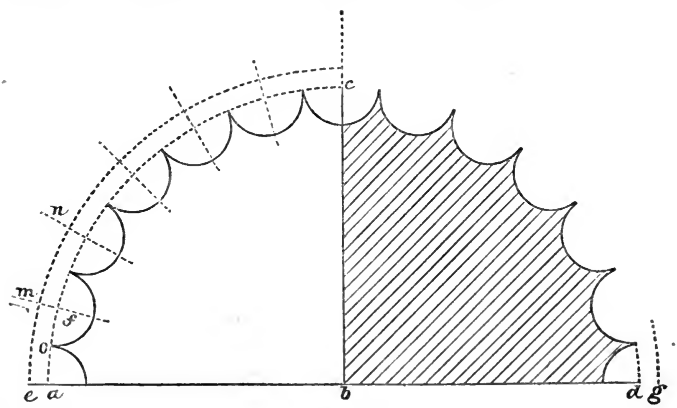


fig. 39.

six equal parts, as *e, m, n,* &c., giving to the entire column twenty-four flutes as before. Draw radial lines from *b*. Divide *a f* into four equal parts, and lay one of these on *a b* produced to *e;* from *b*, with *b e*, describe a semicircle as *e m n*, cutting the radial lines. Bisect *a f* in *o*, and with *f o* as radius, from the points—where the dotted semicircle intersects the radial lines—as centres, describe the arcs as in the copy. Another method is shown in

Example 40, fig. 40. Describe a semicircle *a d e*, and divide the quadrant *b a d* into five equal parts, so as to give twenty flutes to the column. Produce *a b* to *f;* bisect *a e* in *h*, and from *e* lay off *e h* to *m;* join *h m*, and

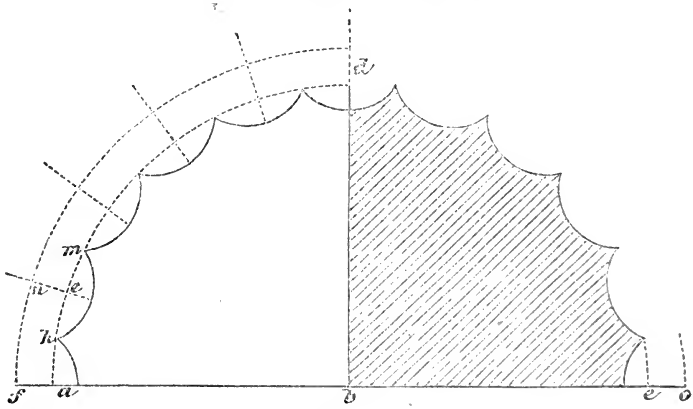


fig. 40.

with distance *h e* lay off on the radial line *b e* to *n*. From *b*, with *b n*, describe the dotted semicircle, *f n o*. The centres of the flutes are placed where the radial lines intersect this semicircle. From *n*, with *n m*, describe the curve *m h*, and draw the others in the same manner.

Example 41. *To describe the flat flutes and fillets as in fig.* 41. Describe the semicircle *a d c*, and divide the quadrant *b a d* into six equal parts;

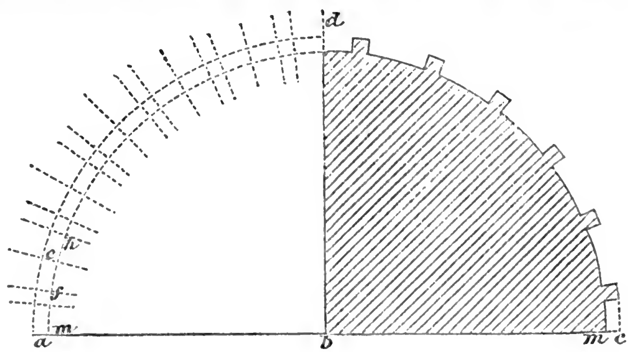


fig. 41.

divide *a e* into five equal parts. With two of these from the radial line, lay off on each side, as *f, h.* With one part lay off from c to m, and from *b*, with *b m,* describe a semicircle *c d a;* complete the diagram as shown. This will give the depth of the flutes, one; the width, four; and the width of fillets, one.

EXAMPLE 42. *To describe the cabled moulding in fig.* 42. Divide the semicircle *a c d* in the same proportion as in fig. 38, giving an equal number

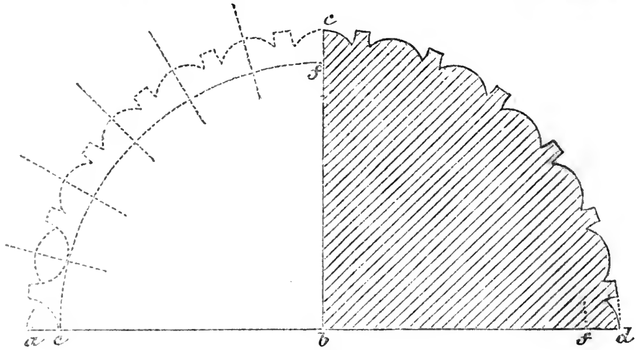


fig. 42.

as in that example. From *b*, with *b e,* describe the semicircle *e f f.* From the points where the radial lines intersect this, as centres, with radius *a e,* describe the curves as in the copy.

EXAMPLE 43. *To delineate the flutes in a pilaster,* fig. 43. Let *a b* be the breadth; divide it into twenty-nine equal parts: each flute is three parts in breadth, and each fillet one. This gives to the pilaster seven flutes and

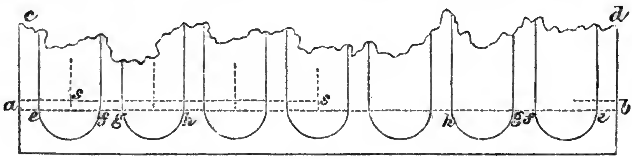


fig. 43.

eight fillets. Draw *a c, b d* at right angles to *a b;* and parallel to these lines, from the first point next these, as at *e;* at the fifth of these points, as at *f;* the sixth, at *g,* draw lines. The first fillet is *a e,* the first flute, *e f;* *f g* the second fillet, *g h* the second flute, and so on. The centres from which the termination to the flutes are described will be on the line *s s,* this being intersected by lines drawn parallel to *a e,* drawn through a point bisecting the fillet *e f, g h,* &c.

EXAMPLE 44. *To describe the curves in the twisted Doric column in fig.* 44. Proceed as in

EXAMPLE 45, fig. 45. Draw the centre-line *a b,* and the line of base *c c,* the width *d d* being that below astragal in capital; join *d c, d c.* With distance *c c,* lay off on *a b* from *a* to *e,* and draw through this point the line *g h,* parallel to *c a c.* With half *c c,* as *a c,* lay off on *a b* to *f.* From *f* as centre, with *f g* as radius, describe the arc *g c;* with *f h* as radius, from the points *c* and *h* as centres, describe arcs cutting in *m*; from *m* as centre, with *m h* as radius, describe the arc *h c*. Make *e n* equal *g h*; with *e g*, or *e h*, lay

fig. 44.

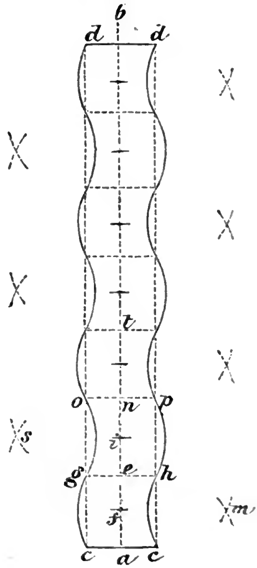


fig. 45.

off to *i*. From *i*, with *i p* as radius, describe the arc *p h*; from the points *g*, *o*, with same radius, describe arcs cutting in *s*; from *s*, with same radius, describe the arc *o g*. Next make *n t* equal to *o p*, and proceed as already described. The various centres are shown by the intersection of the arcs.

We now proceed to describe the method of laying out complete plans of houses. The first example of which we give in

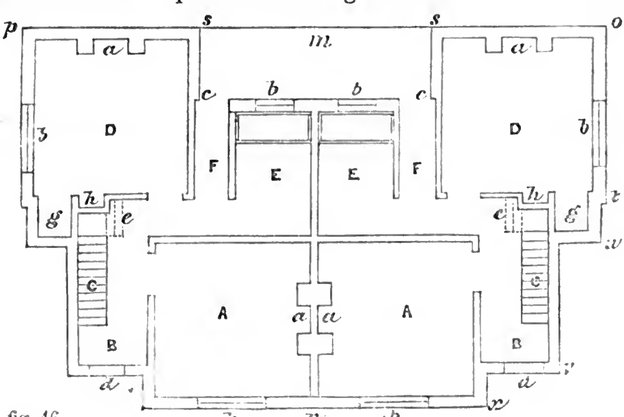


fig. 46.

EXAMPLE 46, fig. 46, which is the 'ground-plan' of a pair of cottages, the division or party-wall being at *m n*, A A the living-rooms, D the kitchen, E the scullery, F the back lobby, B the front lobby: *a a* are fire-places, *b* windows, *d* doors. The method of copying this is given in

EXAMPLE 47, fig. 47. Draw the line *o p*, fig. 46, and bisect it, drawing from the point of bisection another line *m n* at right angles to *o p*; next, as in fig. 47, draw the lines *c d*, *a b* at right angles, corresponding to *p o*, *m n* in

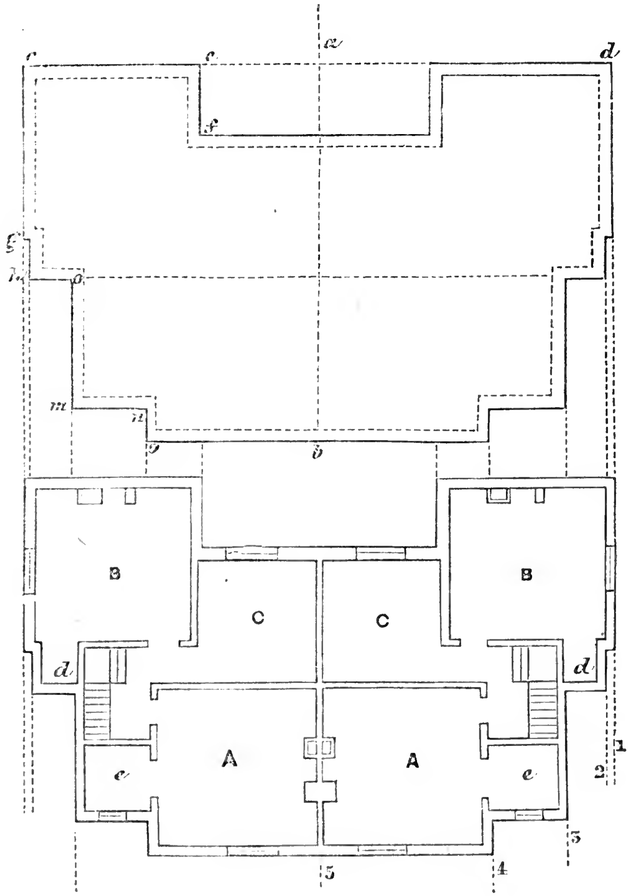


fig. 47.

fig. 46. Measure *o s*, fig. 46, and lay it off from *c* to *e*, fig. 47; at right angles to this draw *e f*, and make it equal to *s c* in fig. 46. Draw *c g* at right angles to *c e*, and make it equal to *o t* in fig. 46; make the short 'return' at *g* equal to that at *t* in fig. 46. Parallel to *g c* draw *g h*, and make it equal to *t u* in fig. 46; make the return *h o* at right angles to *g h*, and equal to that at *u* in fig. 46. At right angles to this draw *o m*, equal to *u v*;

make the return at *m n* equal to that at *v*, fig. 46; draw, parallel to *a b*, the line *n o;* make *o b* equal to *x d*, fig. 46. The other half, which is exactly similar, should be drawn in simultaneously with the first. After the outline is thus obtained, the thickness of the walls should next be put in, as shown by the dotted lines in fig. 47. The example in fig. 47 is also designed to show the method of drawing a 'bedroom plan,' or floor above the ground one, from the data given by the lines on the latter. Suppose the upper figure (in 47) to be filled in with the partitions, fire-places, &c. &c., as in fig. 46, thus representing the ground-plan *finished*. By means of the T square produce all the boundary-lines of the upper figure to an indefinite distance on the paper below it, as shown by the lines 1, 2, 3, 4, 5; then proceed as before described in copying fig. 47 from the outline of fig. 46. The diagram will, it is hoped, be sufficiently explanatory of the method to be adopted, bearing in mind the lessons previously given. The pupil, in copying the various lessons given, should use a much larger scale than the limits of our pages will admit of. In the lower part of the figure 47, A is the principal bedroom, B the back bedroom, C the children's bedroom, *d* a small wardrobe, and *e* a small closet or bath room.

EXAMPLE 48. *To draw the plan of cellar in fig.* 48. Bisect *a b* in *c*, draw *c d;* corresponding to these, on the board draw lines *a b*, *c d*. From *c* measure to *a b*. Draw from these, at right angles to *a b*, to *e e;* parallel

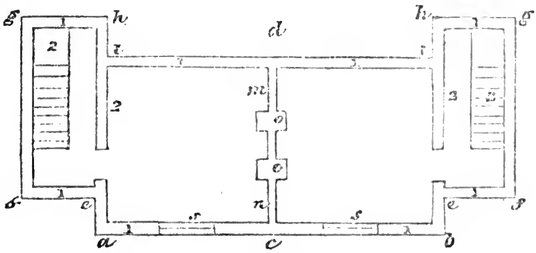


fig. 48.

to *a b* draw *e f*, and parallel to *c d*, *f g*. Parallel to *e f* draw *g h;* parallel to *c d*, *h i*. Join *i i;* the outline of the plan is thus obtained. Put in the thickness of the walls, the horizontal lines 1 1 first, the vertical 2 2 thereafter; and the central partition *m n*, with fire-jambs *o o*. Put in also the windows *s s*, and stairs, as in the drawing.

EXAMPLE 49 is designed to show the method of getting the position of the doors and windows in the front elevation, from the data afforded by the plan A P P E, fig. 49. The plan below represents the ground-plan of a row of four cottages, of which one-half is the counterpart of the other; we have, therefore, only shown the one-half fully drawn. The line G F, dividing the length into equal parts, is prolonged to H; the line *a b r* is drawn at right angles to this, and represents the ground-line: the distance of this above the plan will be decided according to circumstances, size of paper, &c. The openings of doors A, B, and E, are each bisected, and from the points lines are drawn parallel to G F, cutting the ground-line in the points *u*, *v*, and 3. In like manner, the windows C and D are bisected, and lines from the points drawn parallel to G F, cutting the ground-line in the points 1, 2.

The line 3 is the centre-line of end-door *p r*, the line 2 centre-line of window *n o*, line 1 centre-line of second window *h m;* the line *b*, of the window *d e; c*, of *f g*. The sizes of doors, &c., being previously ascertained, and

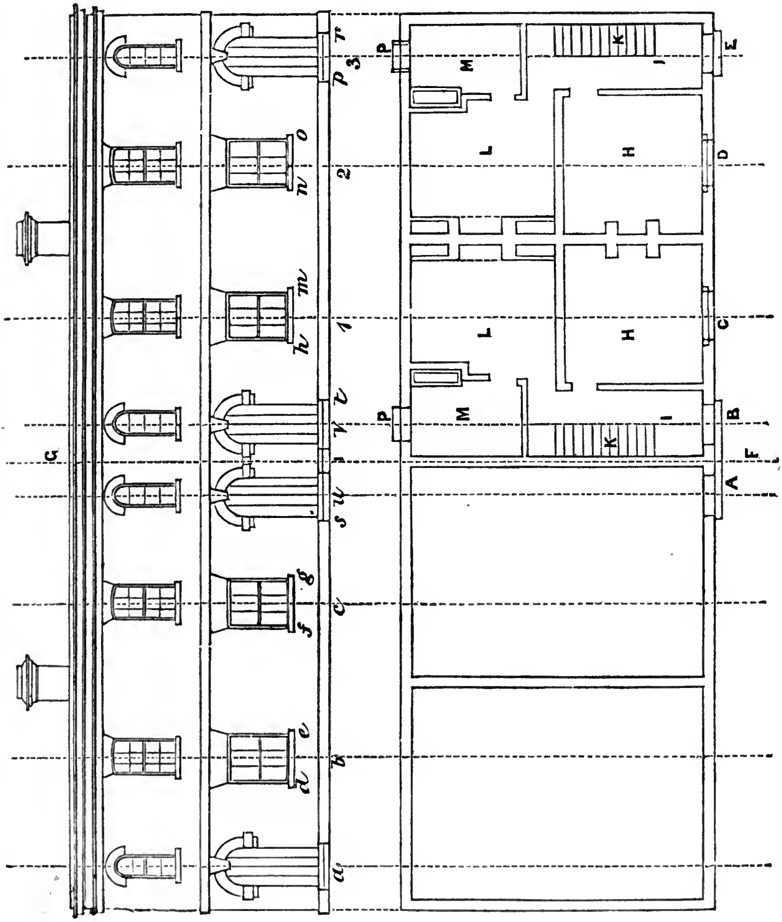


fig. 49.

the scale known, the centre-lines obtained will enable the various parts to be drawn. In like manner, supposing the front elevation correctly drawn to scale given, also a rough sketch of ground-plan, with sizes, divide the length of front into two parts, and draw a line G at right angles to the ground-line. Draw any line parallel to the ground-line, at any distance below the elevation; this will form the back line of wall. Produce G to F; this will form the centre-line of the houses. Next bisect the breadth-line of doors in the points *a, u, v*, and 3; and from these points, parallel to G F, draw lines to A, B and E; next divide the windows *h m, n o* in the points 1, 2, and draw as before lines to C, D. From the points thus given, if the pupil has carefully attended to the foregoing lessons, he will have no difficulty in drawing the various parts accurately. In the plan here given B and E are the principal doors, I I the lobby, K the stairs to bedrooms, H the living-room, L the kitchen, M the scullery, P the back entrance.

In the work on Practical Geometry we have amply illustrated the method of reducing irregular figures by means of squares; to that work, therefore, as introductory to the present, we refer the reader for information; we here content ourselves with giving, in

EXAMPLE 50, fig. 50, an architectural subject, having a series of squares

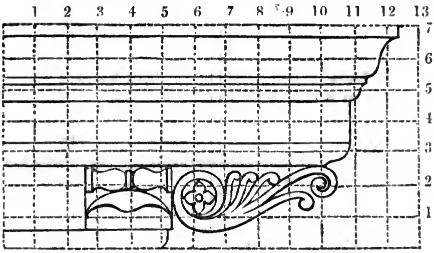


fig. 50.

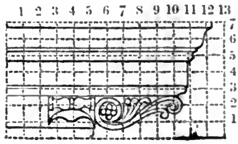


fig. 51.

drawn over its surface, preparatory to its being reduced one-half, as shown in

EXAMPLE 51, fig. 51. Should it be required to enlarge fig. 50, all that is necessary is to draw the same number of squares, but of double the size, when, the various points being transferred to the proper places, an exact copy of fig. 50, but of twice the size, may be obtained.

In architectural drawing it is sometimes necessary to delineate the material of which the walls, &c., are constructed. Thus, in

EXAMPLE 52, fig. 52, a series of bricks built on one another is delineated. The bricks are so disposed as to 'break joint,' as it is termed;

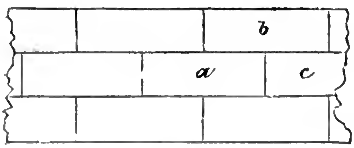


fig. 52.

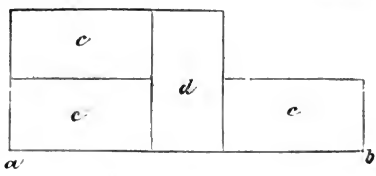


fig. 53.

that is, the solid part of *b* is placed over the joint formed by the juxtaposition of the bricks *a* and *c*. In ordinary work, bricks are used in two ways—as 'headers' and 'stretchers'—the 'headers' being placed across the wall, the 'stretchers' running along in the direction of its length. Thus, in

EXAMPLE 53, fig. 53, suppose *a b* to be the line of wall, the bricks *c c c* are 'stretchers,' and *d* a 'header.' The size of a brick of the ordinary dimensions is 9 inches long, $4\frac{1}{2}$ inches wide, and 3 inches thick. Brick-work is generally laid in two kinds of bond, termed 'English' and 'Flemish' bond. By the term 'bond' is meant the tie between the various members of a brick wall, and which is generally secured by the proper disposition of the bricks; this is effected by the arrangement of the 'headers' and 'stretchers.' Thus, in

EXAMPLE 54, fig. 54, which is a specimen of an elevation of a brick wall in 'English,' or as it is sometimes termed, 'old English bond,' where it con-

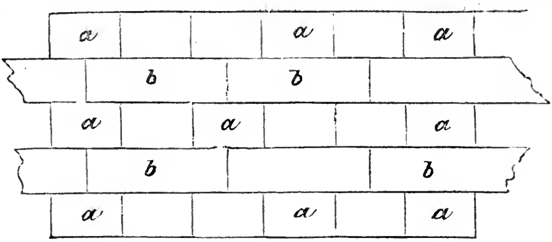


fig. 54.

sists of alternate layers of brick 'headers' and 'stretchers,' *a a* being the 'headers,' and *b b* the 'stretchers.'

EXAMPLE 55, fig. 55, shows a specimen of 'Flemish' bond, in which each row is made up of 'stretchers' and 'headers' laid alternately; *a a* are

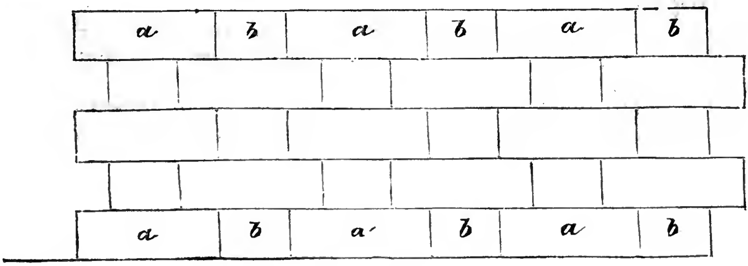


fig. 55.

the former, *b b* the latter. In delineating plans, various methods are in use for filling up. Thus, in

EXAMPLE 56, fig. 56, *a* represents the method of filling up walls in a

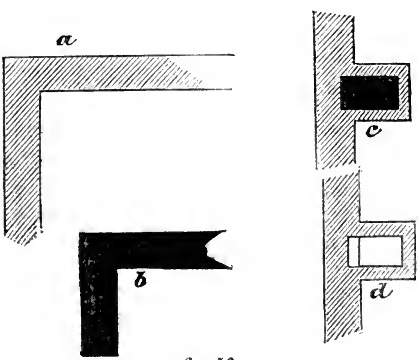


fig. 56.

plan by means of cross lines *b* where the whole is dark, all openings, at doors and windows, being left unshaded. The method of showing a chimney flue in the thickness of a wall is shown at *c;* another method in *d*. Stone work may be classed into three different kinds, as generally adopted; these are 'rubble,' 'coursed,' and 'ashlar.'

EXAMPLE 57, fig. 57, shows the method of delineating 'rubble work,' in which the wall is composed of stones of all sizes and shapes.

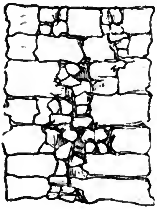


fig. 57.

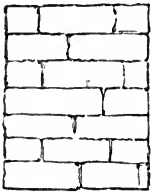


fig. 58.

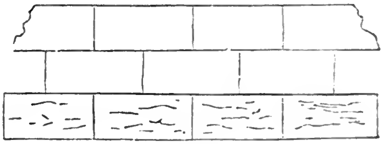


fig. 59.

EXAMPLE 58, fig. 58, shows the method of delineating 'coursed work,' in which the stones are, to a certain extent, squared and set in courses: hence the term.

EXAMPLE 59, fig. 59, shows the method of delineating 'ashlar work,' in which all the stones are squared up to certain given sizes, and set in regular courses.

EXAMPLE 60, fig. 60, shows the method of delineating 'vermiculated' work, in which the surface of the blocks is left with rough projections, a

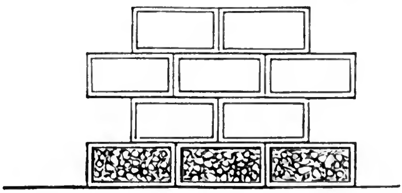


fig. 60.

narrow margin, tooled flat, being generally left round. This kind of work is used for 'keystones,' rusticated basements, doorways, &c.

The department now to be considered is that of

THE FIVE ORDERS—THEIR PROPORTIONS AND METHODS OF DELINEATION.

EXAMPLE 61, fig. 61, is an elevation of the 'Tuscan' order as generally received. The part from *a* to *b* is the 'pedestal,' from *b* to *c* the 'base,' from *c* to *d* the 'shaft,' from *d* to *e* the 'capital,' from *e* to *f* the 'entablature,'—the parts base, shaft, capital, and entablature, being termed a 'column.' The heights of the mouldings and the projections are all taken from the standard of measurement of each column; this standard being the diameter of shaft immediately above the base. This is divided into two equal parts, termed 'modules;' each of these again into thirty equal parts. The diameter is therefore divided into sixty equal parts; if necessary, each part is divided into sixty parts, called seconds. The standard is, therefore, thirty parts equal one module; two modules equal one diameter, or sixty parts. According to Palladio and other authorities, the height of column (Tuscan) now under consideration is, including base and capital, equal to seven diameters. To obtain, therefore, the diameter of any column, its height being given, all that is necessary is to divide the height into seven equal parts, one of which is the diameter; or where, on the contrary, the diameter is given, seven times this will give the height of column, including base and capital. We may now proceed to describe the laying out of the various members of a complete 'order,' showing the proportions of the mouldings, their height and projections. Although some writers discard the pedestal as an integral portion or a correct feature of any of the orders, we follow the majority of those who adopt it as a distinguishing feature. It is not here our province to enter into a detail of the æsthetic rules guiding the laying out of the various orders; we merely give examples of the parts as generally received. To those of our readers anxious to go into the matter, we refer to more technical works, or the treatise in this Series entitled *Ornamental and Architectural Design.*

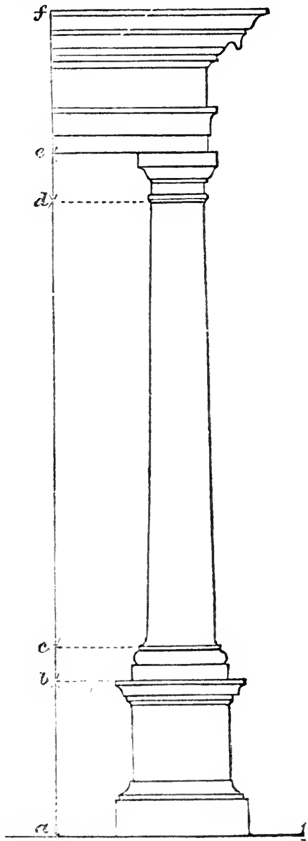


fig. 61.

EXAMPLE 62. Suppose the line *ab* (fig. 62) to represent the diameter of a 'Tuscan' column. Dividing *ab* into two parts in the point *c*, *ac*, *cb* will be the two modules; dividing each module into three equal parts at *d*, *e*, *f*, and *g*, and these again into five equal parts, a scale will be constructed from which to measure the various mouldings. Number as in the drawing.

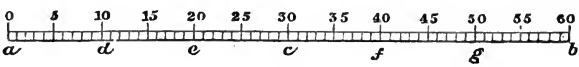


fig. 62.

EXAMPLE 63, fig. 63, shows the method of proportioning the mouldings of the 'Tuscan pedestal.' Every pedestal is divided into three parts,—the 'base,' as A B; 'die,' B C; and the 'cornice,' C D. In the figure given the whole height of the pedestal is four modules, or *a b*, fig. 62. In order to keep our sketches within the limits of the page, we take the proportions from a scale, the divisions of which are only half the size of those in fig. 62. At *a*, fig. 63, draw a line, as *iai*, of indefinite length, and at right angles to it a line *a b;* make *a b* equal to 2 diameters, or 4 modules, *a c* equal 26 parts, *cd* equal 4 parts, *d e* equal 8. Make the 'die' *en* equal 2 modules 4 parts; make *b f* equal 3 parts, *f g* equal 8, *g h* equal 2, *g n* equal 4: the heights of the 'members' will thus be found. The projections of the mouldings are all set out from the central line *a b*. From *a* with 53 parts lay off to *i*, *i*, and from these draw lines meeting that drawn from *c*; parallel to *i a i* make

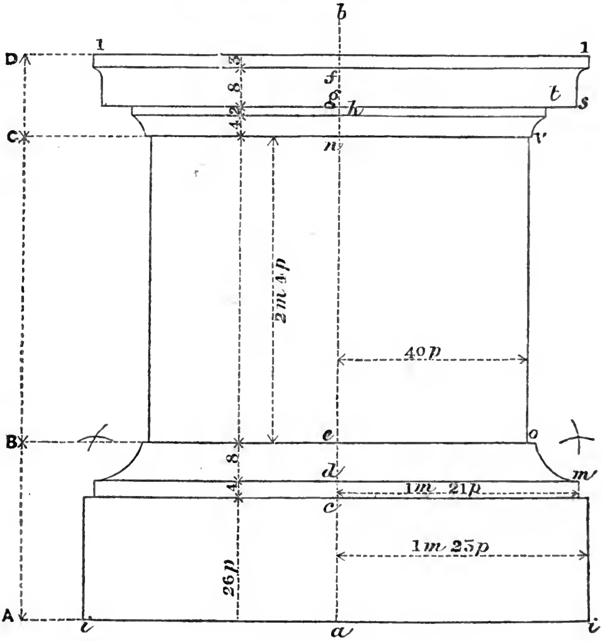


fig. 63.

d m equal 51 parts, or set back the line *m d* 2 parts from the end of line *c*: make *e o* equal $41\frac{1}{2}$, and the die equal 40 parts; make *b* 1 equal 53 parts; make *g s* equal $50\frac{1}{2}$, and *s t* equal 7, and *n v* equal *e o*.

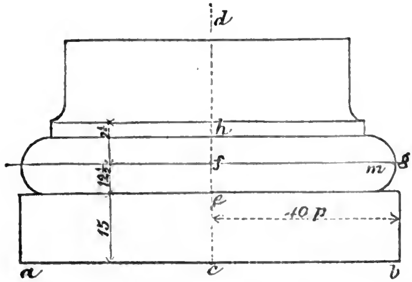


fig. 64.

Example 64, fig. 64, shows the 'base' of the Tuscan order. Draw the centre-line *c d*, put the 'plinth' *a b*, making *c b* equal 40 parts, and *c e* equal 15; make the 'torus' moulding in height equal $12\frac{1}{2}$ parts. The centre *m* of the circular termination is found on the line *f*. Make the fillet *h* equal $2\frac{1}{2}$ parts, and its projection from centre-line equal $33\frac{3}{4}$, or nearly 34 parts. To describe the 'apophygee,' by which the lines of shaft are connected with the base, see work on Practical Geometry, where also the various forms of mouldings met with in the Orders may be found described, and the methods of delineating them.

EXAMPLE 65, fig. 65, is the Tuscan 'capital,' drawn to the same scale as the others. Draw *c d*, *a b* at right angles; make *c a*, *c b* equal $22\frac{1}{2}$ parts, or *a b* equal 45; make the fillet of the astragal *e n* equal $24\frac{1}{2}$ parts, or *n e n* equal 49 parts. Make *g h* equal 27; *g i*, the 'neck,' equal *a b* or 45 parts, and the fillet *m* above the neck equal *e n*. Make the diameter of 'abacus' *n' o* equal 60 parts, or 1 diameter. These are the projections; the heights are as follows:—The fillet *e f* equal 2 parts; *f g* equal 4; *g m* equal $8\frac{1}{2}$; the fillet above this $1\frac{1}{2}$; the quarter-round *m n'* equal 10; the abacus or plinth *n' o* equal 10. The quarter-round begins at 1 division of the scale from *s*.

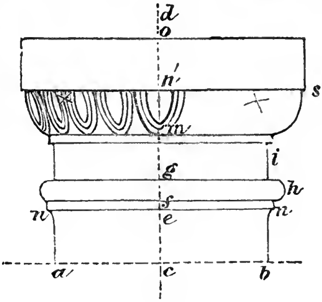


fig. 65.

EXAMPLE 66, fig. 66, is an elevation of the Tuscan 'entablature.' Every entablature consists of three parts,—the 'architrave' A B, the 'frieze' B C, the 'cornice' C D. Draw the line *b d* representing the centre line of column,

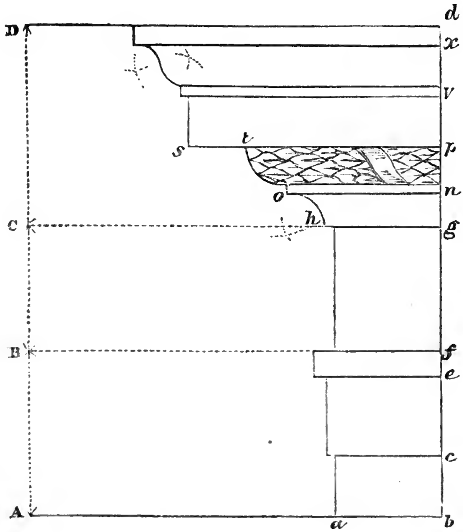


fig. 66.

and *a b* at right angles to it. The connection of the entablature with reference to the column will be seen in fig. 61. In the present figure the position is reversed. Make *b c*, the lowest 'fascia,' equal $12\frac{1}{2}$ parts in height and $22\frac{1}{2}$ in width from the central line *b d* to *a*. The upper 'fascia' *c e* is 17 parts in height and 24 in width; the 'fillet' *e f* is 5 parts in height and $27\frac{1}{2}$ in projection; the height of the 'frieze' *f g* is 26 parts, and its projection $22\frac{1}{2}$; the first moulding in the cornice *g n* (the cavetto), equal $7\frac{1}{2}$ in height, and projection *gh* equal 24. Make the fillet equal $1\frac{1}{2}$, and its projection *n o* equal 32; make the height of 'quarter-round' from *n* to *p* equal 9, and its projection *p s* equal $52\frac{1}{4}$; make *p t* equal 40, and join *o t*; make the 'corona' *p v* equal 10 in height, and the 'fillet' above it equal 2; its projection equal $54\frac{1}{4}$. Put in the 'cyma recta' to *x*, equal 10 parts, the last fillet equal $3\frac{1}{2}$, and its projection equal 66.

EXAMPLE 67, fig. 67, shows the elevation of the 'Doric column,' with 'pedestal' *a b*; *b c* the 'base,' *c d* the 'shaft,' *d f* the 'capital,' and *f e* the

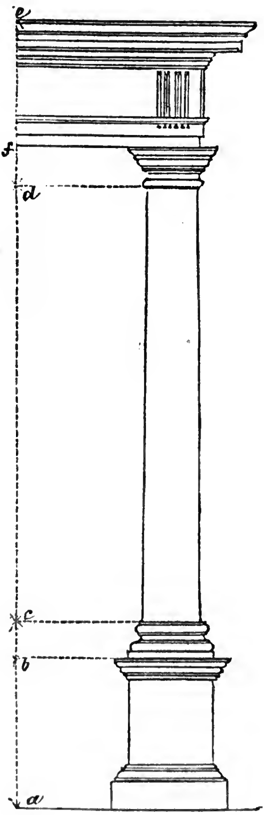


fig. 67.

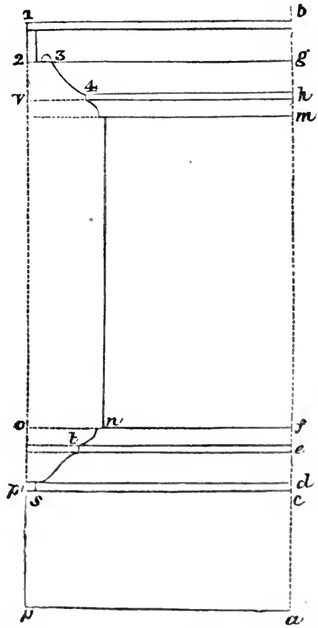


fig. 68.

'entablature.' The height of the column, including base and capital, is equal to seven diameters.

EXAMPLE 68, fig. 68, is the elevation of half of the pedestal of the Doric column to same scale as the last example. Draw *a p* *a b* at right angles, make *a b* equal to 4 modules 5 minutes, or 4 modules 20 minutes. Make the 'plinth' *a c* equal 26 parts in height; the 'fillet' *c d* equal $1\frac{1}{2}$; the 'cyma recta' *d e* equal $6\frac{1}{2}$; the 'fillet' *e* equal 1; the 'cavetto' *f* equal 4. Proceed now to put in the cornice; make the top 'fillet' at *b* equal 2 parts; the 'corona' below equal $6\frac{1}{2}$; the 'quarter-round' equal $6\frac{1}{2}$; the 'fillet' equal 1, and the 'cavetto' equal 4. Put in the breadth of the 'die' by measuring from f to n, equal 40 parts. From n, the face of the die, measure off to o, equal 16 parts; through o draw a line to p parallel to $a\,b$. From p' set off to s, equal 2 parts; from the line $p'o$ to t, equal 11 parts. Make the projection of the cavetto at top of base and at cornice equal to 1 part from line of die. From v lay back to 4, equal 12 parts; from 2 to 3, equal $5\frac{1}{2}$. Put in the cyma at $s\,t$, and the quarter-round from 4 to 3.

Example 69, fig. 69, represents the base of the column now under consideration; it is sometimes termed the 'Attic base;' 10 parts are given to the 'plinth;' 7 to the 'torus;' $1\frac{1}{2}$ to the 'fillet;' 4 to the 'scotia;' 1 to the

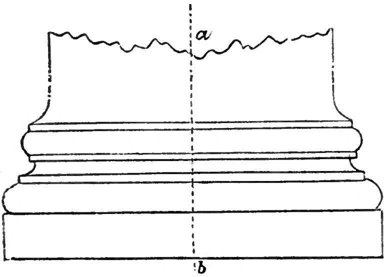


fig. 69.

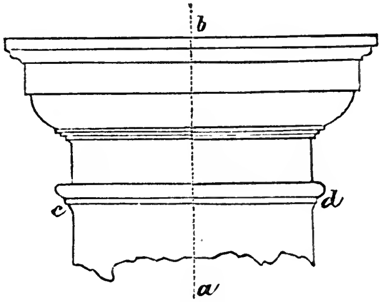


fig. 70.

fillet above it; $5\frac{1}{2}$ to the second torus, and 1 to the fillet above. The projections are set off from the centre-line $a\,b$, and are as follows, commencing with the 'plinth' equal 40; 'torus' equal 40; 'fillet' equal $36\frac{2}{3}$; fillet beneath the second torus 35; second torus $36\frac{2}{3}$; last fillet 34.

Example 70, fig. 70, is the 'capital' of the Doric order. The various 'heights' and 'projections' are as follows, beginning with the fillet $c\,d$. The diameter of top of shaft is 52, or 26 parts on each side of the centre-line $a\,b$; fillet $c\,d$ is $1\frac{1}{2}$ parts in height, and projection 28; the astragal or bead $3\frac{1}{2}$, projection 30; the neck 9 parts, projection 26. The three fillets below the quarter-round are together $3\frac{1}{3}$ parts in height; this is divided into three equal parts, as in the drawing. The quarter-round is $6\frac{1}{2}$ in height; the 'abacus' $6\frac{3}{4}$, and its projection 36: the quarter-round below it begins at a point 1 part back from end of abacus; the last fillet is 39.

Example 71, fig. 71, shows an elevation of the Doric entablature. The line $x\,x$ is the centre-line of column (see fig. 67), from which the projections are taken. The architrave $a\,f$ is composed of two fasciæ $a\,b$, $b\,d$, with a fillet $d\,f$. The 'guttæ' or 'drops' in the upper fascia $b\,d$ are $3\frac{2}{3}$ parts in height, surmounted with a fillet $1\frac{1}{3}$. The 'triglyph' is over this in centre of column, and its width is 30 parts; the distance between the 'triglyphs' is exactly a square, the side of which is the depth of the frieze $f\,g$; the distances between the triglyphs are called 'metopes,' and are generally filled in with some ornament as in the drawing. The following are the heights of the various mouldings, with their projections: $a\,b$ 11 parts, projection from $x\,x$ equal 26; $b\,c$ equal $9\frac{1}{2}$; $c\,d$ equal $3\frac{2}{3}$; $d\,e$ $1\frac{1}{3}$, the projection of b and d equal 27; of the fillet $f\,d$ equal 28, its height being 4 parts; the height of frieze $f\,g$ equal 45; $g\,h$ equal 5, projection of $g\,h$ equal 27. Height of $h\,k$

equal 5, the fillet 1; projection of *h* equal 32; of *k* $35\frac{1}{2}$; height of *k m* equal 6; projection of *m* equal $64\frac{1}{2}$; of *v t* equal $39\frac{1}{2}$. Height of *m n* equal 8;

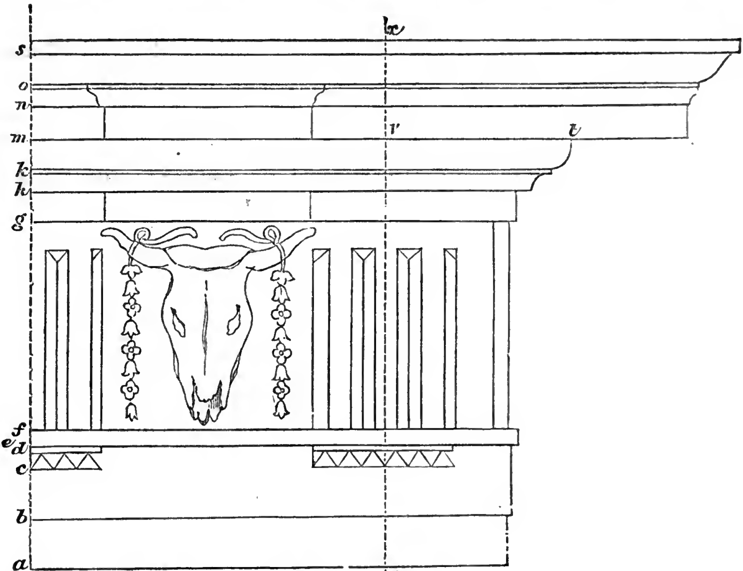


fig. 71.

n o $3\frac{1}{4}$; the fillet $\frac{3}{4}$; its projection 68. Height of *o s* equal $6\frac{3}{4}$; fillet equal $2\frac{1}{4}$; projection 76. The method of drawing the 'triglyphs' and 'guttæ' of this order is further elucidated by

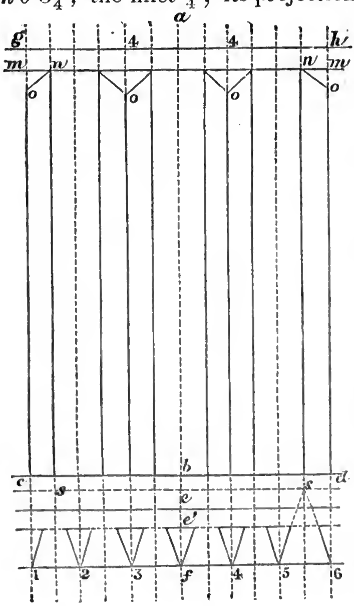


fig. 72.

EXAMPLE 72. Let *a b* (fig. 72) be the height of 'frieze,' and *c d* semi-diameter of column at base. Make *b e* equal 4 parts; the fillet *e e'* beneath this equal 2; and from *e'* to *f* equal 4. Divide *c b*, *b d* each into six equal parts; and parallel to *a b*, draw through these lines as in the drawing to the line *g h*. On *g c*, *h d*, lay off equal $2\frac{1}{2}$ parts to *m*, *m*; and with *m n* from *m*, lay off to *o*; join *n o*, *n o*. On the lines 4 4 draw to *o o*, and put in the angular lines. Bisect the fillet *b e* in the line *s s*; from the points 1, 2, 3, &c. at *f*, draw lines to *s s* where this line intersects the vertical ones, dotted as in the sketch. These angular lines are only continued to the under side of fillet *e'*.

EXAMPLE 73 represents the elevation of the 'Ionic' order. A, fig. 73, is the base of pedestal, B the die, C the cornice, D the base of column, E the shaft, F the capital, G the architrave, H the frieze, I the cornice of entablature.

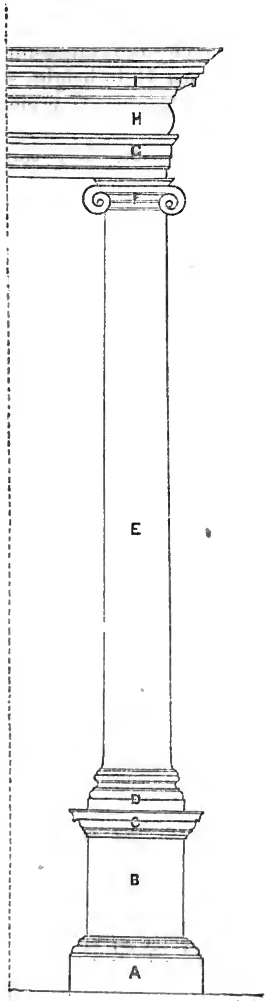


fig. 73.

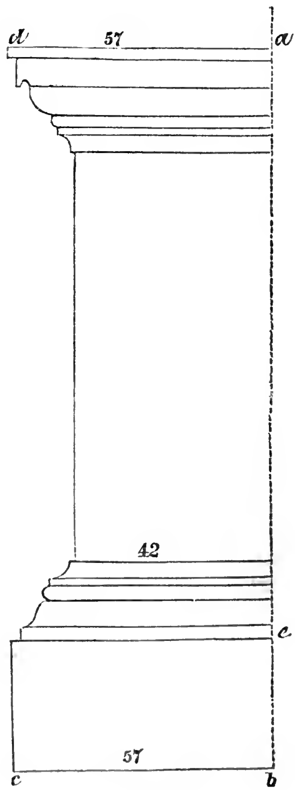


fig. 74.

EXAMPLE 74, fig. 74, shows the elevation of half of Ionic pedestal; the line *a b* being that from which the projections are taken; the plinth *b c* is $28\frac{1}{2}$ parts in height, and 57 in projection. The upper fillet *a d* is 2 parts high, and 57 in projection. The width of die is 42 parts. The whole height of pedestal from *a* to *b* is two diameters 34 parts, or 4 modules 4 parts. The heights of the other mouldings and projections are as follows, commencing with the fillet at *e* above the plinth, which is in height 1½ parts, projection 54½; the cyma 6½ in height, projection 48½; the astragal 2½ in height, projection 50; the fillet 1, projection 48½; the cavetto, 3½, projection 43. The height of die 87 parts; the height of cavetto above die 4 parts, projection 43; the fillet 1, projection 46; the astragal 3½; projection 48; the quarter-round 6; the corona 6, projection 55.

EXAMPLE 75, fig. 75, is the Ionic base, the line *a b* being the centre-line. The heights and projections are as follows: the plinth *c d* 10 in height, 42 projection; the torus, 8 height, 42 projection; fillet, 1 height, 37 projection; scotia, height 5; second fillet, height 1, projection 34½; second torus, height 5, projection 37; astragal, height 2, projection 34½; third fillet, height 1½; projection 33.

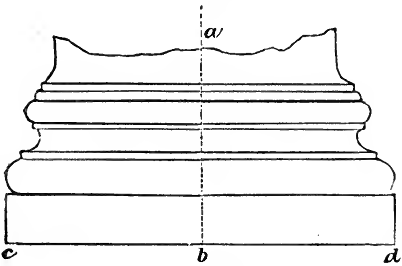


fig. 75.

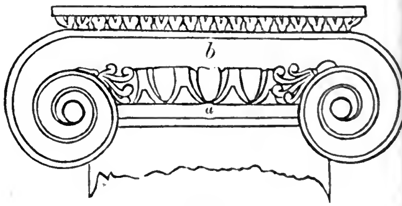


fig. 76.

EXAMPLE 76, fig. 76, shows the elevation of Ionic capital drawn to same scale as the others. The plan of the capital is shown in

EXAMPLE 77, fig. 77, and the side view in

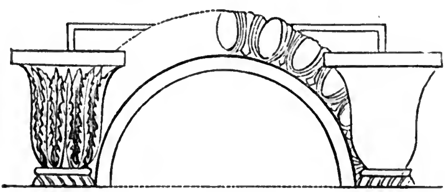


fig. 77.

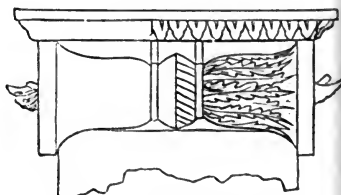


fig. 78.

EXAMPLE 78, fig. 78. The method of describing the scroll termed the 'volute' is explained in

EXAMPLE 79, fig. 79. Draw *a b*, *c d* at right angles; let *e f* be the diameter of the eye of the volute corresponding to the breadth of the astragal *a* (see fig. 76); with half *e f* from the point where *a b*, *c d* intersect, describe a circle; within this inscribe a square. In fig. 80 the centre of the volute is drawn to a larger scale, to enable the pupil to mark out the centres used to describe the scroll in fig. 79. From *e*, fig. 80, with radius *e d*, describe the circle, and within it inscribe the square *a b d c* corresponding to the square *e g f h* in fig. 79. Through *e*, the centre, parallel to *c a* draw *f h*, and parallel to *a b*, *i g*; join the extremities, and form a square *i h g f*. Divide the diagonals *i g*, *f h* each into six equal parts, at the points 1, 2, 3, 4, 5, 6, 7, 8. At these points draw lines at right angles, forming squares of which the corners are only given in the diagram to avoid confusion. Divide *i k* into four equal parts; from *h* lay one of these to *m*; from *i* to *n*; from *f* to *o*; from *g* to *p*; from 8 to *s*; from 1 to *t*; from 5 to *v*; from 4 to *x*; from 7 to *y*; and so

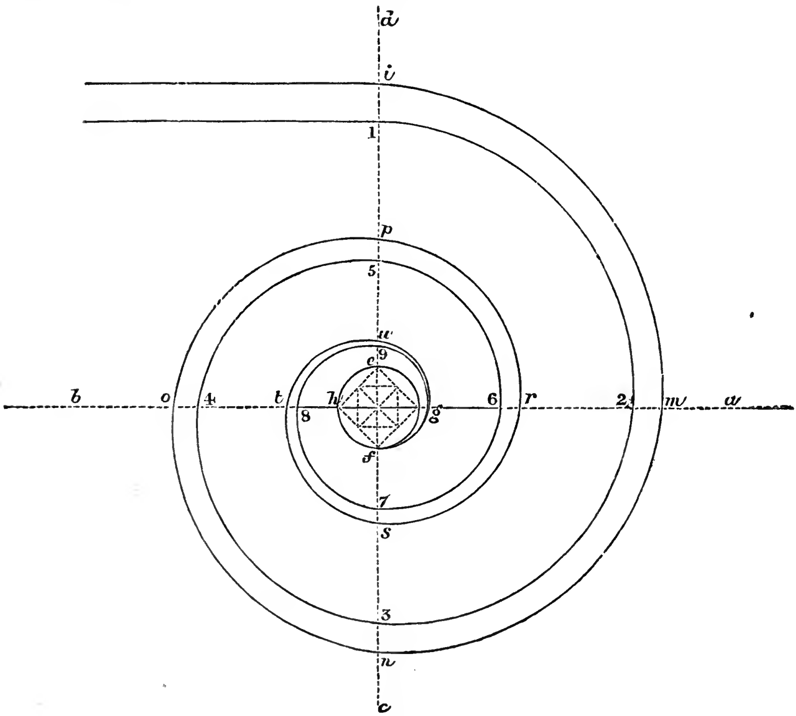


fig. 79.

on to the point of the square corner at 3. These various points thus obtained are the centres from which the curve is described. Suppose the point *i*, fig. 79, to be the under line of abacus of capital, as *b* (see fig. 76), from the centre, on line *e h*, fig. 79, corresponding to the point *c*, fig. 80, with radius *h i* describe an arc of a circle to the point *m*, meeting the diameter of *g h* prolonged to *a*. From the point in the smallest square in fig. 79, corresponding to the point *a*, fig. 80, with radius *e m*, fig. 79, describe an arc *m n*, meeting the diameter *e f* prolonged to *c*. From the point on the small square, fig. 79, corresponding to *b*, fig. 80, as a centre, with *g n* as radius, describe an arc *n o*, meeting *g h* produced to *b*. From *f* as centre, with *f o* describe an arc to *p*, meeting line *c d*. From centre 1 (see fig. 80), with radius 1 *p* describe an arc to *r*. From centre 8 (see fig. 80), with 8 *r* as radius, draw an arc to *s*. From centre 4 (see fig. 80), with 4 *s* describe an arc to *t*; from centre 5, with radius 5 *t*, describe an arc to *w*; from centre 2 (see fig. 80), with radius 2 *w* describe an arc to *g*, and so on. To draw the interior curve proceed as follows: from the point *n* (see line *i f*, fig. 80), with radius *m* 1, describe an arc to the point 2 in the line *a b*, fig. 79; from the point *m* (see line *i h*, fig. 80) with the radius *m* 2, an arc to the point 3 on the line *c d*, fig. 79; from the point *p* (line

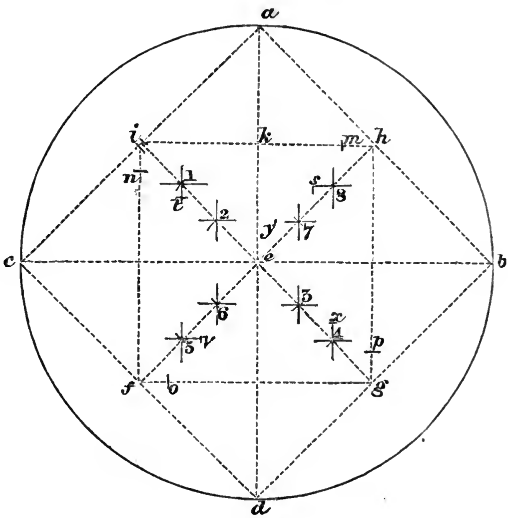


fig. 80.

h g, fig. 80), with the radius *p* 3, an arc to 4; from the point *o* (line *g f*, fig. 80), with radius *o* 4, an arc 5, and so on from the centres corresponding to the points *s, t, v, x, y*, &c., describing curves to the points 5, 6, 7, 8, 9, &c. fig. 79.

EXAMPLE 80, fig. 81, represents the 'Ionic entablature;' *a b* being the centre-line of column, and that from which the projections of the various members are taken. In succession, beginning from the point *b* upwards, the heights and projections of the various mouldings are as follows:—

1st	height	equal	6½	parts,	projection	equal	26½
2nd	,,	,,	2	,,	,,	,,	27
3rd	,,	,,	8	,,	,,	,,	27½
4th	,,	,,	2½	,,	,,	,,	29
5th	,,	,,	10	,,	,,	,,	29½
6th	,,	,,	5	,,	,,	,,	33
7th	,,	,,	3	,,	,,	,,	35
8th	,,	,,	27	,,	,,	,,	33
9th	,,	,,	5	,,	,,	,,	27
10th	,,	,,	1	,,	,,	,,	32
11th	,,	,,	6	,,	,,	,,	36
12th	,,	,,	2	,,	,,	,,	37
13th	,,	,,	7	,,	proj. to *e* equal 38,	to *c* equal	52
14th	,,	,,	3	,,	,,	,,	55
15th	,,	,,	4	,,	,,	,,	60
16th	,,	,,	4	,,	,,	,,	63½
17th	,,	,,	1	,,	,,	,,	64
18th	,,	,,	7	,,	,,	,,	64
19th	,,	,,	2	,,	,,	,,	72

EXAMPLE 81, fig. 82, represents an outline sketch of the 'Corinthian column,' with pedestal complete. The height of column is 9½ diameters, including base and capital. A is the base of pedestal, B the die, C the cornice, D the base of column, E the shaft, F the capital, G the architrave, H the frieze, I the cornice.

EXAMPLE 82, fig. 83, is the pedestal of the Corinthian order. The proportions are as follows, taking them in their order from *b c*: the plinth *b c*, $23\frac{1}{2}$ parts in height, its projection from the central line *b d* to *a* 57 parts;

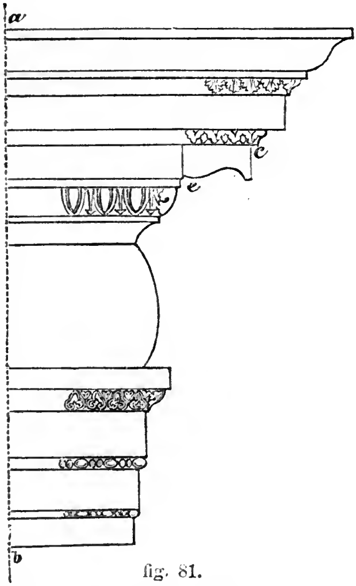


fig. 81.

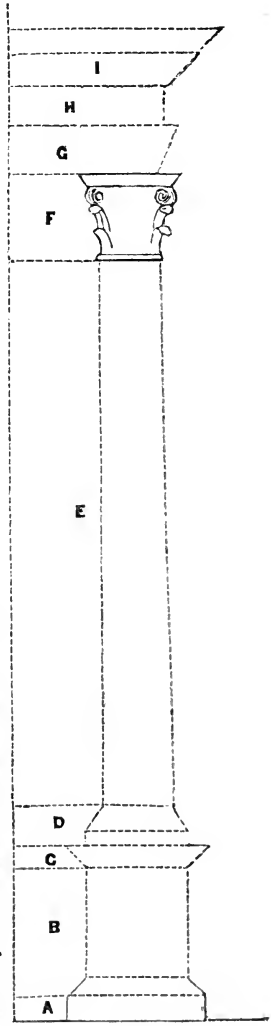


fig. 82.

the torus, height 4, projection 56; fillet $\frac{3}{4}$, projection 55; cyma 5, projection 47; fillet 1, projection 47; cyma $3\frac{1}{2}$, projection 42; die 3 modules $4\frac{1}{2}$ parts; projection of die, 42 parts; the cavetto in cornice $3\frac{3}{4}$, projection 43; fillet $\frac{3}{4}$, projection 46; quarter-round $4\frac{3}{4}$, projection 50; corona $4\frac{1}{2}$, projection 53; cyma $3\frac{1}{2}$, projection 57; the top-fillet $2\frac{1}{2}$, projection 57.

EXAMPLE 83, fig. 84, represents the base of the order, of which *ab* is the centre line. The heights in the progression of their order, commencing with *b c*, are as follows: 10, 7, 2, 1, 4, $\frac{1}{2}$, 2, 6, $2\frac{1}{2}$, 2. The projections, beginning with *b d*, are as follows: 42, 42, 38, 37, 32, 37, 35, 32.

EXAMPLE 84, fig. 85, represents the capital of the order. The diameter of shaft at the neck is $52\frac{1}{2}$ parts; the fillet $1\frac{1}{2}$, its projection 56; the astragal 4, projection 60. The height from *a* to *b* is 70 parts, the projection from *b* to *c* 46, the projection from *b* to *e* 60. Join *ef*, prolong *af*, *b e* to *g* and *h*; join *g h* by a line parallel to *b a*, and mark off on it from *g h*, as in the sketch. From the points obtained draw lines parallel to *b e*; the intersection of these with *e f* will give the position of the acanthus leaves. The method of laying out the plan of this capital

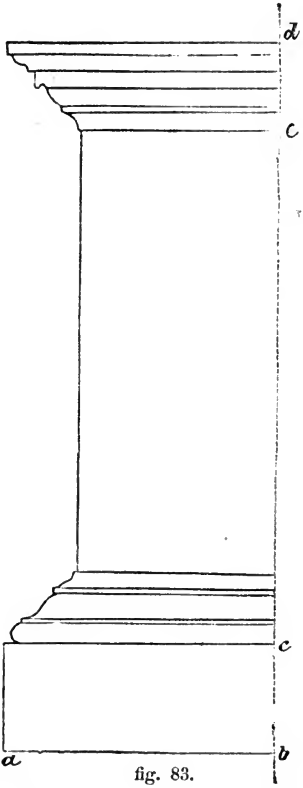


fig. 83.

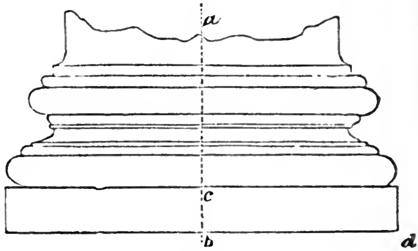


fig. 84.

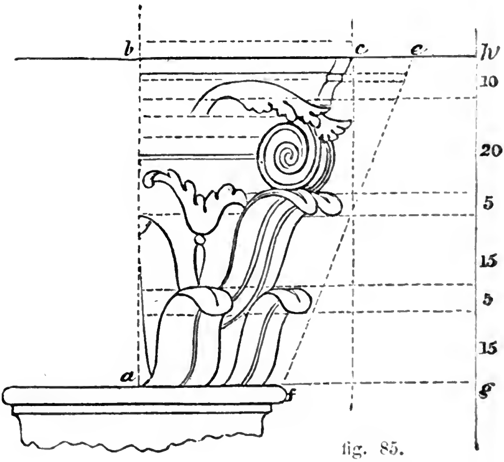


fig. 85.

is shown in fig. 86, where *a b* is the diameter of shaft at neck, *c e* corresponding to the distance *b c*, fig. 85. The centre of the circle of which *d d* is a part, is found by the intersection of the lines at *f*.

EXAMPLE 85, fig. 87, shows a form of capital of this order, with the ornaments filled in.

fig. 87.

EXAMPLE 86, fig. 88, is the 'Corinthian entablature.' The heights of the different mouldings, commencing with *a b*, are as follows: 6, $1\frac{3}{4}$, $8\frac{1}{4}$, $1\frac{3}{4}$, $10\frac{1}{2}$, 5, $2\frac{1}{2}$, $28\frac{1}{2}$, $4\frac{1}{2}$, 1, $5\frac{1}{2}$, 1, $4\frac{1}{2}$, 1, $7\frac{1}{2}$, $2\frac{1}{2}$, 1, $7\frac{1}{2}$, $\frac{2}{3}$, 3, $\frac{2}{3}$, 6, $2\frac{1}{4}$. The projections, beginning with *a c*, are as follows: 26, $26\frac{1}{2}$, 27, $27\frac{1}{2}$, 28, $29\frac{1}{2}$, $34\frac{1}{2}$, 26, $26\frac{1}{2}$, 32, 34, 35, 40, $58\frac{1}{2}$, 60, 62, $62\frac{1}{2}$, 66, 74.

EXAMPLE 87, fig. 89, represents the outline of the Composite order with pedestal complete: the letters and parts correspond with those given in fig. 82, where the pedestal is delineated. Its height, including base and capital, is 10 diameters.

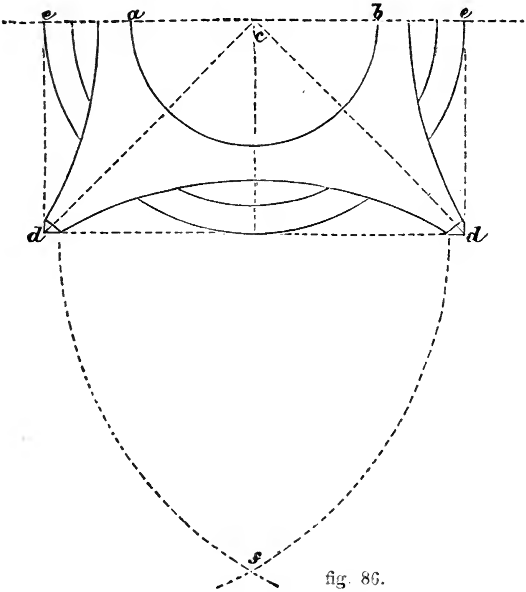


fig. 86.

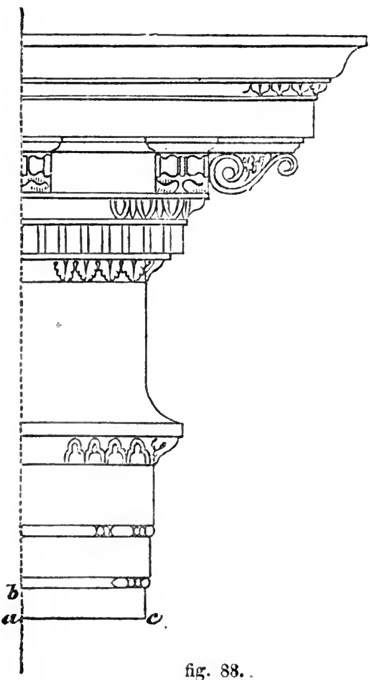


fig. 88.

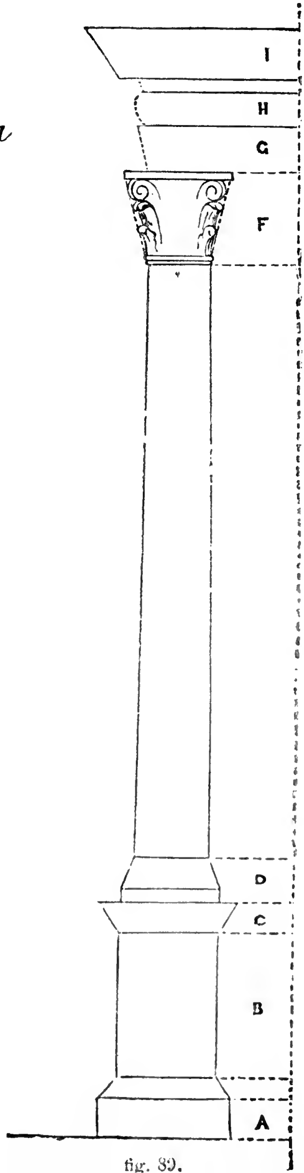


fig. 89.

Example 88, fig. 90. The pedestal. The heights, commencing with b c, are as follows: 33, $4\frac{1}{2}$, 1, 3, $1\frac{1}{2}$; 1, height of die d e 4 modules 5 parts. The height of mouldings in cornice, beginning at e, are as follows: $1\frac{1}{2}$, 3, $8\frac{1}{2}$, 1, $5\frac{1}{2}$, $3\frac{1}{2}$, $2\frac{1}{2}$. The projections, beginning with a b, are 57, 57, 55, 46, 45, 42, $44\frac{1}{2}$, 47, $52\frac{1}{2}$, 53; top-fillet 57.

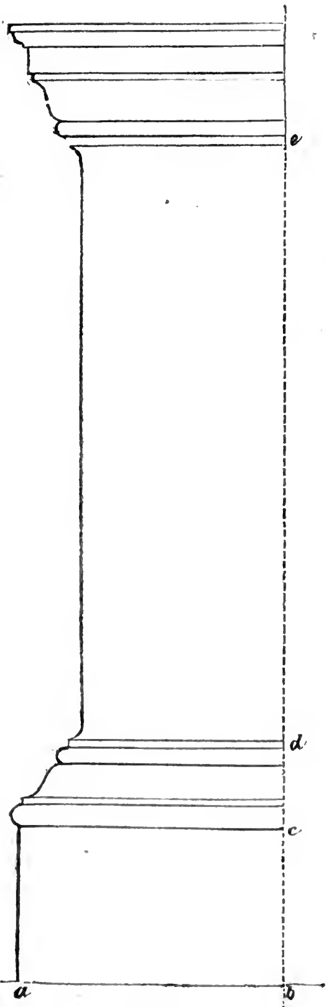


fig. 90.

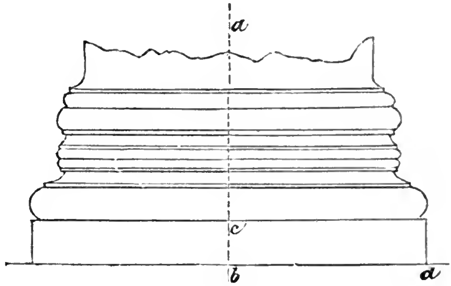


fig. 91.

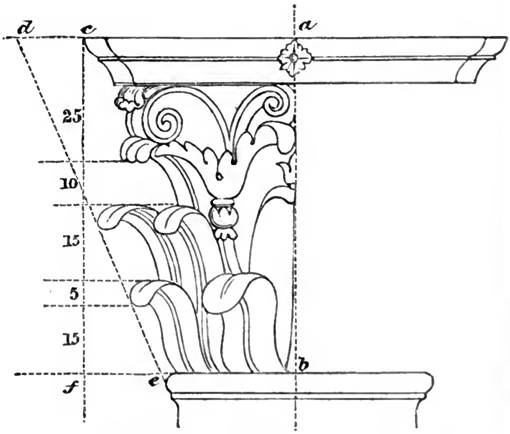


fig. 92.

fig. 93.

EXAMPLE 89, fig. 91, represents the base of the order. Heights, beginning with *b c*, 10, 7, $\frac{1}{2}$, $2\frac{1}{2}$, $\frac{1}{2}$, 2, 2, $\frac{1}{2}$, 2, $\frac{1}{2}$, $4\frac{1}{2}$, 2, 1; projections, beginning with *b d*, 42, 42, 38, 36, 37, 37, 36, 36, 37, 36, 34.

EXAMPLE 90, fig. 92, represents the capital of the order. The semi-diameter of shaft at neck is 26 parts; the fillet $\frac{1}{2}$ in height and 27 in projection; the astragal 4 in height and 29 in projection. The height from *b* to *a* is 70, projection from *a* to *c* 45, and to *d* 60; the heights on the line *f c* are used by the intersection of the line *d c* to find the height of the ornament. (See example 84.) Another form, with the ornaments filled up complete, is given in

EXAMPLE 91, fig. 93.

EXAMPLE 92, fig. 94, is the Composite entablature. The heights of the mouldings, beginning with *b c*, are as follows: 12, $2\frac{1}{2}$, 15, $1\frac{1}{2}$, $3\frac{1}{2}$, 4, 2, 30,

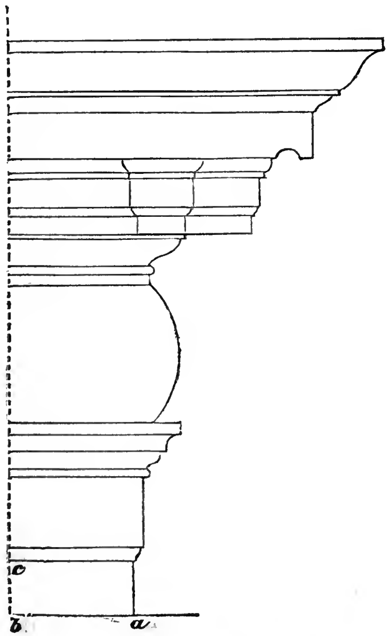


fig. 94.

2, 2, 5, $\frac{1}{2}$, $3\frac{3}{4}$, $1\frac{3}{4}$, $6\frac{1}{2}$, $1\frac{1}{4}$, $2\frac{1}{2}$, $9\frac{1}{2}$, $3\frac{3}{4}$, 1, 8, $2\frac{1}{4}$. The projections, beginning with *b a*, are 26, 28, 29, 34, 37, 36, 32, 52, $53\frac{1}{2}$, 54, 55, 66, 67, 70, 78.

The next example shows the manner of delineating intercolumniations. By this term is meant the distance between two columns, as *a* and *b*.

EXAMPLE 93, fig. 95, which is the intercolumniation of the Tuscan order. The distance between the columns is 6 diameters, the general distance, however, being 4 diameters. The pupil, at this stage of his proceedings, should make drawings to a large scale, as of that in fig. 62 of the intercolumniation of all the orders, to assist him in which we here give the various distances for each. The distance between the Doric columns is equal to three diameters; the distance in the Ionic is two diameters and a quarter; the distance between the columns in the Corinthian is two diameters and a quarter; and that of the Composite one diameter and a

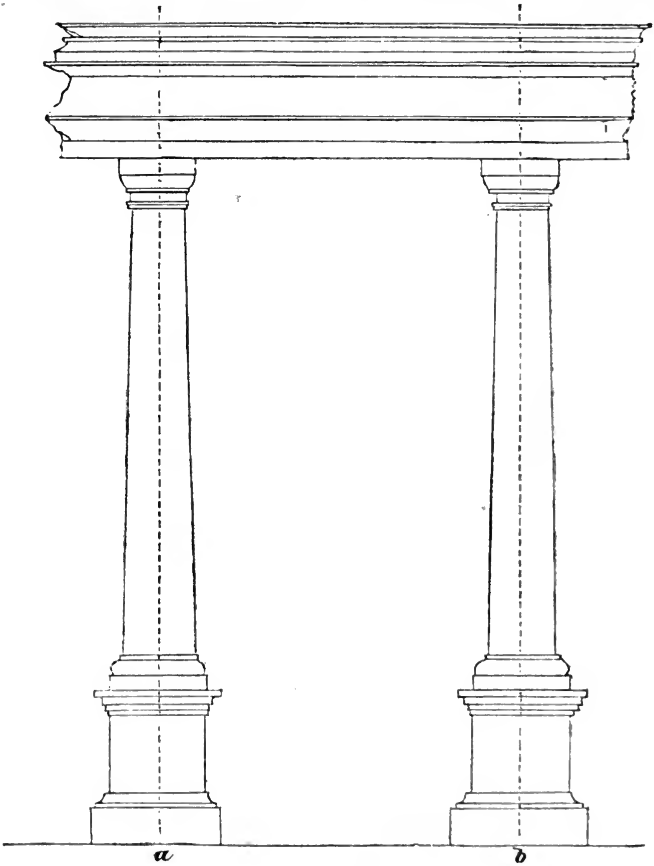


fig. 95.

quarter to one diameter and three quarters. For the various species of intercolumniation, with their distinguishing names, see the work in this Series on *Ornamental and Architectural Design*.

Where it is necessary to introduce doors, windows, &c., thus widening the space between the columns to a greater extent than true proportion requires, 'coupled columns' are introduced, the distance between them being such as to allow of the proper projection of their 'capitals.'

EXAMPLE 94, fig. 96, shows coupled columns in the Corinthian order, where the space between the two columns is a little over two diameters.

Pilasters bear a considerable resemblance in their elevation to columns. The height of members and their projections are the same as the columns of the same order; the plan, however, instead of being circular as in columns, is square, the external surface being flat.

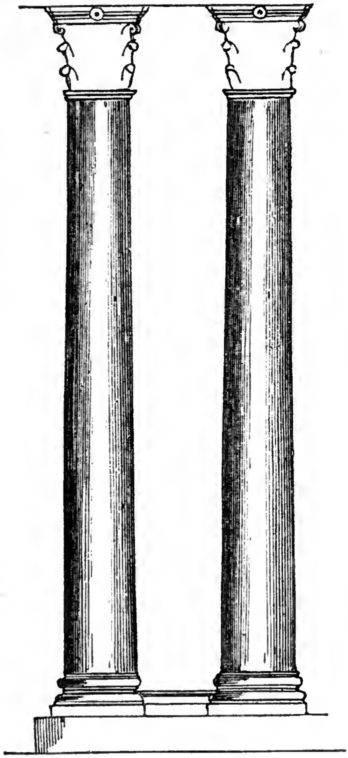


fig. 96.

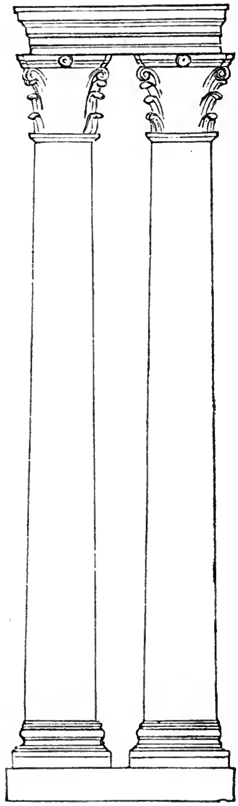


fig. 97.

EXAMPLE 95, fig. 97, shows 'coupled pilasters' in the Corinthian order.

Caryatides are sometimes used in place of columns and pilasters. These are representations of the human figure. When female, they are known by the name as above; when male, as 'Persians.'

EXAMPLE 96, fig. 98, is an exemplification of a caryatides. As a series of columns at proper distances form a colonnade, so columns with arches between them, are termed *arcades*. The Tuscan arcade is given in

EXAMPLE 97, fig. 99. The distance between the columns *a* and *b* is six diameters; A is termed a 'pier,' B the 'impost,' C the 'archivolt,' and D the 'keystone.' A semi-diameter of column is laid from *c* to *d*, which gives the line of pier *h d*. The distance from *p* to *t* is six diameters and three-quarters; a line through *t* parallel to *a b* gives the height of im-

fig. 98

post; the capital of impost is obtained by dividing $g\,h$ into seven or eight equal parts, and giving one of these from m to n; the width of archivolt $s\,o$ is equal to one-ninth part of $g\,h$; the width of keystone at $e\,f$ is equal to $o\,s$. By drawing lines to e and f from t, the centre of the circle, $m\,e\,f\,s$, the diverging lines will be obtained. To assist the pupil in making out

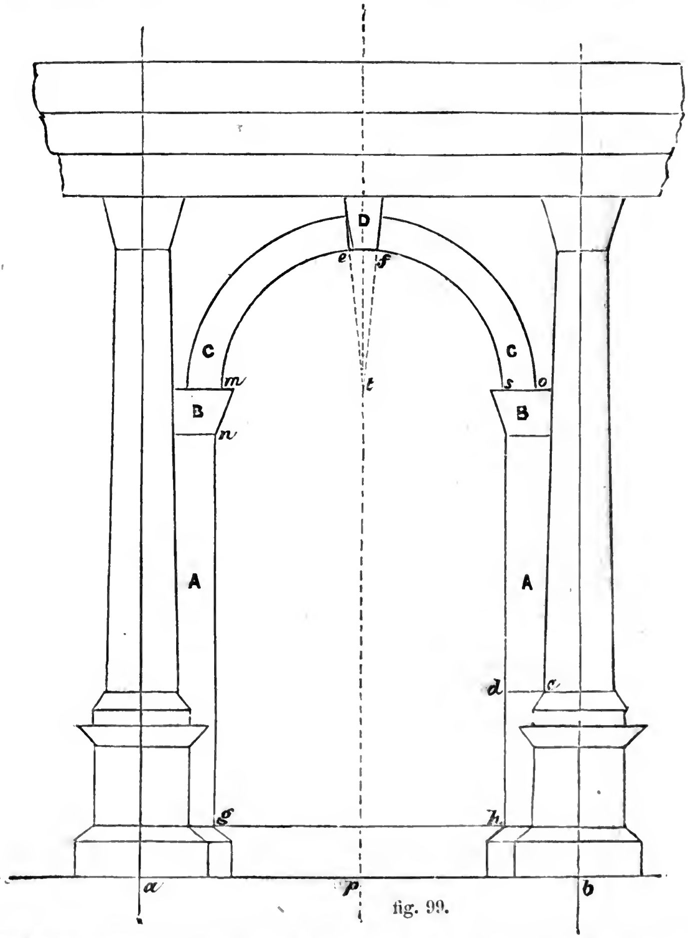


fig. 99.

examples of arcades in the other orders, we quote the following directions of a celebrated author on architecture as to proportions:—"The height of arches to the underside of their crowns should not exceed twice their clear width, nor should it be much less; the piers ought not to be less than one-third the breadth of the arch, nor more than two-thirds." The pupil desirous of studying the principles of architectural design may consult the work on *Ornamental and Architectural Design,* above noticed.

EXAMPLE 98, fig. 100, is an elevation of the Tuscan impost, with the heights and projections. The projections are set forward from b to k, in the line $b\,c$, the line $b\,c$ representing the face of pier corresponding to the line $h\,d$ in fig. 99. The scale from which the measurements are taken is that in fig. 62. The figures 1, 2, and 3 denote the width of the mouldings on the archivolt c c (see fig. 99), and are set back on the line $a\,k$ from b.

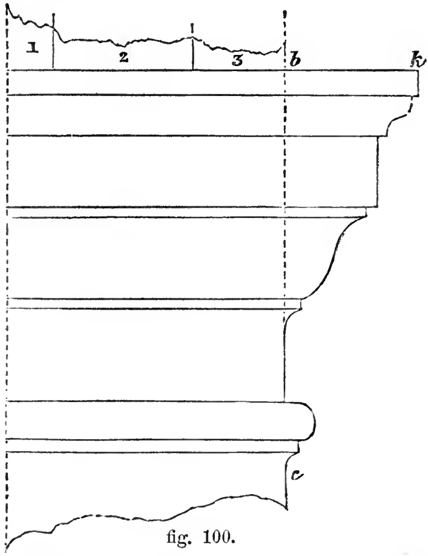


fig. 100.

Example 99, fig. 101, is the Doric impost. The heights are measured from the point b on the line $b\,c$ representing the line of pier, as in last ex-

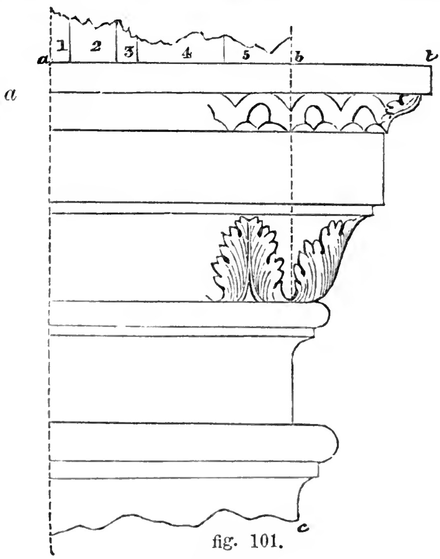


fig. 101.

ample, the projections being set forward from b to w and t, the width of mouldings of archivolt, 1, 2, 3, 4, 5, being from b towards a.

EXAMPLE 100, fig. 102, is the Ionic impost, the projections, heights, and widths 1, 2, &c. of archivolt mouldings being set out as in last figure.

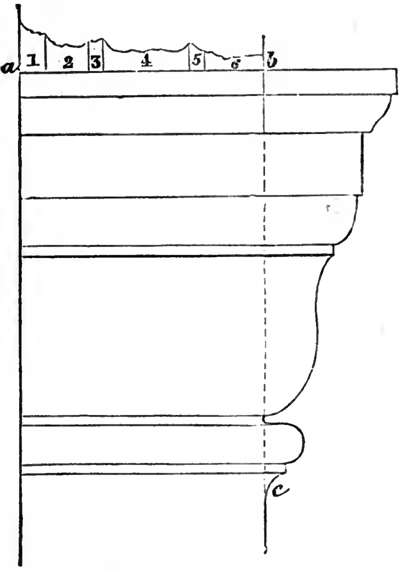


fig. 102.

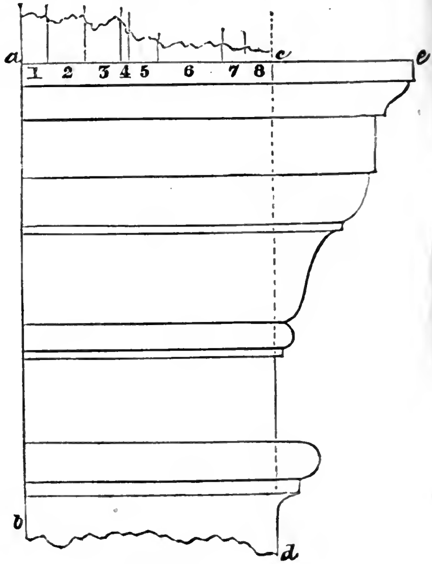


fig. 103.

EXAMPLE 101, fig. 103, is the Corinthian impost. The projections

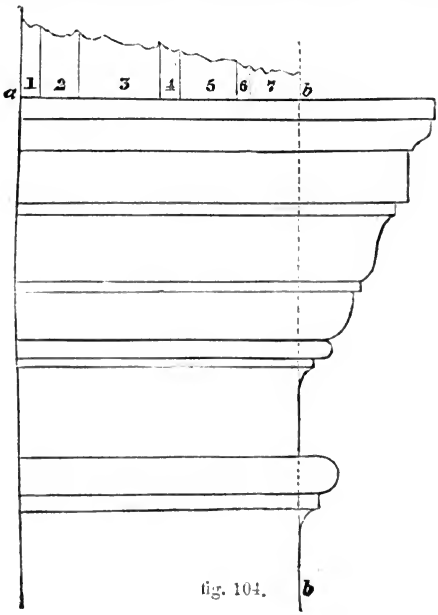


fig. 104.

being set out from the line *c d* towards *e*, the width of archivolt mouldings 1, 2, 3, &c., as *a c*, from *c* towards *a*.

EXAMPLE 102, fig. 104, is the Composite impost, the projections being set from the line *b b*. The scale from which the measurements should be taken is the same for all the imposts, being that in fig. 62.

EXAMPLE 103, fig. 105, shows a 'pediment.' C C, the tympanum, is generally filled in with sculpture. In our work on Practical Geometry, in

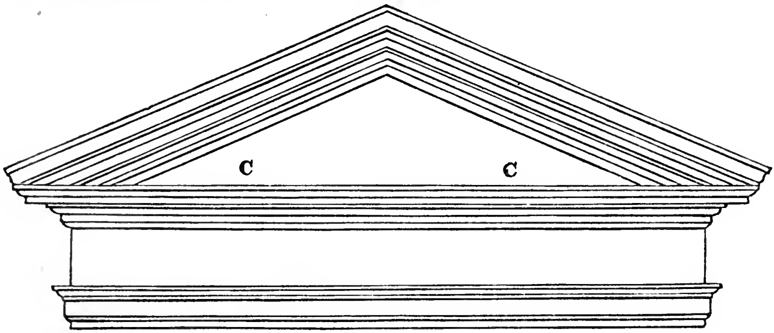


fig. 105.

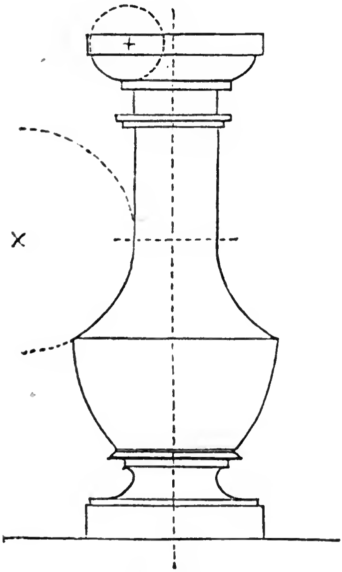


fig. 106.

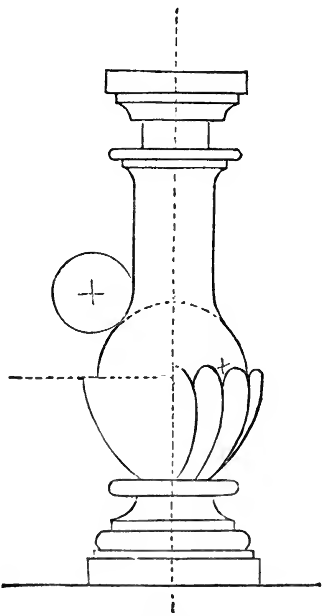


fig. 107.

the latter part, we have shown how geometry is made applicable to the construction of the various forms of arches, vases, and balustrades. We now give, in

EXAMPLE 104, fig. 106, an elevation of the Tuscan balustrade; and in

EXAMPLE 105, fig. 107, an elevation of the Ionic.

The reader desirous of becoming acquainted with the members of the Grecian orders of architecture, and of the principles which regulate the proportions of various architectural features, of which the limits and nature of the present work do not allow us to give even a passing notice, is referred to the work previously mentioned, treating of architectural and ornamental design.

We now purpose giving examples of various architectural forms and decorations, useful to impart to the pupil a correct general idea of the method of proportioning doors, windows, &c.; and also serving as copies by which he may test his proficiency, and enable him to acquire that facility so requisite for the architectural draughtsman to possess. We shall first give forms of windows and doors.

EXAMPLE 106, fig. 108, is the elevation of an ordinary sash-window, the method of laying out of which was explained in Example 4.

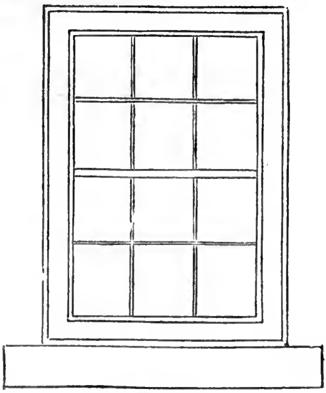


fig. 108.

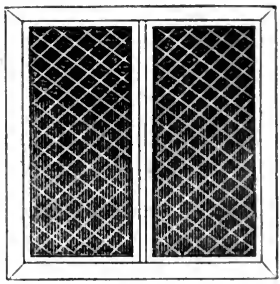


fig. 109.

EXAMPLE 107, fig. 109, is the elevation of a rustic window, with lozenge-shaped panes of glass. For the method of laying this out, see Example 5, fig. 5.

EXAMPLE 108, fig. 110, is an elevation of a three-light (Venetian) window, in the Italian style, drawn to a scale of one-fourth inch to the foot.

EXAMPLE 109, fig. 111, is a one-light window in the same style, to a scale of one-eighth inch to a foot.

EXAMPLE 110, fig. 112, is an elevation of a second-floor or bedroom

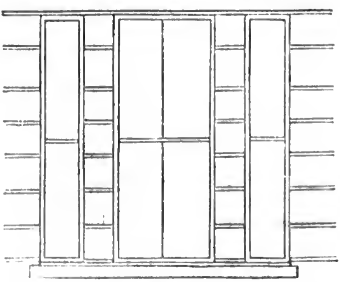


fig. 110.

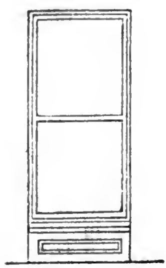


fig. 111.

window in same style, with iron ornamental balustrade in front. As a general rule, the proportion of windows should be, height twice the breadth

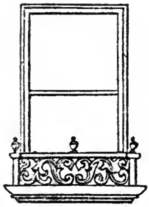


fig. 112.

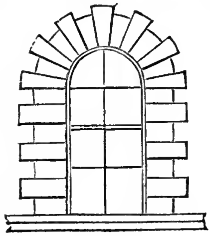


fig. 113.

for those on the ground-floor; those on the second floor the same breadth, but of less height.

EXAMPLE 111, fig. 113, is an example of a circular-headed window, with rusticated dressings.

EXAMPLE 112, fig. 114, is the front elevation of a projecting window, of which the side elevation is given to a scale of one-quarter inch to a foot, in

EXAMPLE 113, fig. 115, which is of the same scale as the above.

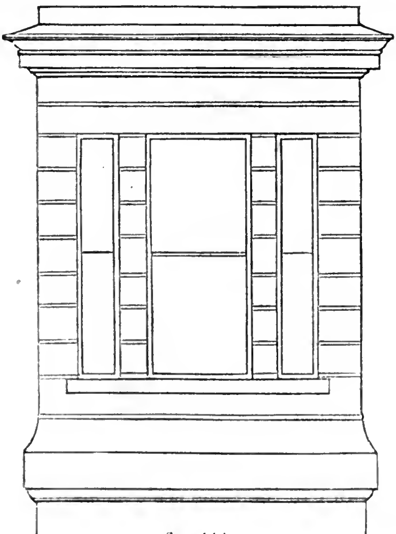


fig. 114.

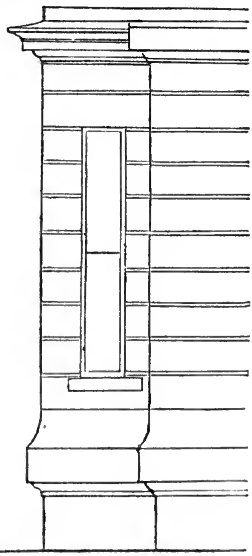


fig. 115.

We shall now give examples of windows placed over windows.

EXAMPLE 114, fig. 116, is the front elevation of a bay-window in the light Italian style, the plan of which shows the three sides of an octagon, with the bedroom-window over it; the scale is one-fourth of an inch to the foot. The side elevation of the bay-window is shown in

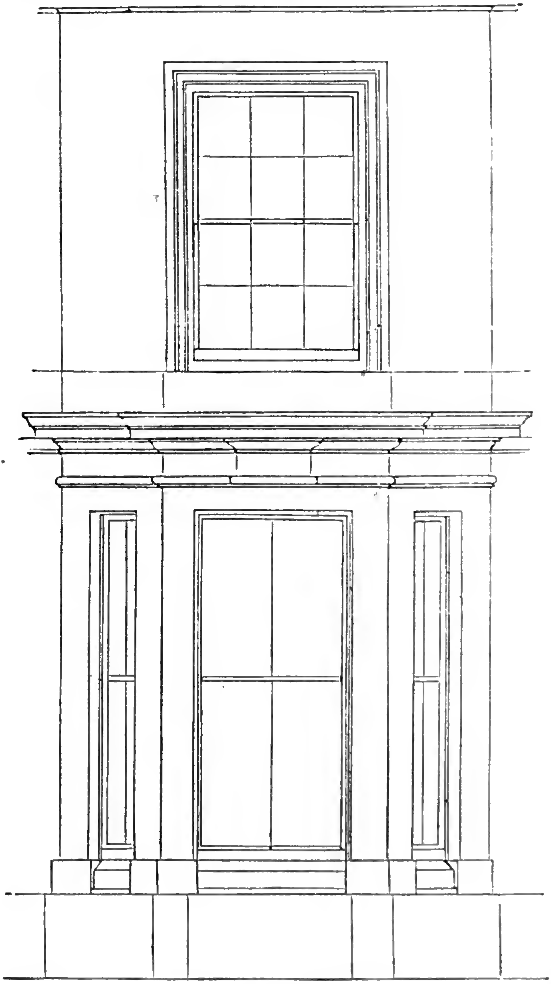


fig. 116.

EXAMPLE 115, fig. 117, which is drawn to the same scale as above.

EXAMPLE 116, fig. 118, is the elevation of a bay-window on the ground-floor, in the Domestic Gothic style, with bedroom-window over it. The scale is one-eighth of an inch to the foot.

EXAMPLE 117, fig. 119, is another sketch, showing elevation of bay-window in Italian style, with bedroom-window over; same scale as above.

EXAMPLE 118, fig. 120, shows the elevation of window over window in the Tudor style; scale three-sixteenths of an inch to the foot.

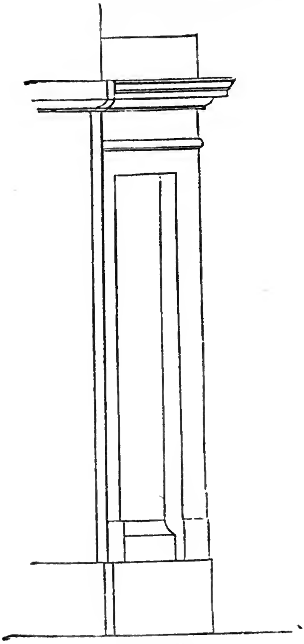


fig. 117.

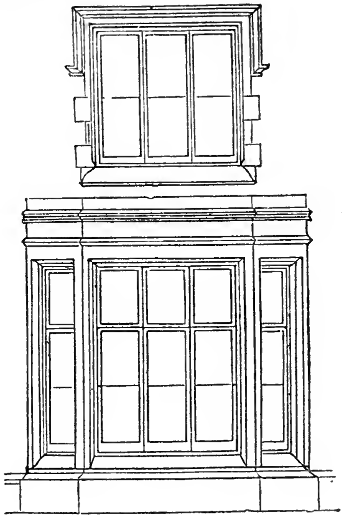


fig. 118.

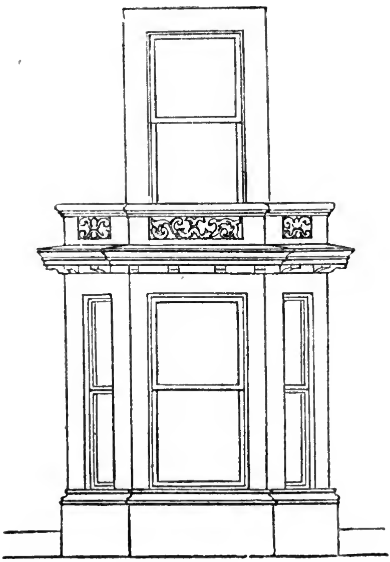


fig. 119.

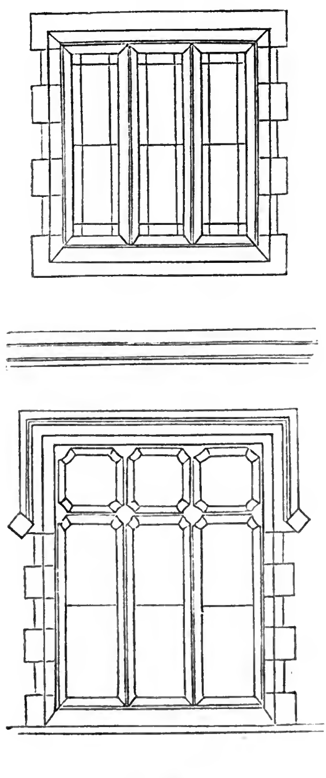


fig. 120.

EXAMPLE 119, fig. 121, is the front elevation of a bay-window on ground-floor, with projecting or oriel window over it on bedroom-floor, in the Elizabethan or Jacobin style, drawn to a scale of one-eighth inch to a foot. The side elevation of this drawing is shown in

EXAMPLE 120, fig. 122, same scale as above.

EXAMPLE 121, fig. 123, is a sketch, showing front elevation of Venetian or three-light window on ground-floor in Italian style, with bedroom-window over, with ornamental dressings and segmental pediment.

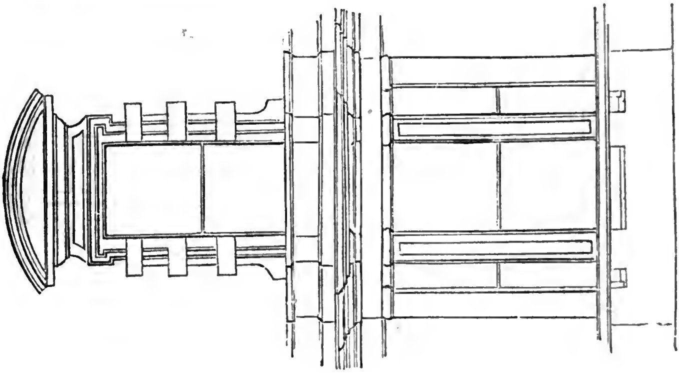


fig. 123.

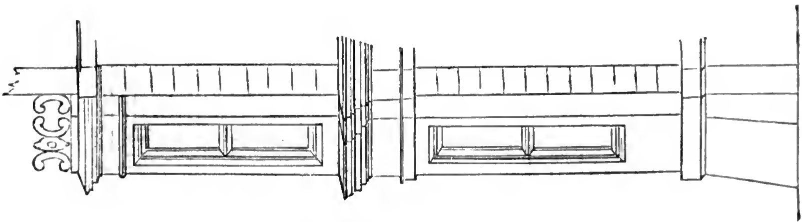


fig. 122.

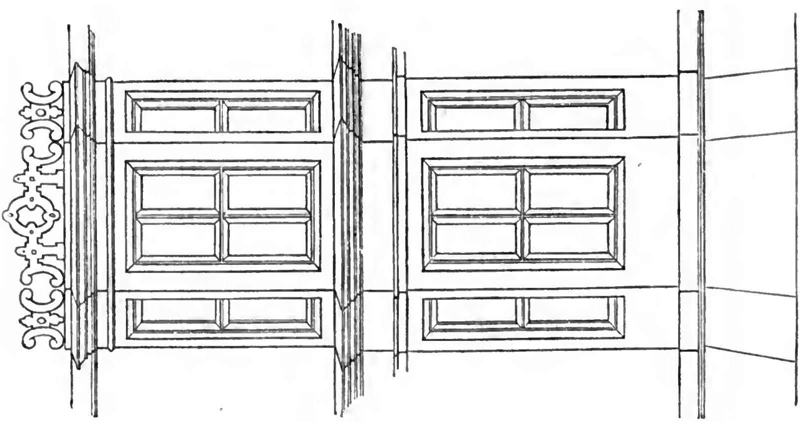


fig. 121.

We now proceed to give examples of doors, and windows over doors. First, as to doors, of which, in

EXAMPLE 122, fig. 124, we give the elevation of one in the Roman style.

EXAMPLE 123, fig. 125, is the front elevation of another form in the Italian style.

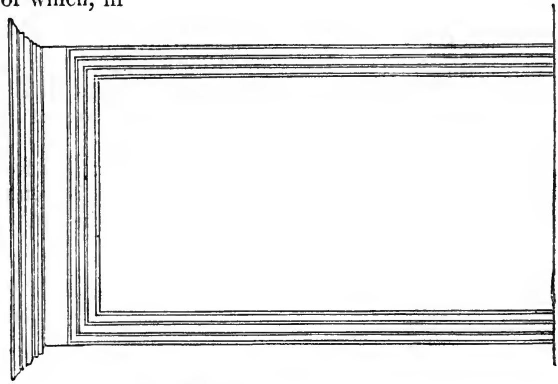


fig. 124.

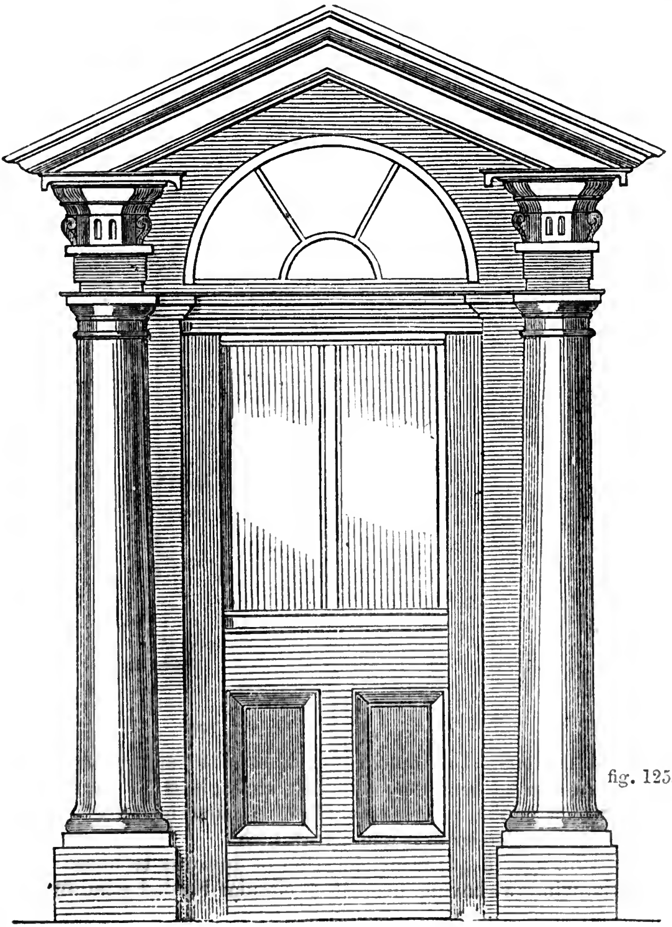


fig. 125.

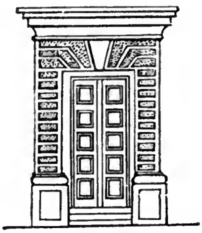


fig. 126.

Example 124, fig. 126, is the elevation of a form suitable for a public building, with vermiculated dressings. Another form is given in

Example 125, fig. 127.

Example 126, fig. 128, is front elevation of door, with vermiculated dressings, in the Italian style (of which fig. 111 is the window belonging to same design), with circular-headed window over it. The scale is one-quarter inch to the foot.

Example 127, fig. 129, is front elevation of door, to the house of which fig. 114 is the principal window. The scale is one-quarter inch.

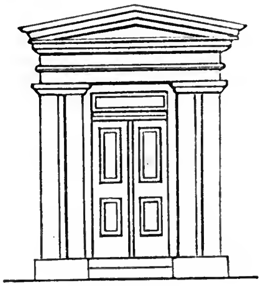


fig. 127.

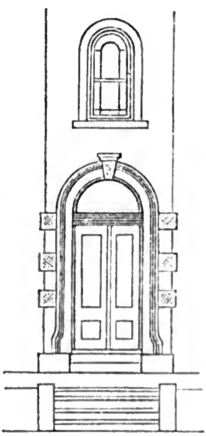


fig. 128.

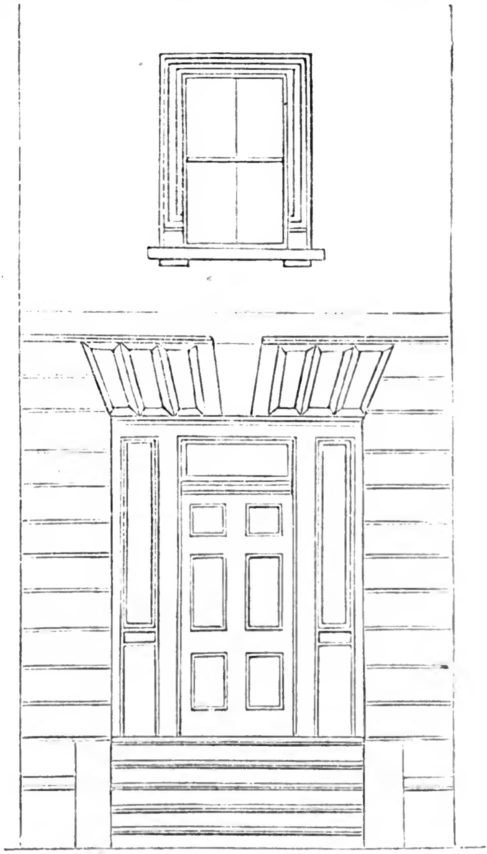


fig. 129.

Example 128, fig. 130, is front elevation of door at the end of house, with window on second floor over it. This example is in the same style as fig. 123, which is the principal window to same house of which this figure is the door. The scale is one-eighth inch.

Example 129, fig. 131, is front elevation of doorway to house of which fig. 116 is the window, having over it a circular-headed window in bedroom-floor. The scale is one-quarter inch. The side elevation of the door in this drawing is given in

EXAMPLE 130, fig. 132, the scale of which is the same as above.

EXAMPLE 131, fig. 133, is front elevation of principal door to a house, with bed-room-window over it, with ornamented dressings. Scale one-eighth inch.

The central portion of house (of which figs. 123 *and* 130 *are parts of the same design).*

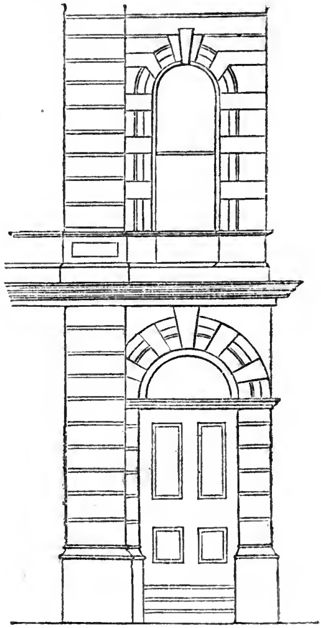


fig. 130.

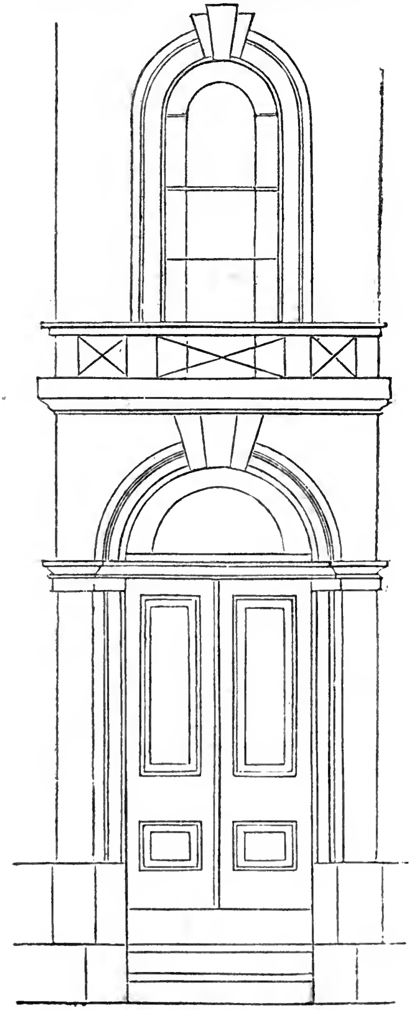


fig. 131.

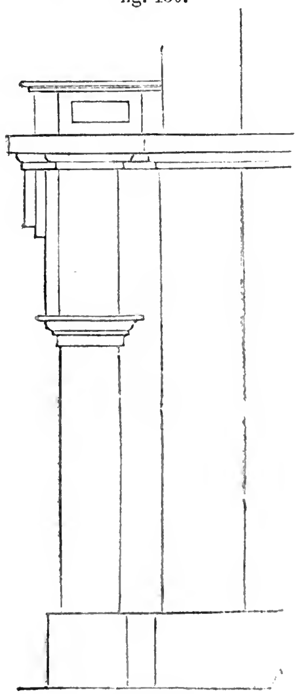


fig. 132.

EXAMPLE 132, fig. 134, is front elevation of principal door to house, in Domestic Gothic style (of which the drawing in fig. 118 is the window), with closet-window over it on bedroom-floor.

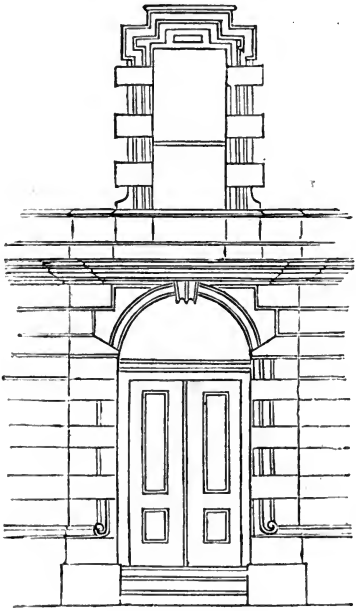


fig. 133.

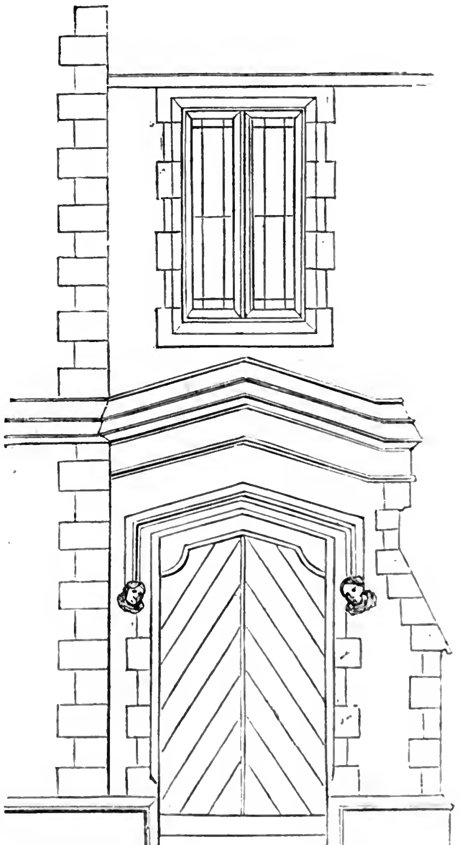


fig. 135.

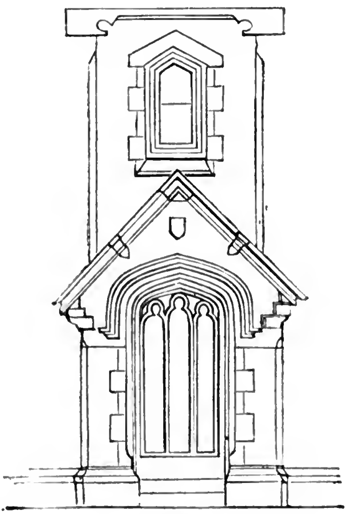


fig. 134.

EXAMPLE 133, fig. 135, is elevation of principal entrance to house, in Tudor style, of which the drawing in fig. 120 is the window.

EXAMPLE 134, fig. 136, is elevation of principal entrance, with window over it, of house of which fig. 121 is the window.

We now give the elevations of a few examples of fireplaces, the first of which is in the Tudor style, and is shown in

EXAMPLE 135, fig. 137. The part *c* shows the profile of the mouldings. Another form, in same style, is given in

EXAMPLE 136, fig. 138.

EXAMPLE 137, fig. 139, is in the Italian style; A shows the profile of

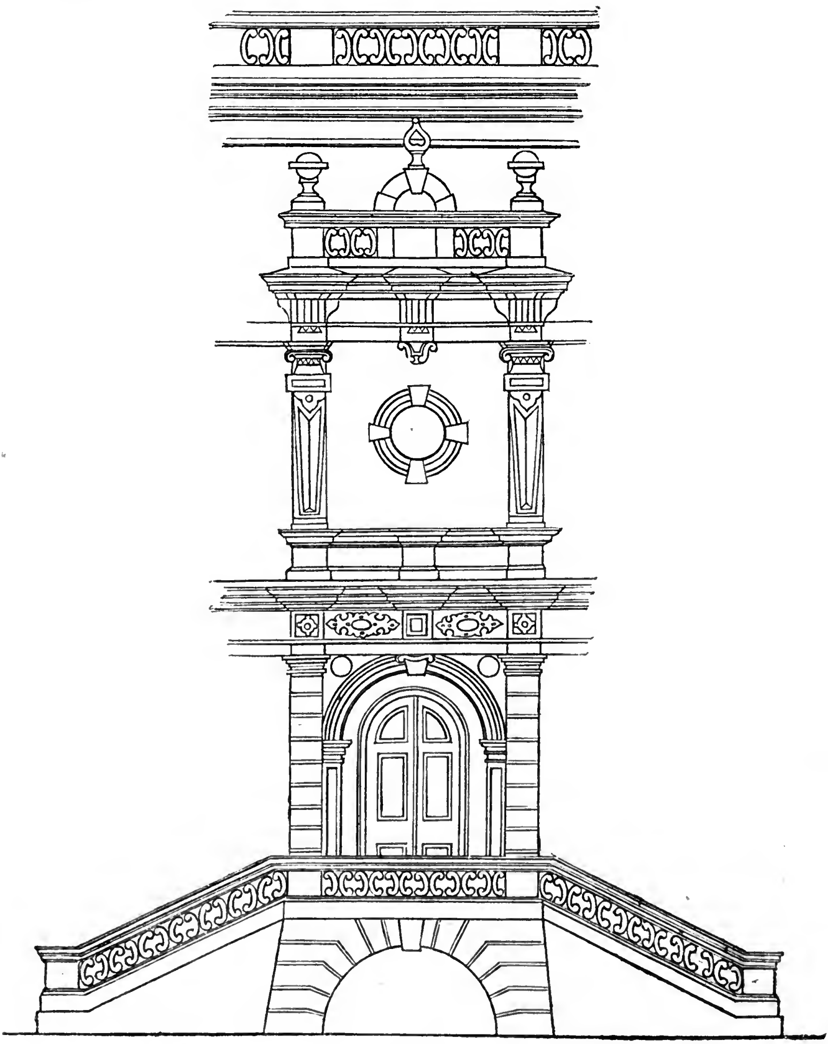


fig. 136.

the skirting-board running round the room, of which the lines at B show the front elevation.

EXAMPLE 138, fig. 140, is in the Elizabethan style. In these examples

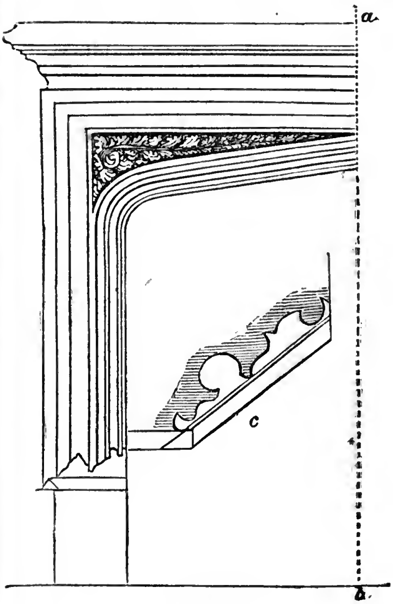


fig. 137.

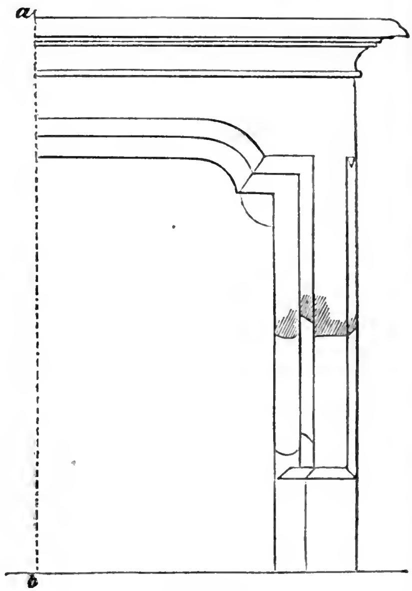


fig. 138.

of fireplaces, we have only shown half, the other being an exact counterpart. The pupil should, however, draw them complete, the line $a\ b$ being the centre-line.

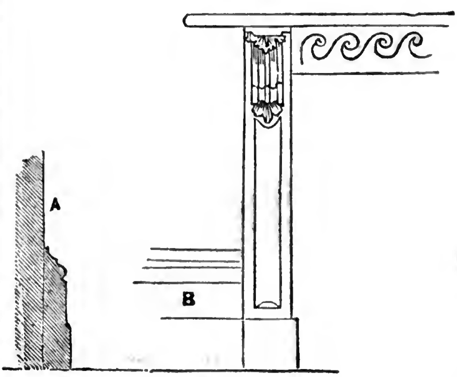


fig. 139.

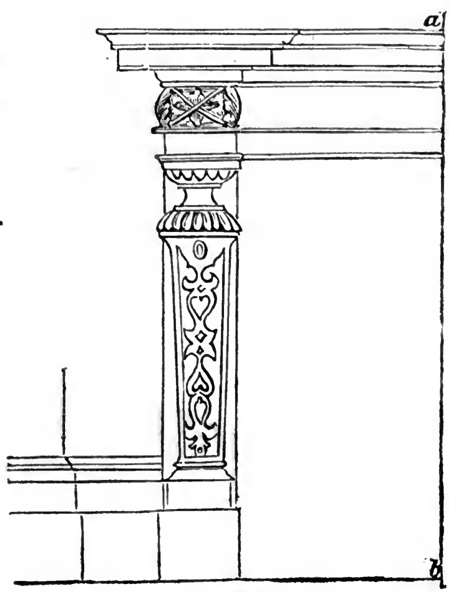


fig. 140.

We now proceed to the more elaborate copies, in which the pupil will find ample exercise for the display of that facility for copying which the foregoing lessons have been designed to impart. From the limits of the page we have been compelled to adopt a small scale; it is to be understood, however, that the pupil is to copy them to a larger one, at least twice as large as those we have adopted.

EXAMPLE 139, fig. 141, is the front elevation of a school-house, with railings to the front. Another design is given in

EXAMPLE 140, fig. 142.

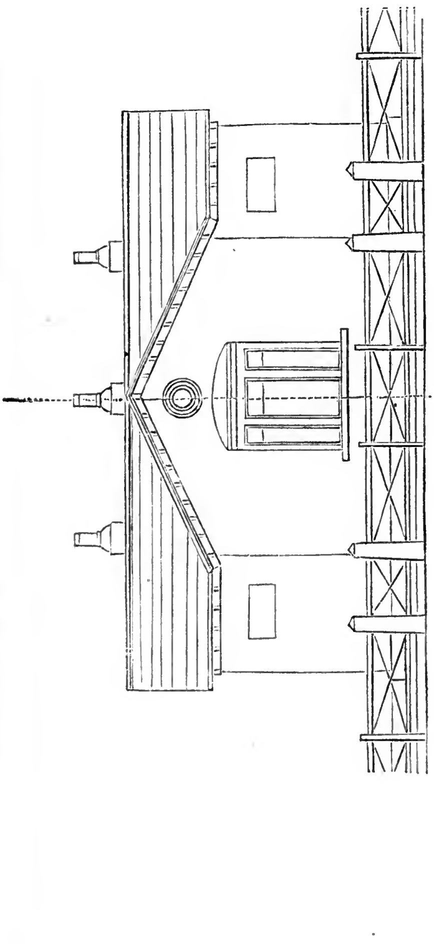
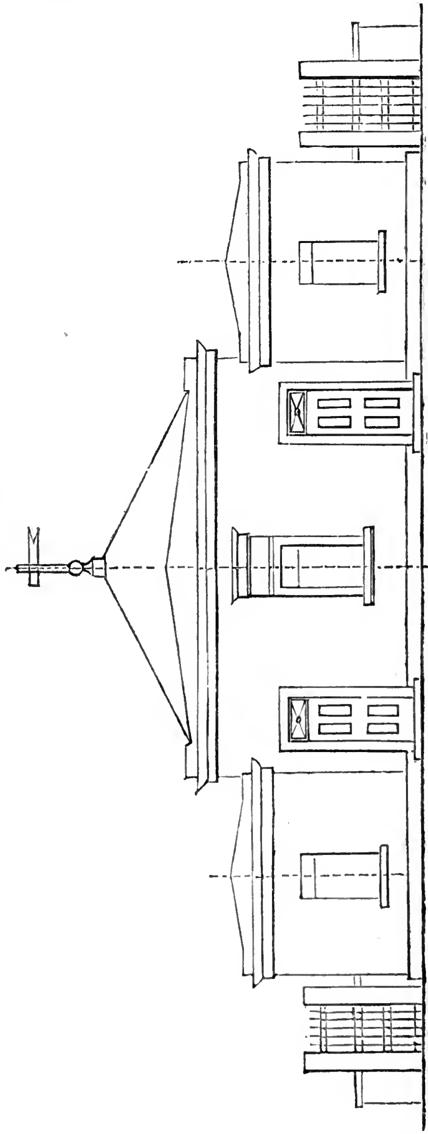


fig. 141.



EXAMPLE 141, fig. 143, is the front elevation of a row of cottages, drawn to a scale of one-eighth inch to the foot.

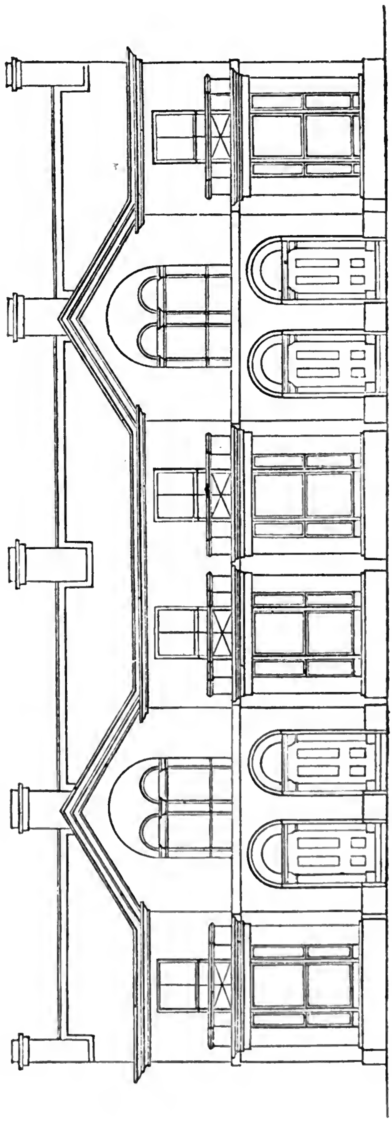


fig. 143.

EXAMPLE 142, fig. 144, is the front elevation of a shop-front, drawn to a scale of one-eighth inch to the foot.

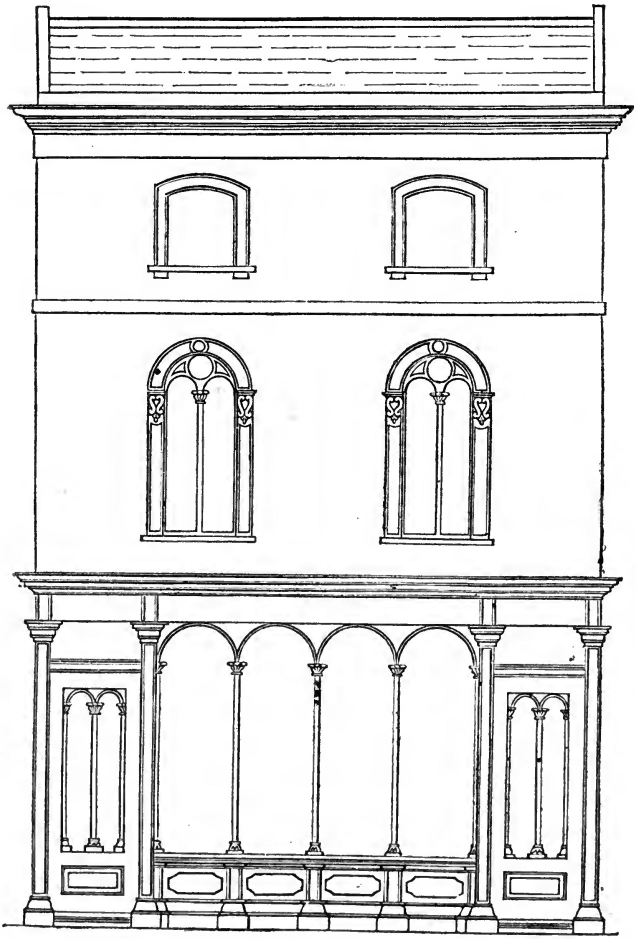


fig. 144.

EXAMPLE 143, fig. 145, is front elevation of a greenhouse, of which the end elevation is given in

EXAMPLE 144, fig. 146, and the plan in

EXAMPLE 145, fig. 147; they are all drawn to a scale of one-sixteenth inch to the foot.

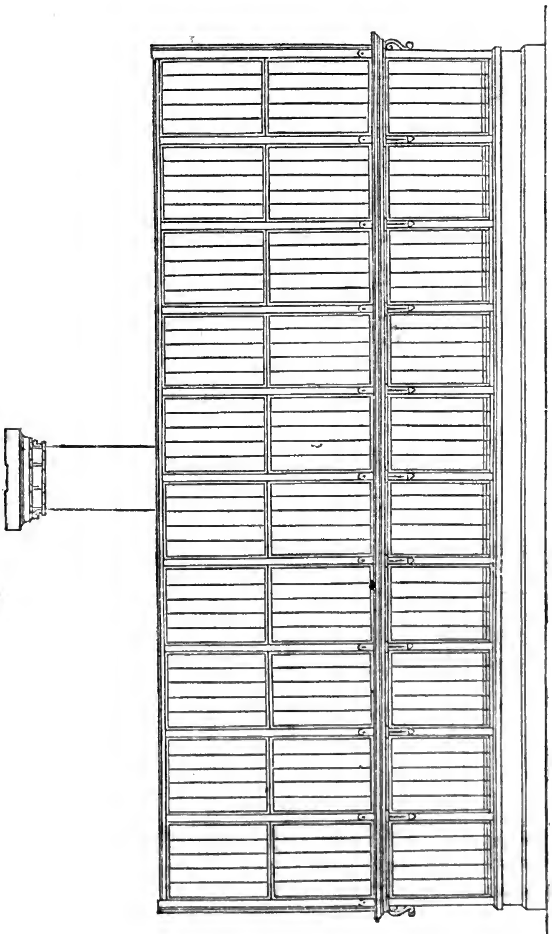


fig. 145.

In order to give the pupil an idea as to the way in which a set of plans are set out for the guidance of the artisan and workman, we have prepared a series of drawings illustrative of the design for a town-house in the Italian style. It is necessary to mention that the design when finished is double that given in the drawings; two houses being attached, the other half of the drawing (not shown) is the exact counterpart of that given in the copy. The scale we have adopted is one-eighth inch to the foot. The pupil, in copying them, should make the scale at least double this, or one-fourth inch to the foot.

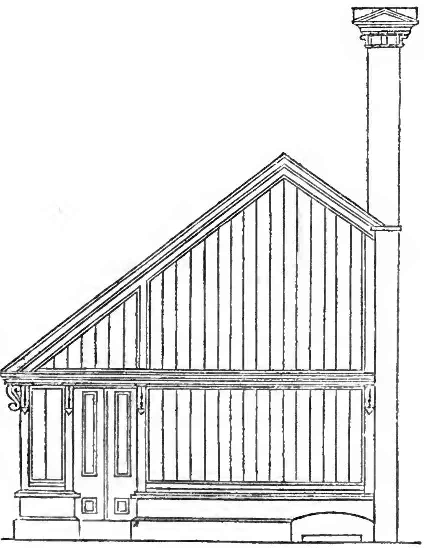


fig. 146.

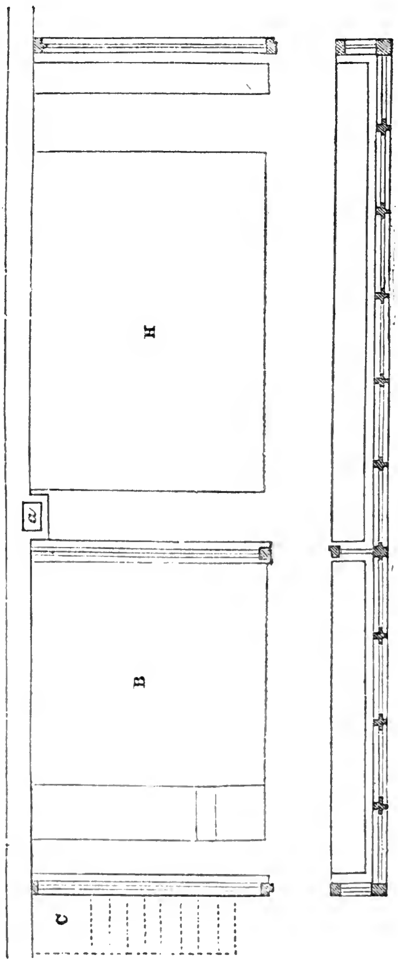


fig. 147.

Example 146, fig. 148, is the "*basement plan*" of the house; the line *a b* is the centre-line.

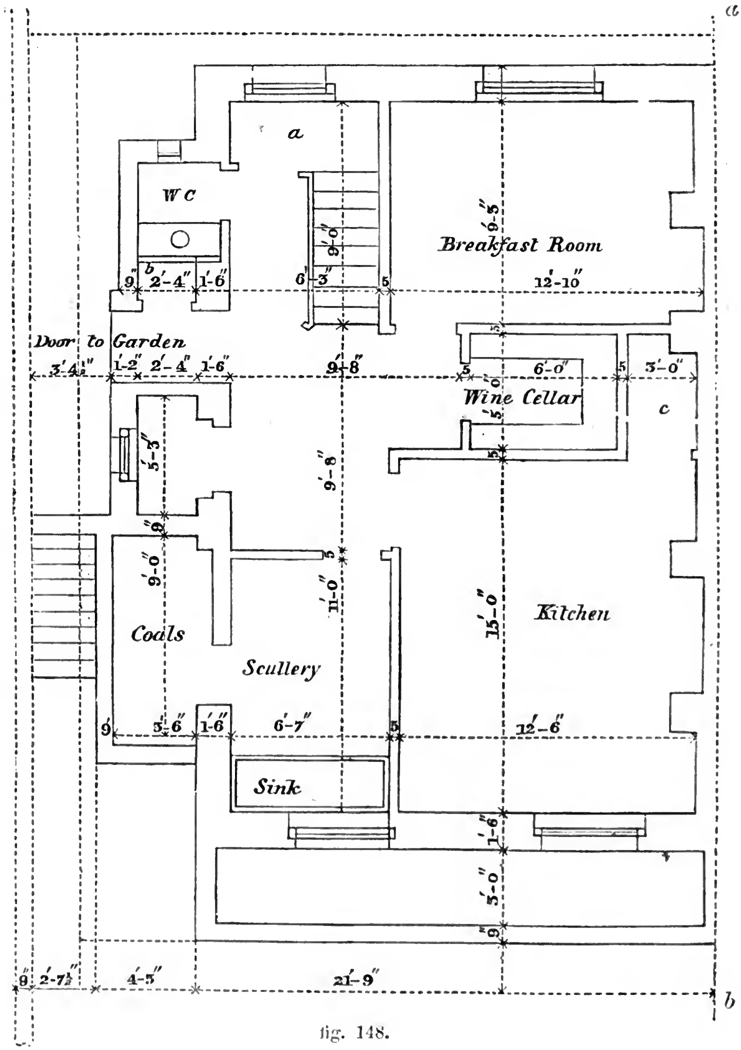


fig. 148.

EXAMPLE 147, fig. 149, is the "*ground plan.*"

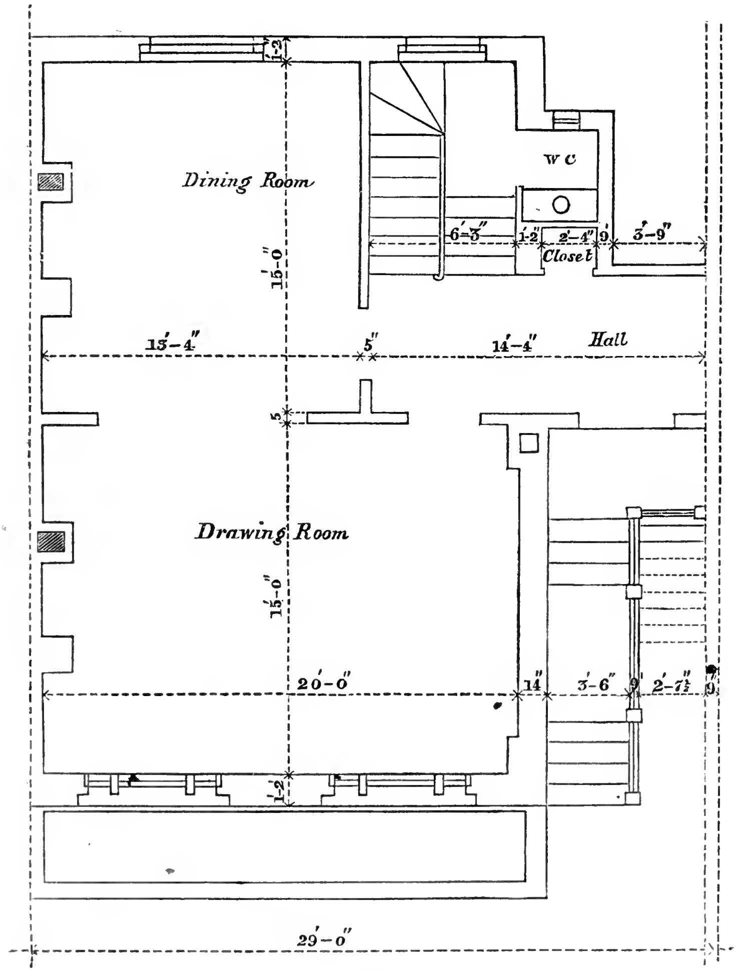


fig. 149.

Example 148, fig. 150, is half plan of *first bedroom floor.*

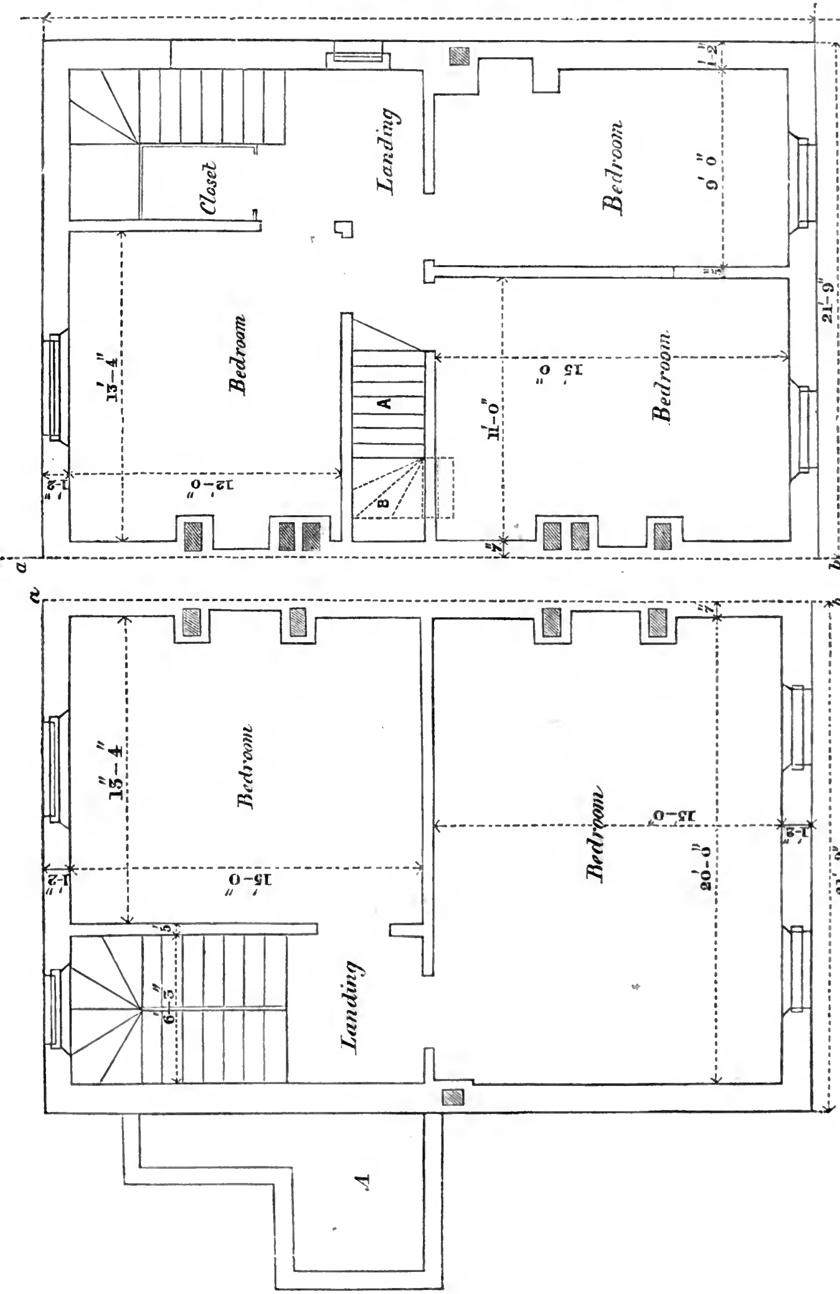


fig. 151.

fig. 150.

EXAMPLE 149, fig. 151, is the half plan of *second bedroom floor.*

EXAMPLE 150, fig. 152, is half *front elevation.* From the minuteness of the scale we give detail drawings, which will show the decorative portions more fully than in the sketch. The first of these we give is the elevation

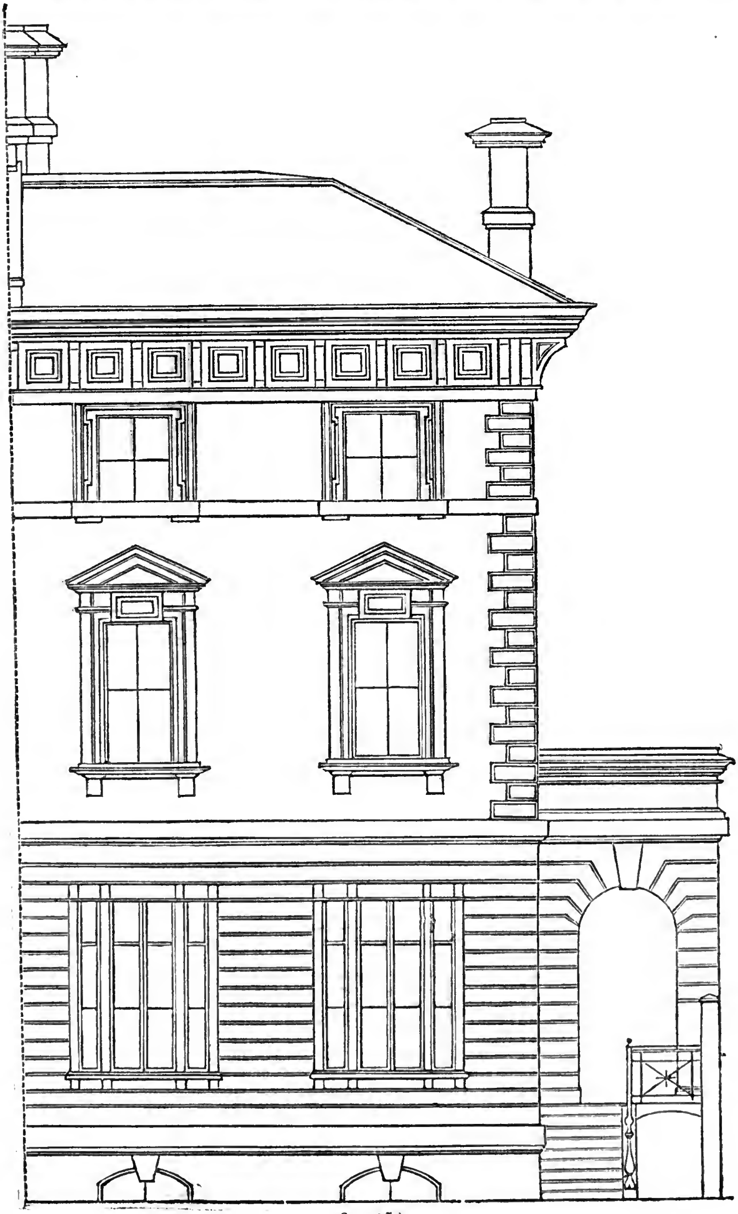


fig. 152.

of the first bedroom-floor window, and its section drawn to a larger scale; it is shown in

EXAMPLE 151, fig. 153. The front elevation of cornice is given in EXAMPLE 152, fig. 154; and the section showing form of bracket in

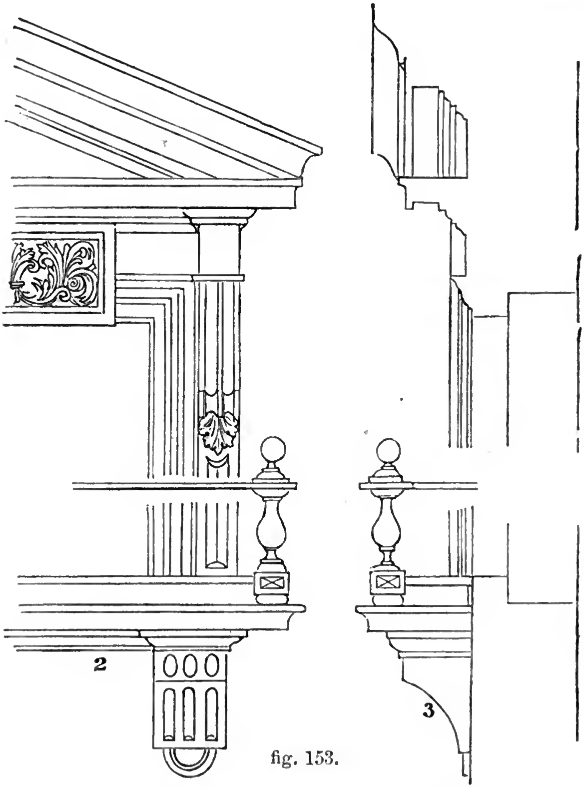


fig. 153.

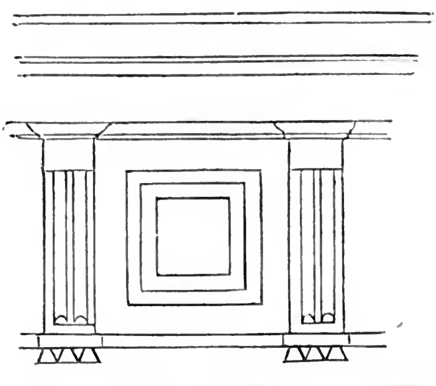


fig. 154.

EXAMPLE 153, fig. 155. The elevation of chimney is shown in
EXAMPLE 154, fig. 156, and the elevation of cornice and finial to principal entrance is given in
EXAMPLE 155, fig. 157.

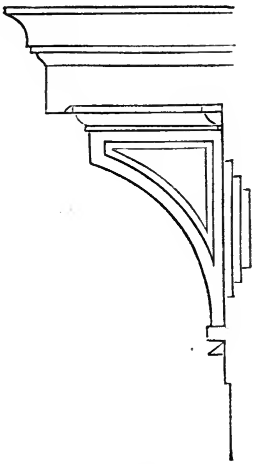


fig. 155.

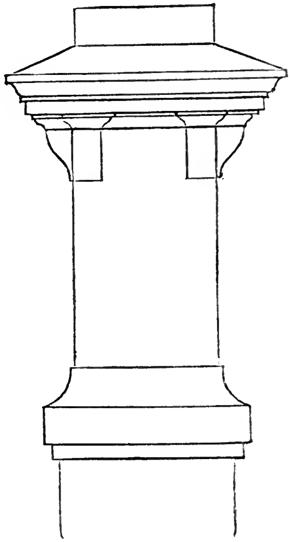


fig. 156.

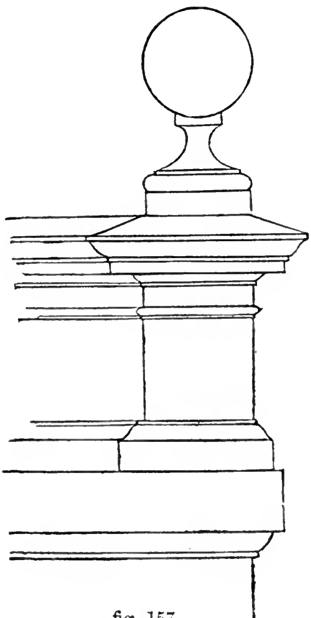


fig. 157.

Example 156, fig. 158, is *end elevation.* We give this in full, as one side is different from the other. The *half back elevation* is given in

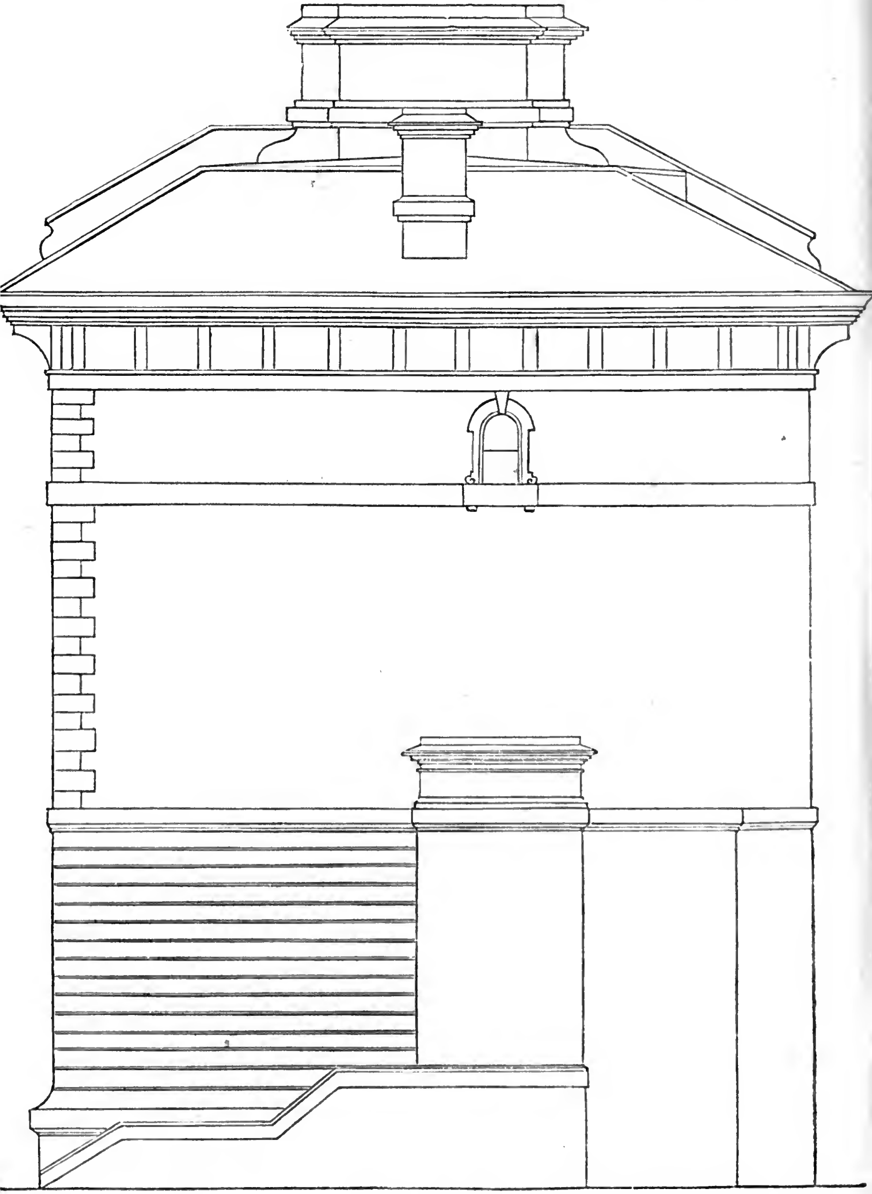


fig. 158.

EXAMPLE 157, fig. 159. The *transverse section* is taken across the *plan*. The right-hand half of this is given in

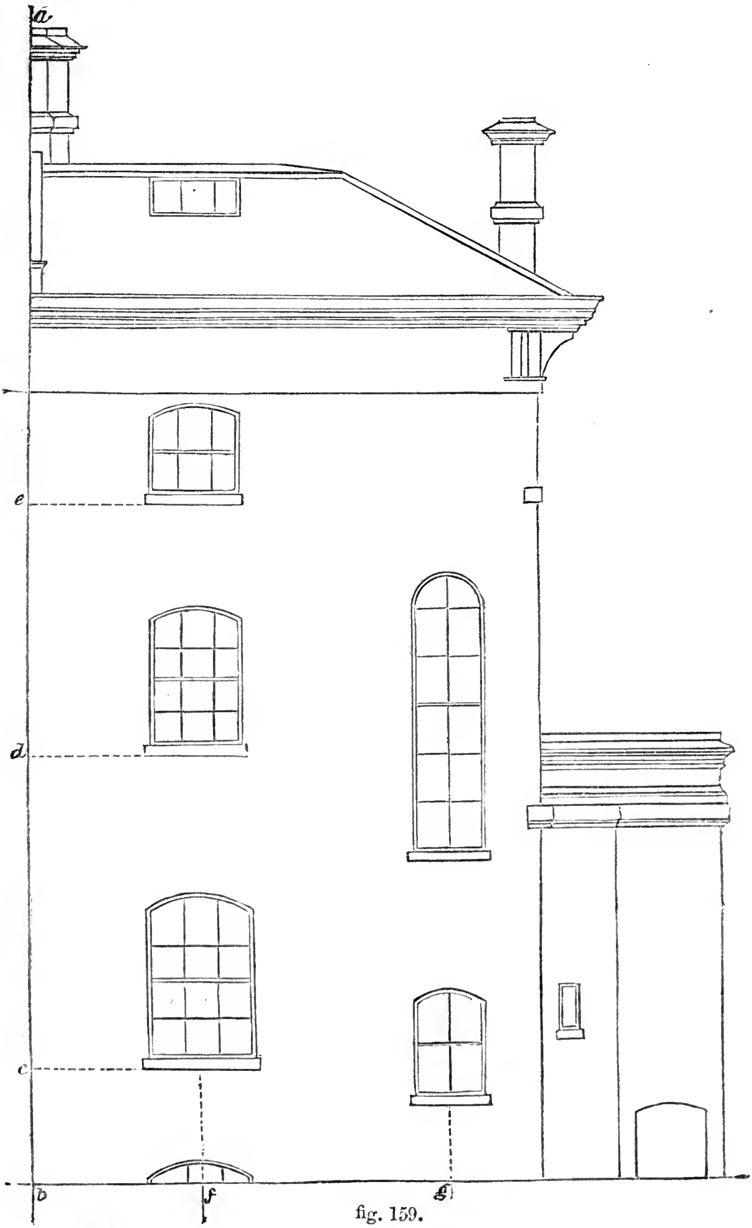
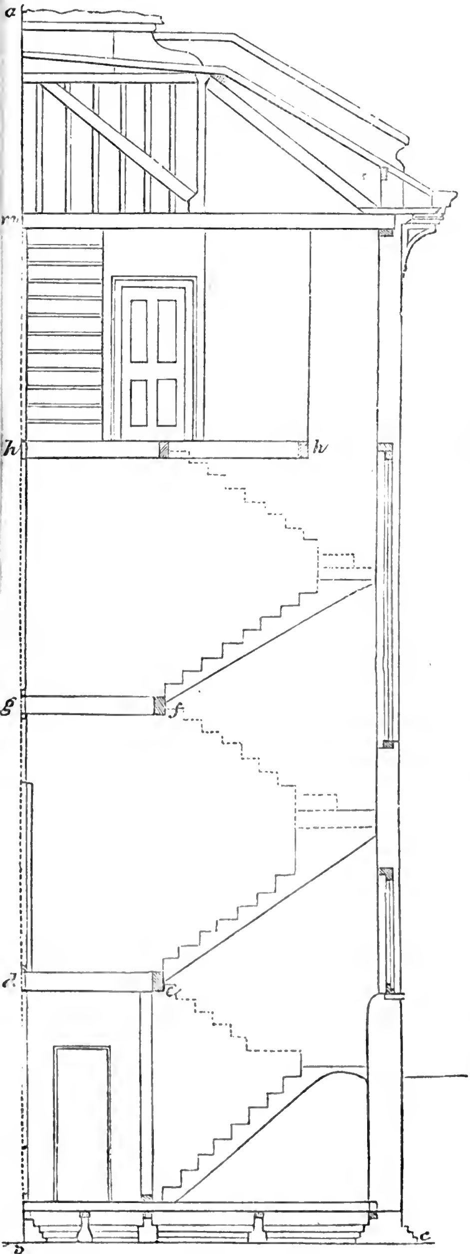


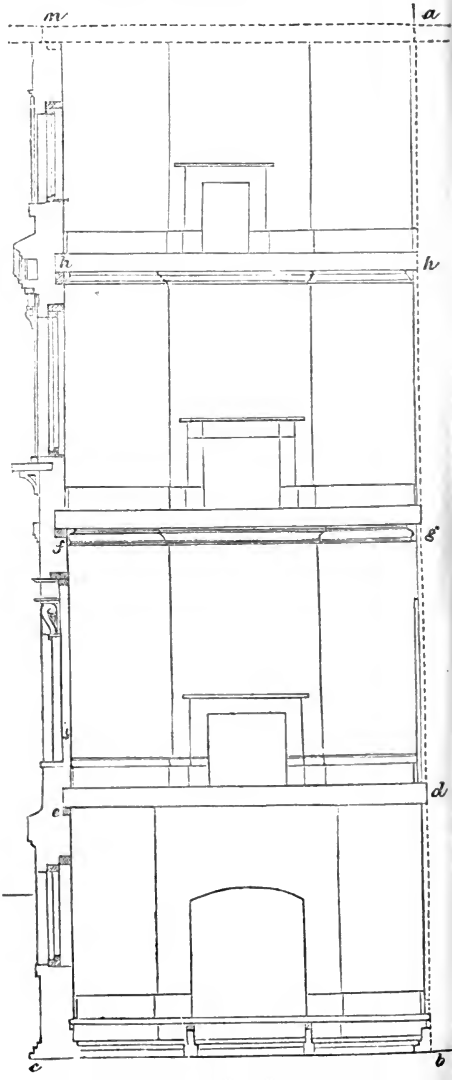
fig. 159.

F

Example 158, fig. 160; the left-hand half in

Example 159, fig. 161. The same letters of reference apply to both drawings. The pupil should make this section in one complete drawing. We have only shown one part up to the roof-line, the other without the chimney-shaft, but showing the roof-timbers. The pupil should be able to finish these sections from the other drawings.





Example 160, fig. 162, is half plan of roof, showing timbers. The other half, showing the slated surface, and position of flues, is given in

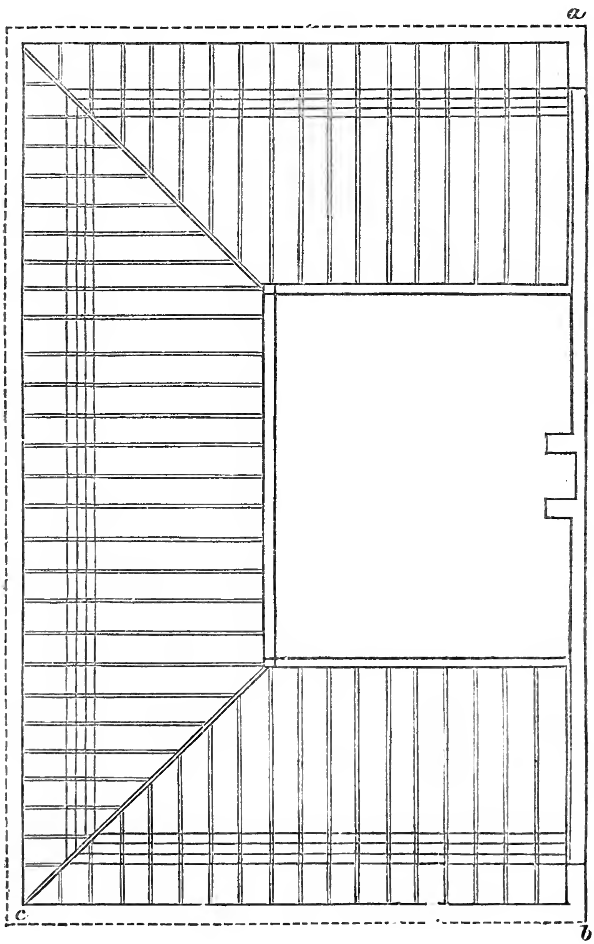


fig. 162.

EXAMPLE 161, fig. 163. In setting out this, the pupil may copy it, by drawing the line *a b*, and continuing it to *c;* measuring from *d* to *c* will give the position of the end *a b* of the flue. From *d* to *f* the position of the point *e*, *g h*, the distance of line *e g n* from line *d h*.

EXAMPLE 162, fig. 164, is a transverse section of a fireproof vaulted warehouse, where *a*, *a* are the retaining walls, a strong iron tie passing

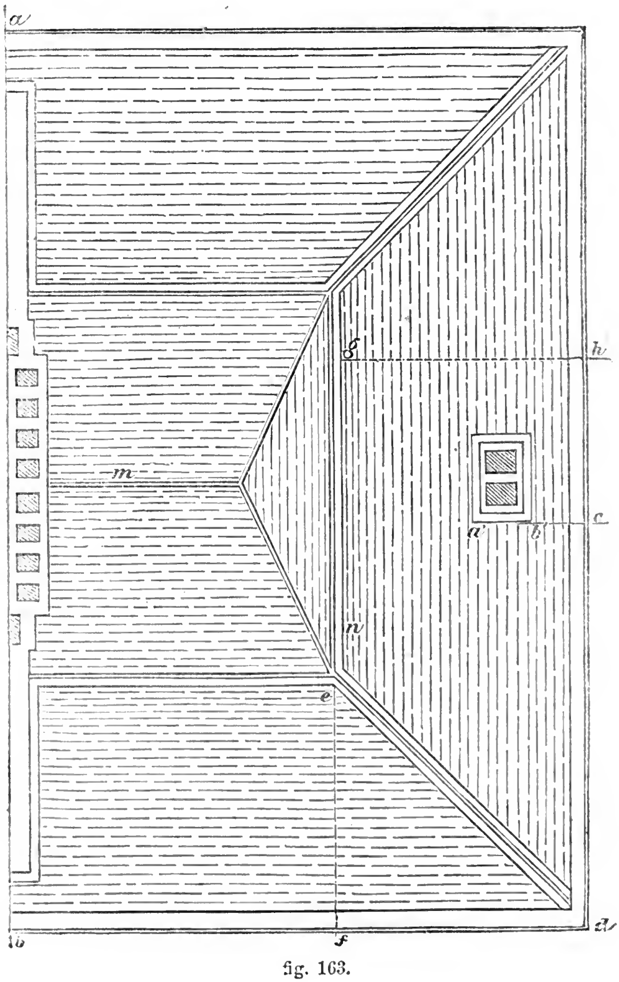


fig. 163.

through both, and secured by a screw bolt, and nut. The arches *m*, *m* are described from their centres *g*, *g* on the lines *h*, *h*, springing from the pillars *c*, *d*; the arch *n* is described from centre *i*.

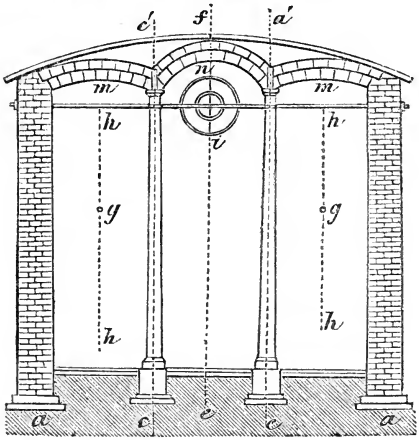


fig. 164.

EXAMPLE 163, fig. 165, is a transverse section of a fireproof cottage.

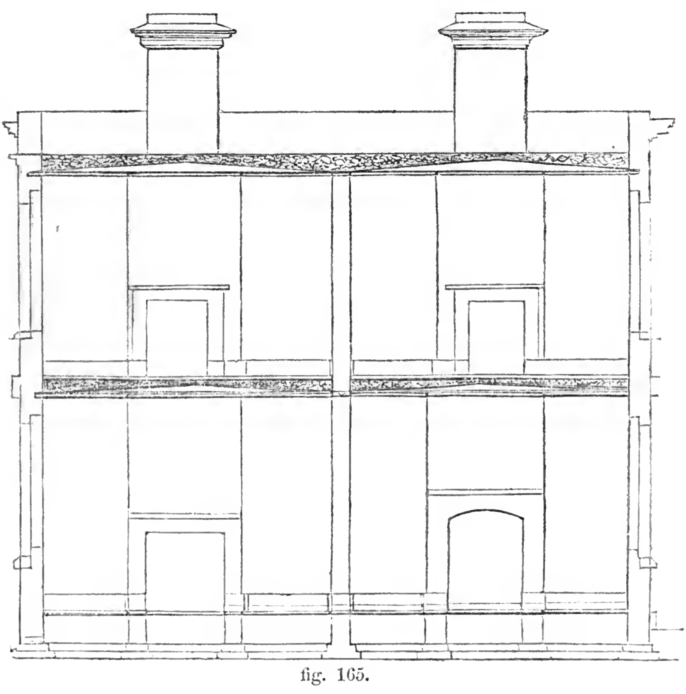


fig. 165.

In our work in the present series, the *Illustrated Drawing-Book*, we have given directions for delineating architectural subjects perspectively. We now present a few additional examples, which will serve as copies with which the pupil may still further exercise himself in architectural drawing; premising that in this department he is supposed to have the advantage of a knowledge of the rules by which objects are put in perspective, and a facility in copying such subjects as depend chiefly on the eye, aided by a readiness of hand in pencilling. These desiderata are indispensable before the pupil can copy the examples which we are now to present to his notice; for assistance as to the readiest means of attaining them, we beg to refer the pupil to the above work.

EXAMPLE 164, fig. 166, is the perspective drawing of a public asylum, in the Italian style, with a campanile tower.

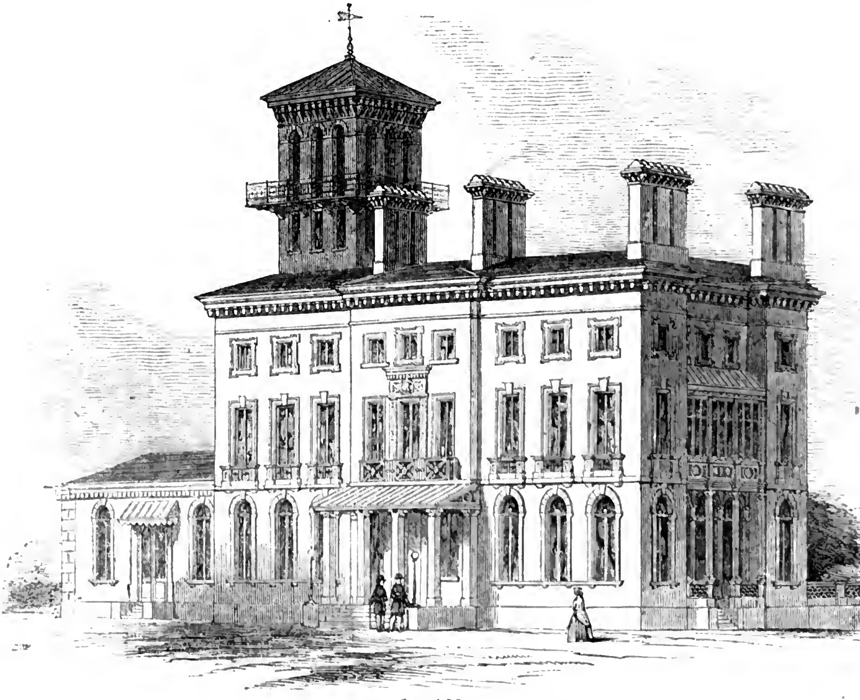


fig. 166.

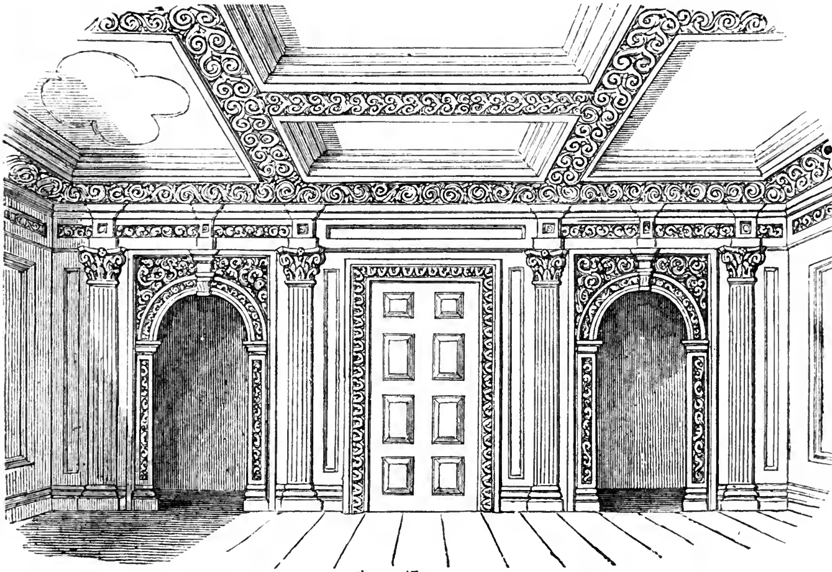


fig. 167.

fig. 168.

EXAMPLE 165, fig. 167, is a perspective sketch of the interior of an apartment, with carved panels, &c., in the Italian style.

We now present a few examples of churches perspectively delineated; the first of these,

EXAMPLE 166, fig. 168, is a perspective drawing of a church in the Early-English style.

fig. 169.

EXAMPLE 167, fig. 169, which is in the Early-Decorated or Pure Geometrical style. The peculiarities of the various styles of Gothic architecture will be seen by an inspection of figs. 202, 203, &c.

EXAMPLE 168, fig. 170, is in the Transitional from Decorated to Perpendicular.

EXAMPLE 169, fig. 171, is in the Middle or Second Pointed Period.

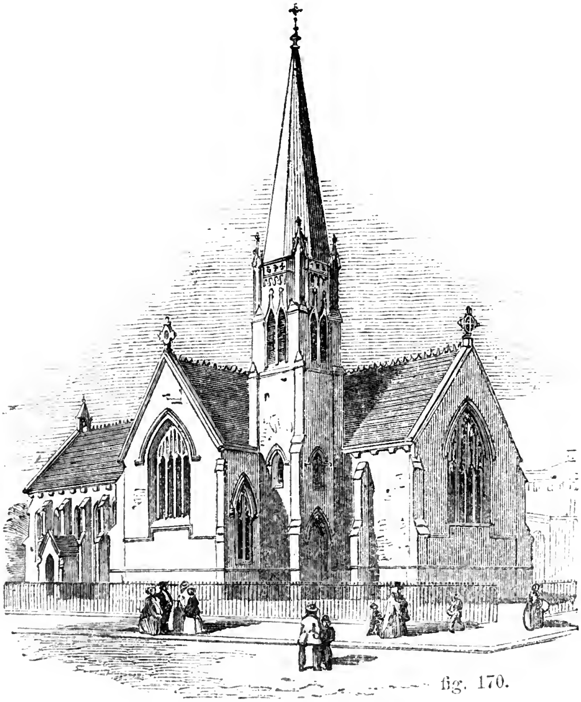


fig. 170.

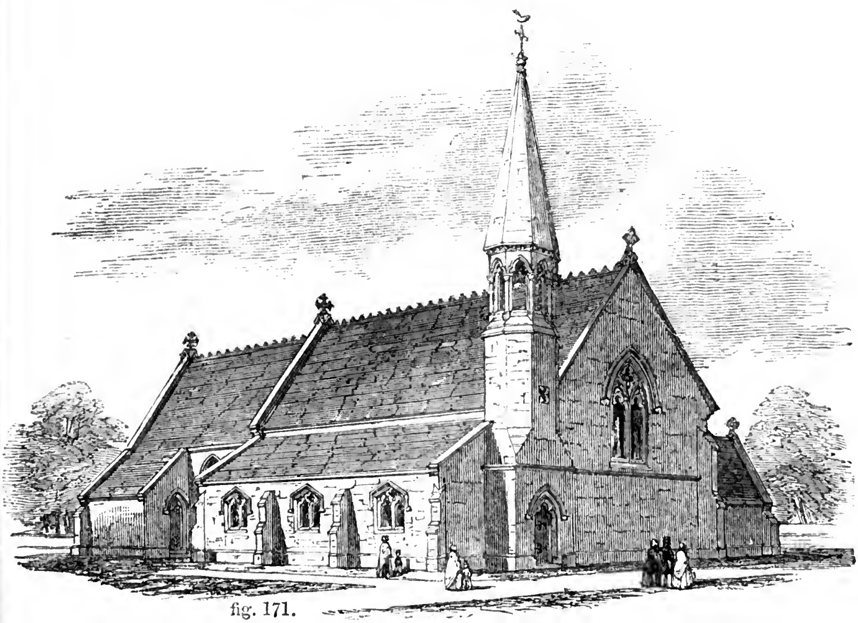


fig. 171.

EXAMPLE 170, fig. 172, is in the Early-Decorated style.

fig. 172.

EXAMPLE 171, fig. 173, is in the Early-English style.

fig. 173.

Example 172, fig. 174, represents in perspective the interior of part of a church (the nave) in the Norman style. This is considered to be a fine specimen of the architecture of the period.

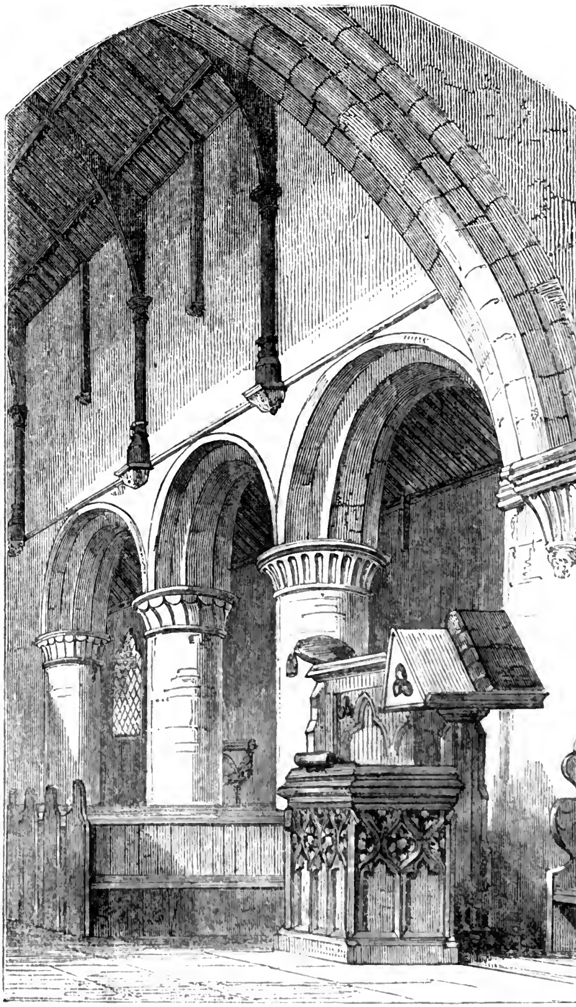


fig. 174.

EXAMPLE 173, fig. 175, represents the interior of the Lady chapel in Tynemouth Priory church; the architectural features of which belong somewhat both to the Decorated and Perpendicular styles.

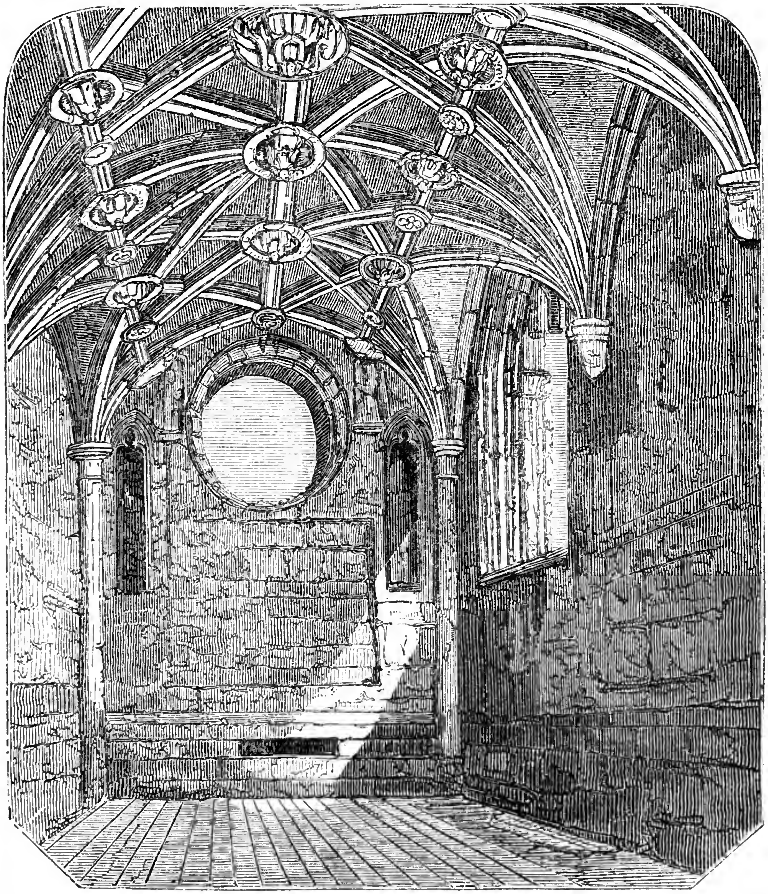


fig. 175.

We now proceed to give a few illustrations of architectural ornament; the drawings of which are nearly in all the instances produced by hand, only here and there aided by the drawing-board and instruments. A knowledge of pencil-sketching is therefore necessary for these examples.

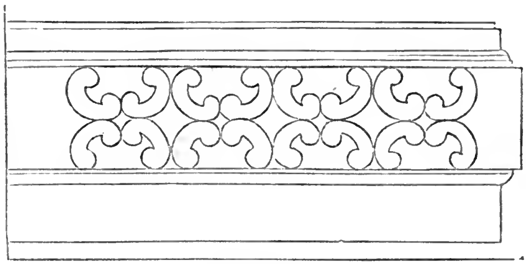


fig. 177.

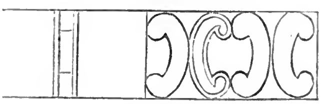


fig. 176.

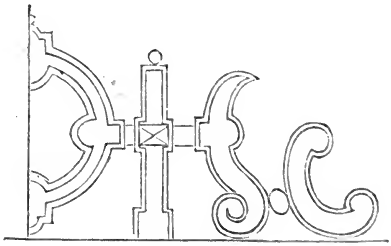


fig. 178.

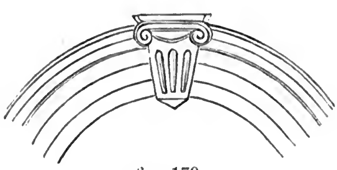


fig. 179.

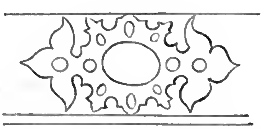


fig. 180.

Example 174, fig. 176, is the elevation and end view of a pierced parapet in the Elizabethan style.

Example 175, fig. 177, is a side elevation of panelling, in the same style as the last figure.

Example 176, fig. 178, is another example of a pierced parapet, in the same style as in fig 177.

Example 177, fig. 179, is the front elevation of a key-stone.

Example 178, fig. 180, is another example of raised panel, in the same style as fig. 177.

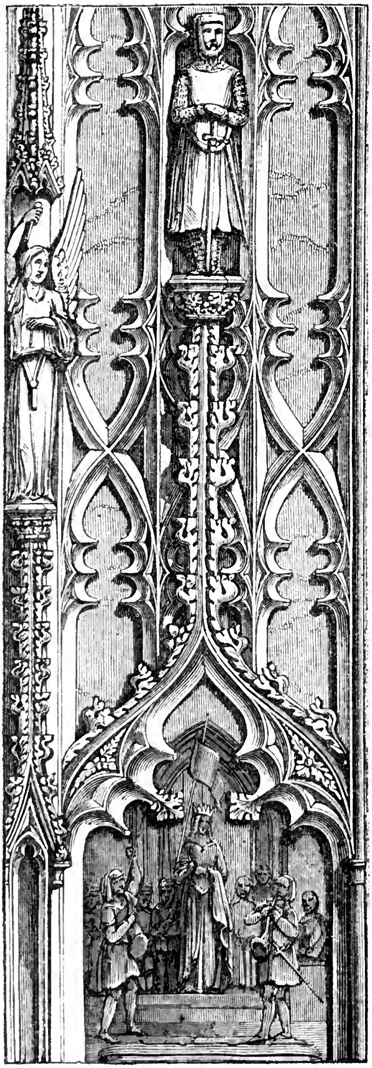


fig. 181.

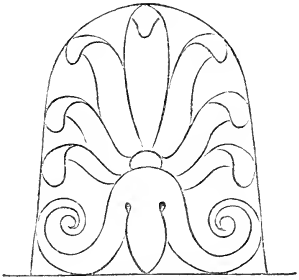


fig. 182.

fig. 183.

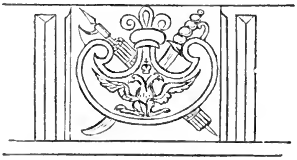


fig. 184.

EXAMPLE 179, fig. 181, is a design for a Gothic panel.

EXAMPLE 180, fig. 182, is the Grecian ornament known as the "honeysuckle."

EXAMPLE 181, fig. 183, is part of an ornamented frieze for the Ionic column.

EXAMPLE 182, fig. 184, is an ornament sometimes used in filling up the space called "metopes" in the Doric order. (See p. 42, ex. 71.)

EXAMPLE 183, fig. 185, is a design for a frieze and cornice.

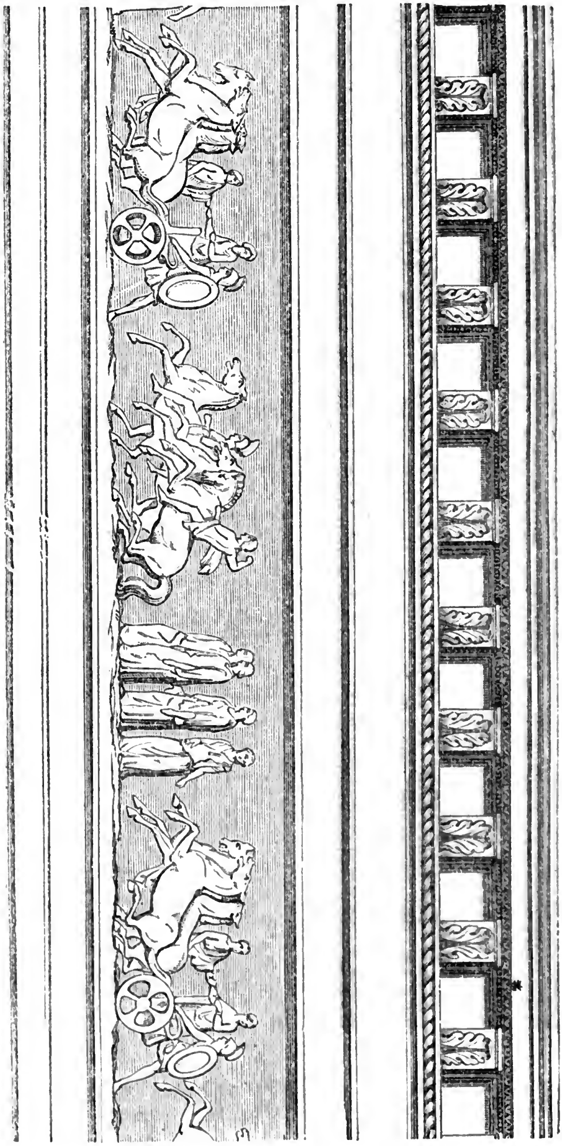


fig. 185.

EXAMPLE 184, fig. 186, is the elevation of a sculptured pilaster forming part of a chimney-jamb.

EXAMPLE 185, fig. 187, is a form of ornament sometimes used in place of balustrades.

EXAMPLE 186, fig. 188, is an example of bracket, of which the side view is given in

EXAMPLE 187, fig. 189.

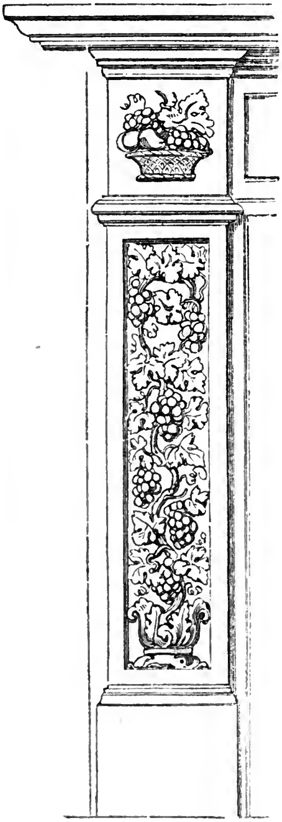


fig. 186.

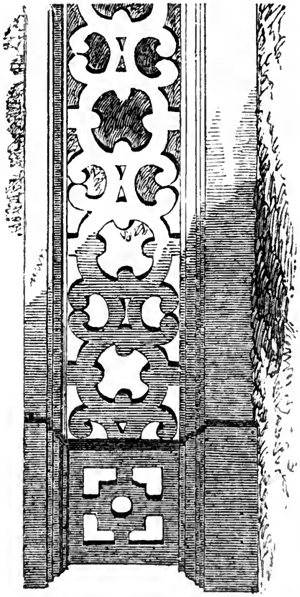


fig. 187.

EXAMPLE 188, fig. 190, is a perspective view of a Grecian 'scroll truss.'

EXAMPLE 189, fig. 191, is an elevation of an Elizabethan scroll truss.

EXAMPLE 190, fig. 192, is an exemplification of the ornament called the 'fret.' Another form is given in

EXAMPLE 191, fig. 193.

EXAMPLE 192, fig. 194, is an exemplification of the ornament termed the 'guilloche.' Another example is given in

EXAMPLE 193, fig. 195.

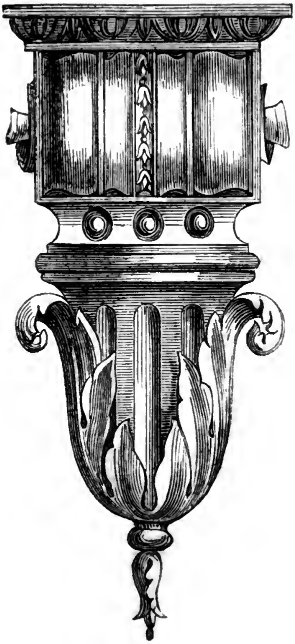


fig. 188.

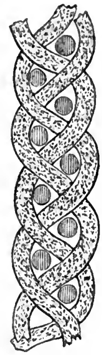


fig. 195.

fig. 191.

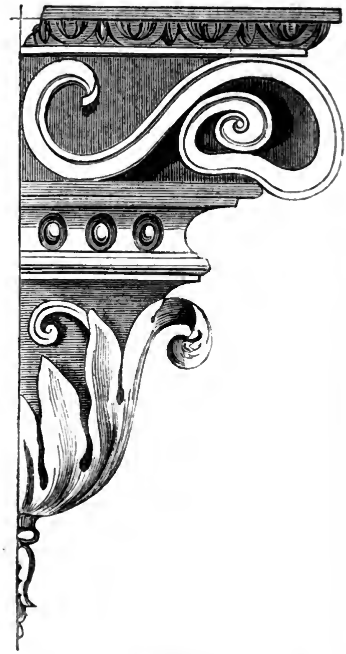


fig. 189.

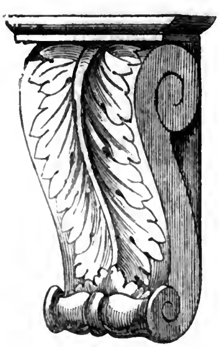


fig. 190.

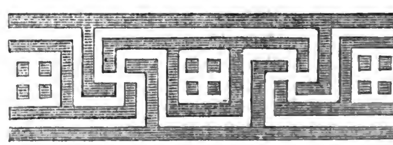


fig. 192.

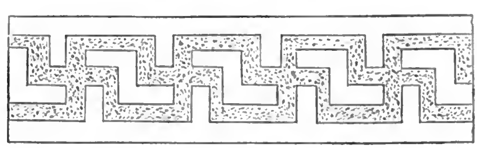


fig. 193.

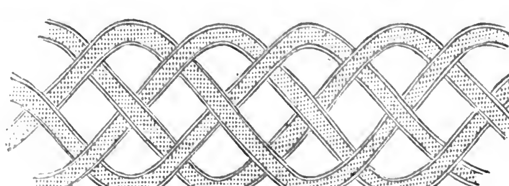


fig. 194.

In the work on *Practical Geometry* we have given examples of outlines of vases, with the methods of describing their curves. We now present a specimen with the outlines ornamented.

Example 194, fig. 196.

Example 195, fig. 197, is an example of 'vase and pedestal.'

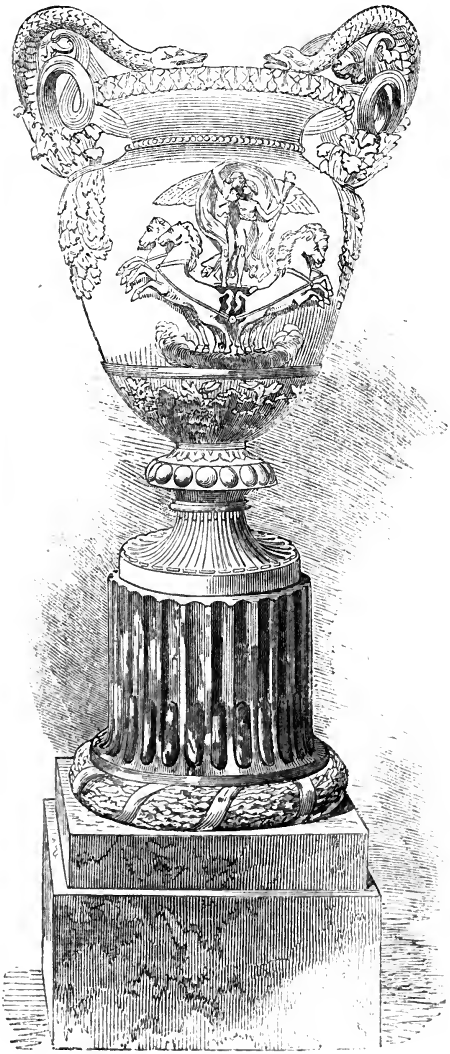


fig. 196.

fig. 197.

EXAMPLE 196, fig. 198. Another example of vase, with the outlines ornamented.

EXAMPLE 197, fig. 199. Design for a Gothic monument.

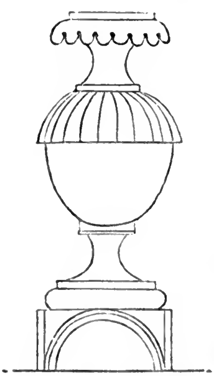
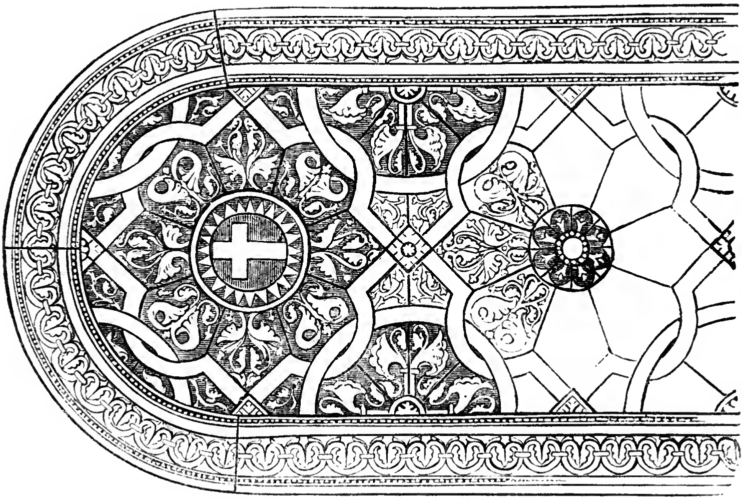


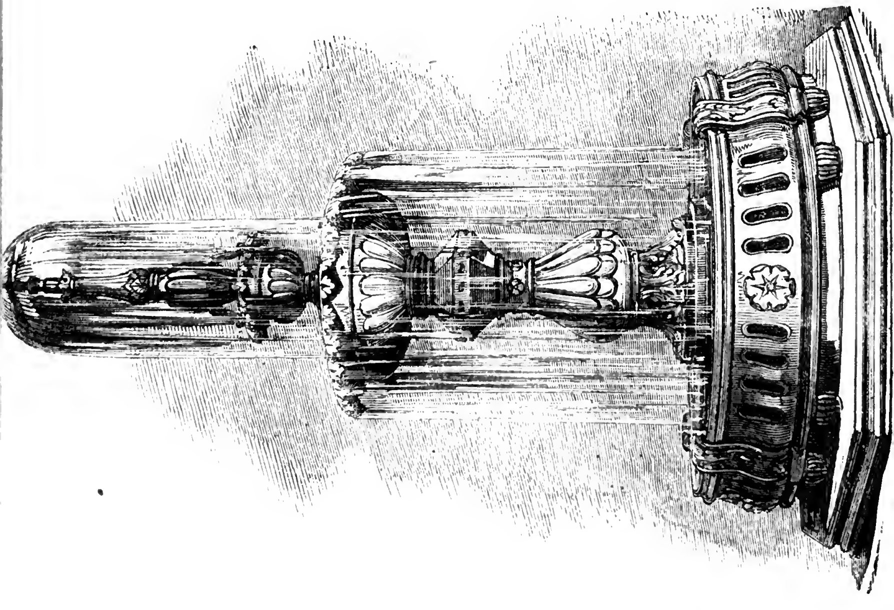
fig. 198.

fig. 199.

EXAMPLE 198, fig. 200. A design for a fountain.

EXAMPLE 199, fig. 201, is the elevation of a stained window in the geometrical style.





We now, as concluding this department of our treatise, proceed to give a series of designs, exemplifying by inspection the peculiarities of the various periods of Gothic architecture as generally received.

EXAMPLE 200, fig. 202, is an elevation of a Norman window.

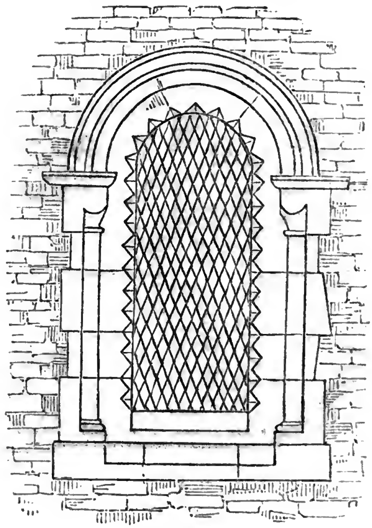


fig. 202.

EXAMPLE 201, fig. 203, is the Early-English (or Lancet). This style

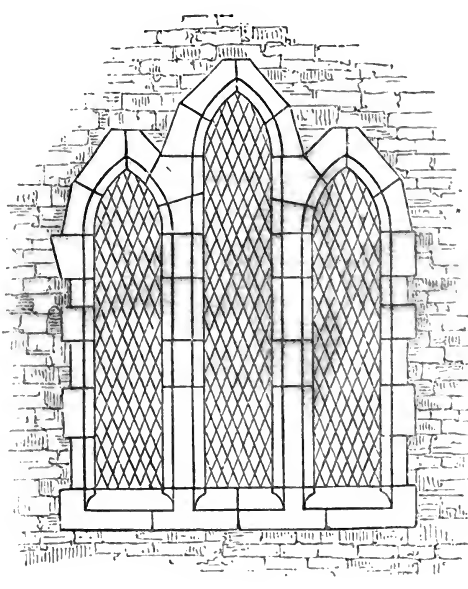


fig. 203.

succeeded the Norman, and was followed by the Decorated, the tracery of which was distinguished by geometrical lines, as in

EXAMPLE 202, fig. 204; and in the later instances by flowing lines, termed curvilinear, as in

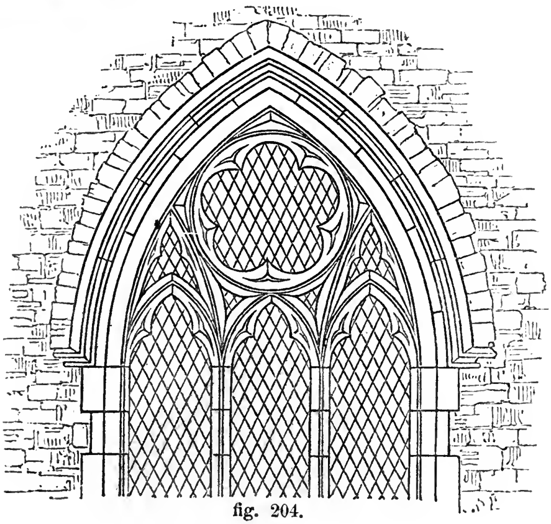


fig. 204.

EXAMPLE 203, fig. 205. The Perpendicular is derived from the Deco-

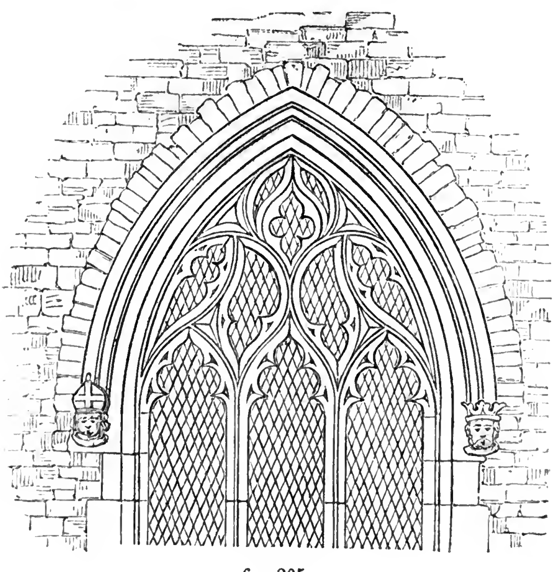


fig. 205.

rated; its distinguishing feature is the perpendicular lines of the tracery, as seen in

EXAMPLE 204, fig. 206.

For further information on the styles and peculiarities of Gothic Architecture, see the work on "Ornamental and Architectural Design."

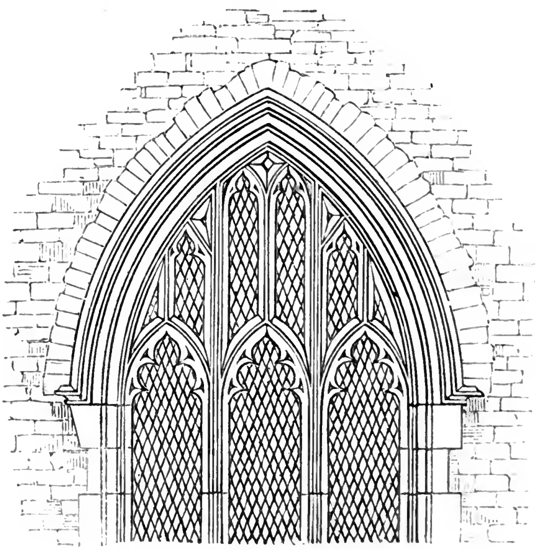


fig. 206.

SECTION II.

ENGINEERING DRAWING.

In this section we purpose explaining, chiefly by appropriate illustrations, the methods of delineating those subjects which are found more particularly the branches of what is generally designated as Civil Engineering, whether these be shown in plans, maps, elevations, or sections. As the rules, or more properly the methods, to be observed in copying subjects of pure outline, where the drawing-board and instruments are available, will obviously be very similar to those which we have already detailed in the First Section, we do not consider it necessary to multiply examples of outlines, such as bridges, &c. The pupil desirous of studying Civil Engineering as a profession will find numerous examples which may serve as "copies" in the more technical and strictly professional works which it will be his duty to consult. We shall content ourselves with giving one or two examples of the method of setting out copies of bridges, &c.

Example 1, fig. 1. Bisect any two of the piers, as *a b*, *c d*, in the points *a* and *c*. Draw lines *a m*, *c d*; put in the piers; divide *a c* into two equal

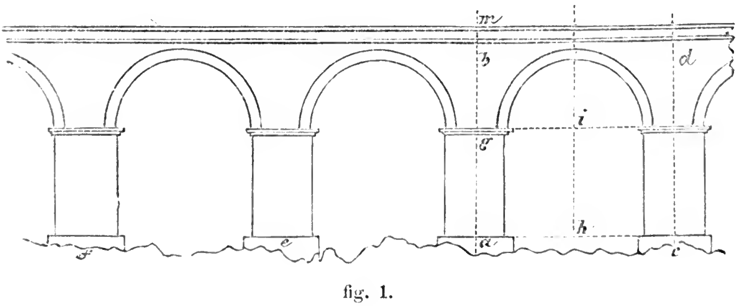


fig. 1.

portions at the point *h*; parallel to *c d* draw *h i*; measure to *i*. This will be the centre of the arch. In like manner the aqueduct arches in

EXAMPLE 2, fig. 2, may be drawn; the lines *d*, *c*, *a*, *b* being the lines of the piers; *g* the centre of the under, and *h* that of the upper arches. The various parts of an arch are shown in

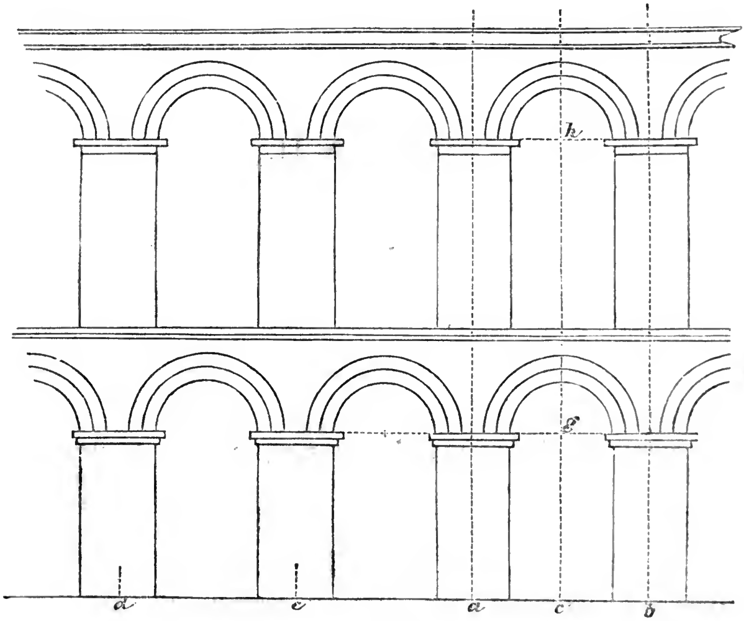


fig. 2.

EXAMPLE 3, fig. 3, where *a b* is the 'span' of the arch; *e d* its 'rise;'

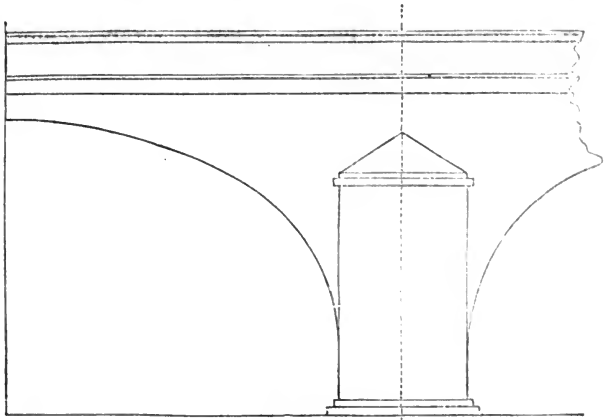


fig. 4.

a d b the inside curve, called the 'soffit,' or 'intrados;' the key-stone is *g*.

The exterior or upper curve of the arch is called the 'extrados.'

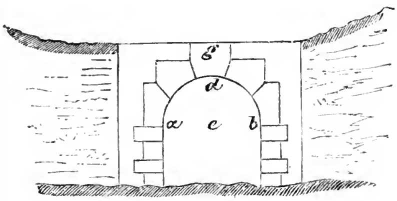


fig. 3.

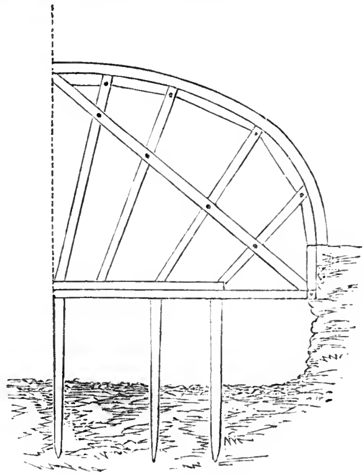


fig. 5.

EXAMPLE 4, fig. 4, is an elevation of bridge with semi-elliptical arch. For method of describing this form see *Practical Geometry*.

EXAMPLE 5, fig. 5, is elevation of the timber framing or 'centering' of a bridge.

The method of delineating the various features of a country or district in a map is shown in

fig. 6.

EXAMPLE 6, fig. 6, where A represents a piece of inland water or lake; E E a river, proceeding from this; B the garden attached to the mansion

C a hill, with trees on its summit; C C, near the river E E, represents rising ground on its margin; H H plantations of trees; O O a swamp or morass; K K meadow-lands; L L a public highway. In the following illustrations the features are shown on a larger scale, as in

EXAMPLE 7, fig. 7, which represents a hilly or mountainous ridge.

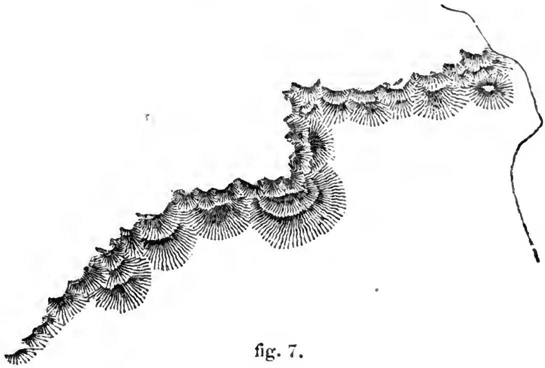


fig. 7.

EXAMPLE 8, fig. 8. Rising ground near a river.
EXAMPLE 9, fig. 9. The same.

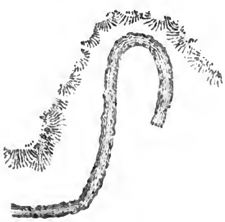


fig. 8.

fig. 9.

EXAMPLE 10, fig. 10, represents a river, with small stream issuing from it and traversing a meadow. In copying this, the pupil should fill up the whole of the part representing the extent of meadow (within the boundary-line) as in the corner of the illustration now given.

EXAMPLE 11, fig. 11, represents swampy ground with trees.

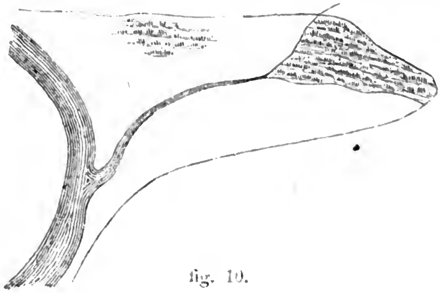


fig. 10.

fig. 11.

Example 12, fig. 12, represents a river entering the sea; the coast is delineated as in the sketch.

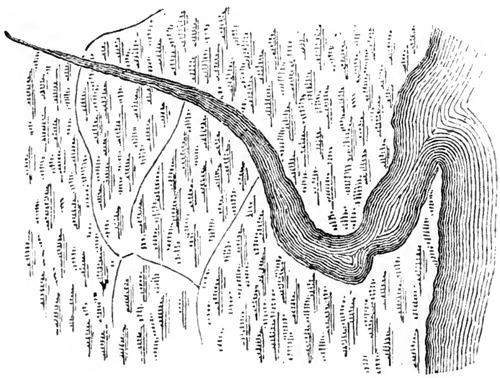


fig. 12.

Example 13, fig. 13, represents part of a sea-line of coast *c c*, with sandy shoal *b b*, and swampy morass *a a*.

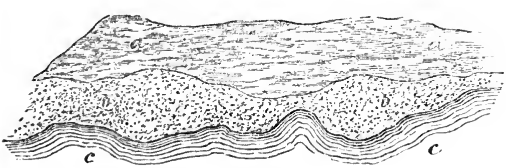


fig. 13.

fig. 14.

Example 14, fig. 14, represents the method of delineating a rock, used in marine maps. A range of rocks is represented in
Example 15, fig. 15, and a rock surrounded by sand in
Example 16, fig. 16.

fig. 15.

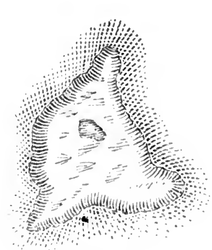


fig. 16.

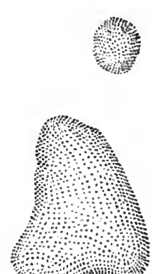


fig. 17.

Example 17, fig. 17, represents a sandy shoal. The method of delineating water in a basin or harbour is shown in

Example 18, fig. 18. The manner of representing blocks of houses in a town or suburban district map is represented in

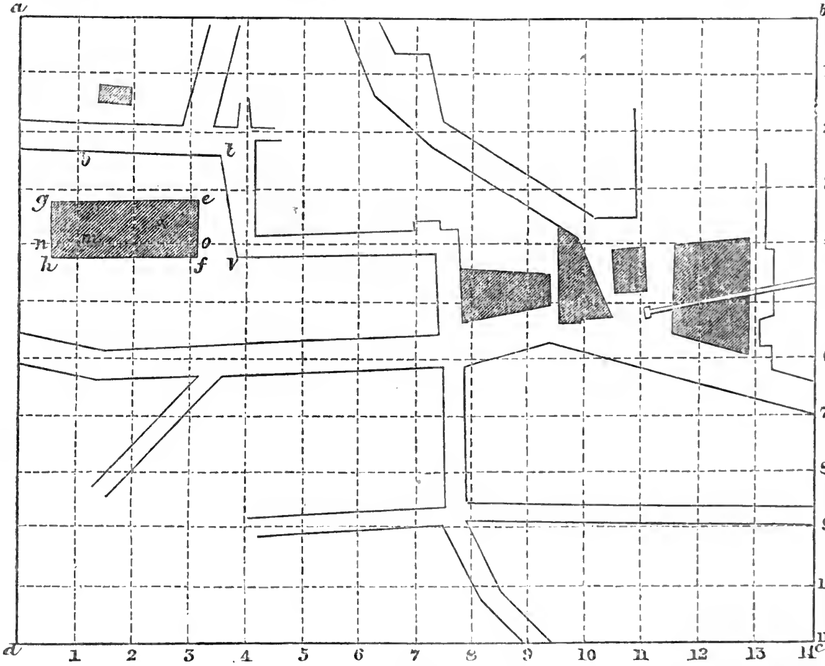


fig. 19.

Example 19, fig. 19. This example is also designed to show the use of squares in reducing or enlarging maps. The principle of this method has been fully described in *Practical Geometry*.

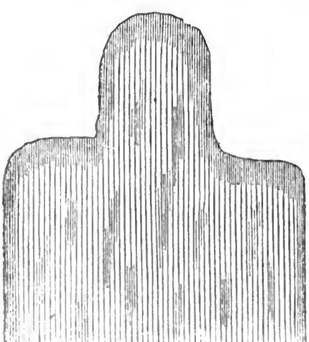


fig. 18.

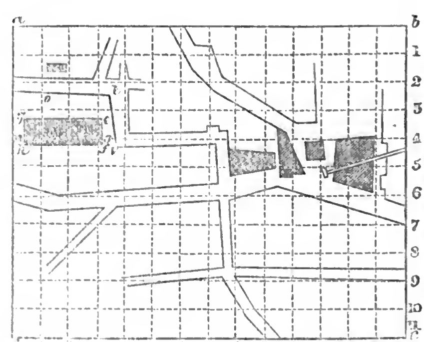


fig. 20.

Example 20, fig. 20, is the same subject as in the previous figure. The pupil, aided by the letters of reference and the figures, should have no difficulty in finding the various points in fig. 20 from fig. 19, and *vice versâ*, if the plan is fig. 20 to be enlarged twice, as in fig. 19. Irregular portions of maps may be copied by adopting offset lines, as in

EXAMPLE 21, fig. 21, which represents part of a river, which is required to be copied and enlarged as below. Draw any line $c\,d$; from any scale set off distances, as $c\,g = 50$, $g\,h = 60$, and so on. Next draw a line, as $p\,o$, corresponding to $c\,d$; from p set off distances corresponding to those in $c\,d$, but taken from a scale larger than that of $c\,d$. From the same scale as that from which the measurements on $c\,d$ were taken, measure the lines drawn at the various points at right angles to $c\,d$ to where they touch the outline of the lowest side of river, as $g = 40$. Make the line t the same distance, but taken from its proper scale; by proceeding thus, points will be found, by tracing through which, an outline will be obtained equal to that of the copy. The angle $d\,c\,b$ is equal to 40°. The pupil should extend this principle of copying irregular figures, by which he will be enabled to judge of its utility in practice.

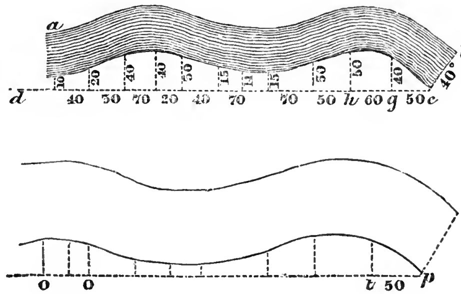


fig. 21.

fig. 22.

fig. 23.

REFERENCES.

GREEN............

RED...............

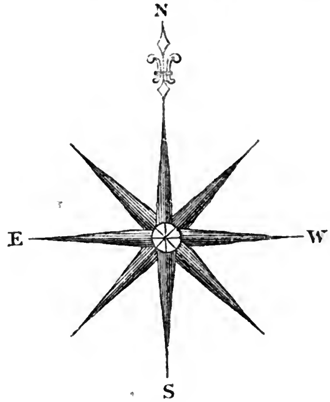
fig. 24.

We now give a few examples of the lettering attached to maps and plans.

P A R I S H   O F

fig. 25.

EXAMPLE 22, fig. 26, shows the compass-mark in plans, by which the directions are obtained. The *fleur-de-lis* always points to the north.



EXAMPLE 23, fig. 27, represents the plan of part of a district through which a road $a\ b$ is to be cut. The section of this is in

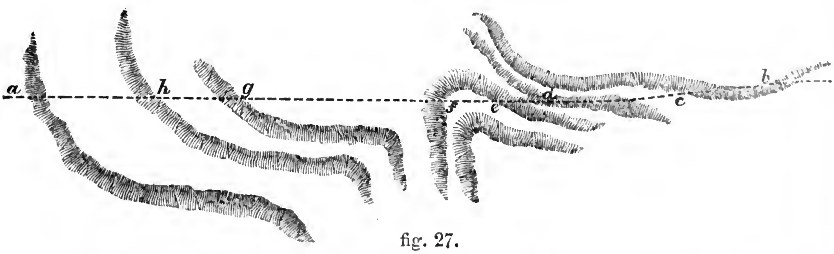


fig. 27.

EXAMPLE 24, fig. 28. The parts filled in with small dots represent hollows filled up; the cross-lines point where a cutting is made. The horizontal line $c\ d$ is termed the 'datum line.' See article 'Levelling' in the work on *Practical Mathematics* in this series.

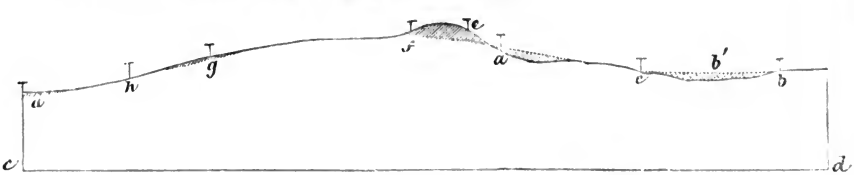


fig. 28.

fig. 29.

EXAMPLE 25, fig. 29, represents a section of road, showing method of delineating it.

EXAMPLE 26, fig. 30, represents the rocks at the side of a section of a railway cutting.

fig. 30.

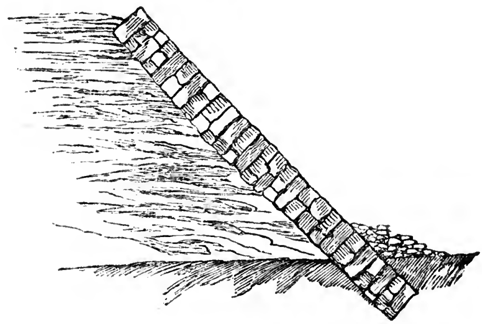


fig. 31.

EXAMPLE 27, fig. 31, represents the method of delineating an embankment faced with rubble masonry.

EXAMPLE 28, fig. 32, represents a breakwater formed of large stones thrown together, sloping outwards to resist the action of the waves.

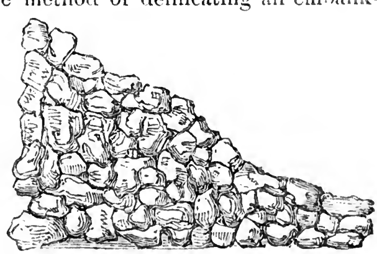


fig. 32.

EXAMPLE 29, fig. 33, is the section of a stone pier, where *a a* is the face toward harbour; *b b* that to the sea; the interior is filled with round stones, as *c c*. The plan of a retaining wall is shown in

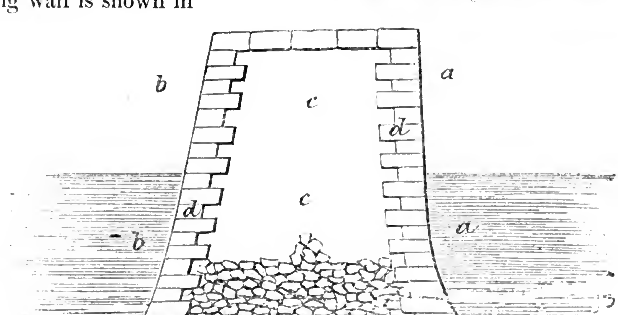


fig. 33.

EXAMPLE 30, fig. 34, where *b c c* is the stone facing; *d* the stones used for filling up.

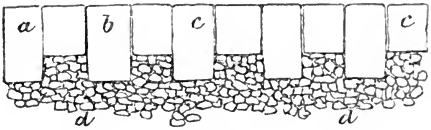


fig. 34.

EXAMPLE 31, fig. 35, represents the footings B of a pier of a bridge resting on a sand foundation at A.

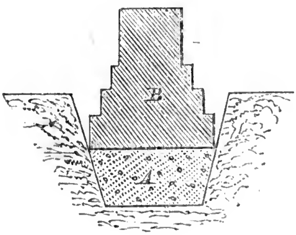


fig. 35.

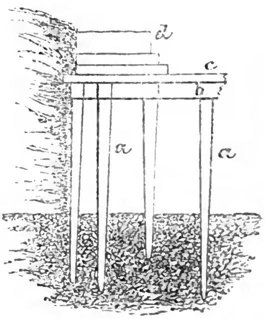


fig. 36.

EXAMPLE 32, fig. 36, represents piles of wood driven into the ground, supporting masonry. A section of a coffer-dam in a bed of 'beton' is shown in

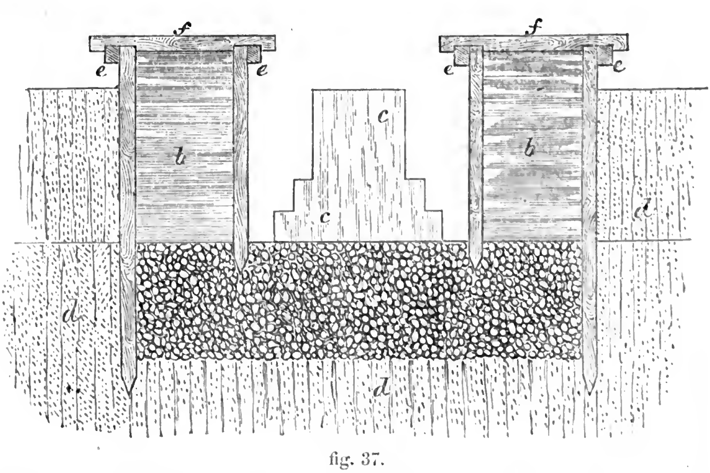


fig. 37.

EXAMPLE 33, fig. 37, where *c c* is the mass of masonry, resting on the mass of beton; *d d* represents mud; *e e* the main piles and 'wales,' and *f f* the cross-pieces; *b* represents the clay-puddling between the piles, which serves to keep out the water from the interior. For explanation of the various terms here used, see treatise on *Mechanical and Civil Engineering.*

Example 34, fig. 38, is elevation of factory-chimney, of which the transverse vertical section is given in

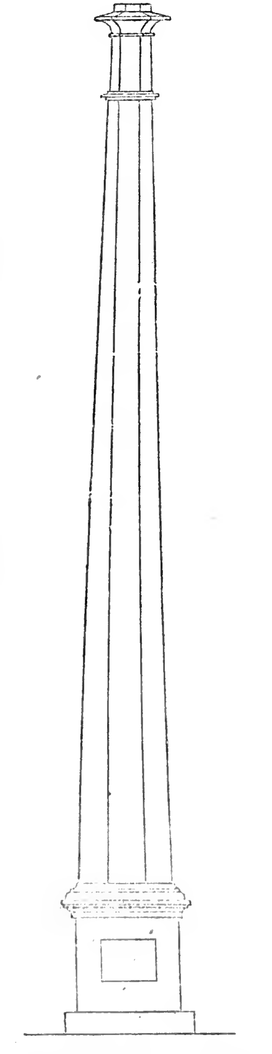


fig. 38.

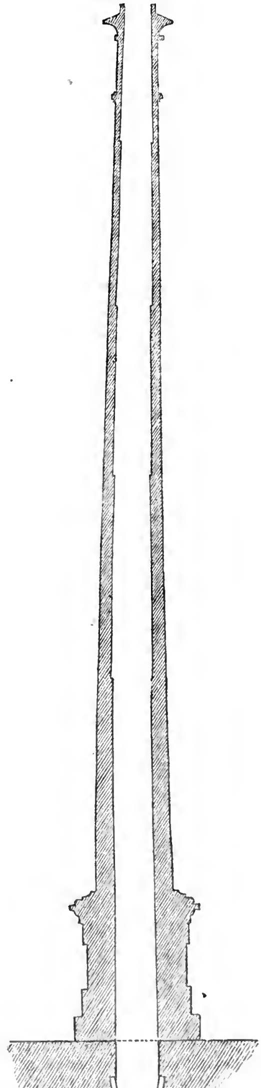


fig. 39.

Example 35, fig. 39. The scale for both figures is given with fig. 38.

SECTION III.

MECHANICAL DRAWING.

In this department we purpose explaining, by the help of appropriate diagrams, the easiest methods of delineating various portions of machinery. In this, as in the others just treated of, a knowledge of the constructions which we have given in *Practical Geometry* will be essential. The preliminary lessons also of the department of this work on Architectural Drawing will be of use in enabling the pupil readily to master the lessons we now place before him.

Example 1, fig. 1. represents a 'bolt,' *c b*, with the solid head *e' d*, and movable 'nut,' *g' g*. This is used for strongly fastening various portions of machinery together. For examples of the method of using this, see our work on *Mechanics and Mechanism* in this Series. To draw the figure now given:—Suppose the copy to be without the centre-line; bisect *e' e'* in the point *a*, draw *a b'*. On the paper on the drawing-board draw two lines *e' e'*, *a b'* at right angles to each other; with *a e'* from the copy measure from the point of intersection of the above lines on the board *a* to *e' e'*; from *a* measure to *b*; from *b* with distance *a e'* measure to *d d*; join *d e'*, *d e'*. From *a* measure to *c* and *b'*; from these points with *a e'* measure to *g' g*, *g' g*; join *g' g'*, *g g*. From *b* measure to *h h*; parallel to *a b'* from *h*, *h* draw lines meeting *g' g*.

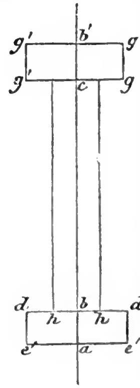


fig. 1.

Example 2, fig. 2. Bisect the line *b' b'* of the copy in the point *a'*, and draw *a' b*. On the paper on the board draw two lines corresponding to these, intersecting at the point *a'*.* From *a'* measure to *b'*, *b'*, from *a'* measure to *c*; with *a' b'* from this point measure to *f f*; draw a line parallel to *b' b'* through *e*; join *f b'*, *f b'*. From *a* or *c* measure to *d*, and through this draw a line parallel to *b' b'*. From *c* measure to *g*, *g*; join *g' g'* by perpen-

* To avoid repetition, the pupil is requested to observe that, in all the lessons, the centre-lines drawn on the various diagrams must be drawn on the paper on the board, it being understood that where a copy is presented him in this book, or elsewhere, without centre-lines being given on it, that these should be adopted and drawn in faint lines, so that data may be obtained from which to take measurements. By dint of practice the facility for copying without these will be attained, or, at least, they will be sparingly required. As the pupil proceeds, he will the more readily decide as to the quickest method of finding datum points from which to take measurements.

dicular lines to *g g* on the line *f f*. From *a′* measure to *e*; draw a line through this parallel to *a b′*; from *e* measure to *c′ e*; from *d* measure to *h h* on the line *g′ g′*; join *h e′*, *h e′*. Where we use the terms 'measure from'—as measure from *a′* to *b*—we mean, in all instances, that the measurement *a′ b* is to be taken from the copy and transferred to the paper on the board, from the point thereon corresponding to the point *a′* in the copy. Again, when we say 'measure from *a′* to *b′*,' we wish the pupil to take the measurement *a′ b′* from the copy, transferring it to the line on the paper corresponding to the line *b′ a′ b′* in the copy, from the point on the paper corresponding to the point *a′* in the copy. Hence the pupil will observe the use of datum-lines—as *a′ b*, *b′ a′ b′*—from which to take the measurements from the copy; these to be transferred to the paper on the board on which the fac-simile is to be constructed. As a means of enabling the pupil readily to decide on datum-points from which to take measurements, we explain another method of copying the last figure. Draw any line *b′ a′ b′*, assume any point on it, and draw there a line at right angles to *b′ a′ b′*. The intersection of these lines will represent the point *b′* in the diagram just given. From *b′* measure to *f* in the copy, and transfer it from *b′* to the line which is at right angles to *b′ a′ b′* as to *f*; from *f* draw a line parallel to *b′ a′ b′*. From *b′* measure to *b′*, or from *f* to *f′*; join *b f′*. The part *b′ f*, *f′ b′* will thus be put in: the part up to *g′ d g′* may thus be put in without the use of a centre-line. The part to *e* can be quickest put in by using one; however, it may be done as follows:—Measure from *d* to *h*; from *h* draw a line to *m*, at right angles to *g′ d g′*; with *d e* or *a e′* measure to *e*, and draw through this a line *e′ e* parallel to *a′ b′*. From *m* measure to *e′*, and from *e′* to *e*; join *h e′*, *h e*. In the following diagram the use of the circle is shown.

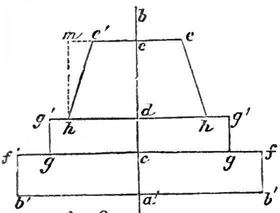


fig. 2.

EXAMPLE 3, fig. 3. Draw any two lines on the board corresponding to *a e*, *g′ g g′* in the copy. From *g* measure to *b*, *c*, and *d*; from *g* measure to

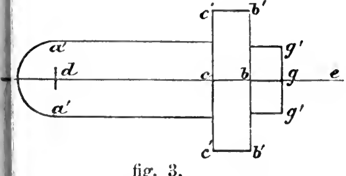


fig. 3.

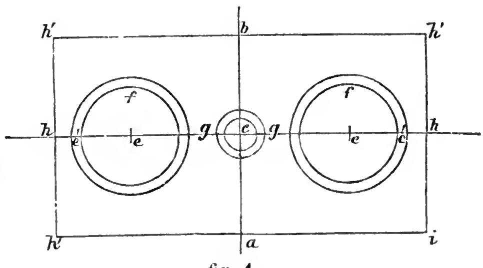


fig. 4.

g′ g′, and from *b* to *b′ b′*; join *g′ g′* to *b′ b′* by lines at right angles to *g′ g′*. From *c* measure to *c′ c′*; join *b′ c′*, *b′ c′*. From *d*, with *d a′* as radius, describe a semicircle *d a′ a′*; by lines parallel to *c b* join *a′ a′* with the line *c′ c′*.

EXAMPLE 4, fig. 4. Draw on the board two lines corresponding to *a b*, *h h* in the copy. From the point of intersection *c* measure to *a b*, and *h h*; through *a b* parallel to *h h* draw lines *h′ h′*, *h′ i*; through *h h* parallel to *a b* draw lines meeting those in the points *h′ h′*, *h′ i*. From *c* with *c g* put in the circle; from *c* measure to *e*, *e*. From these points, with *e′ e′* as radius, describe the circles, and also the interior ones, as *e f*.

Example 5, fig. 5. Draw on the board, lines *a b*, *c c* at right angles, intersecting at *e*, corresponding to those in the copy. From *e* measure to *a*

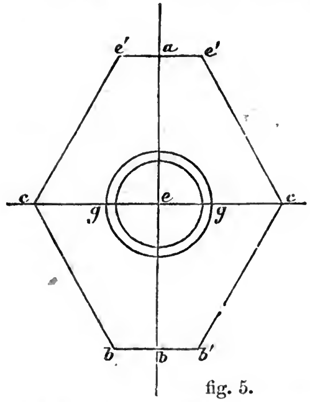


fig. 5.

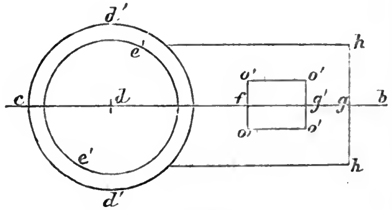


fig. 6.

and *b*; from these points draw lines parallel to *c c*, from *a b* measure to *b b′*, *e′ e′*. From *e* measure to *c c*; join *c e′*, *c b′*, *c e′*, *c b′*. The radius of the circle in the centre is *e g*.

Example 6, fig. 6. Draw lines corresponding to *b d c*, *h h* in the copy. From *g* measure to *d*; put in from *d* as a centre, the circles *d′ d′* and *e′ e′*. From *g* measure to *h*, *h*, and parallel to *b d* from these draw lines touching the circle, *d′ d′*. From *g* measure to *g′* and *f*; from these points measure to *o′ o*; through *o′ o′* draw lines parallel to *h h* and to *b d*.

Example 7, fig. 7, represents a set of what are termed 'speed pulleys' (see *Mechanics and Mechanism*). Draw any two lines corresponding to *a b*,

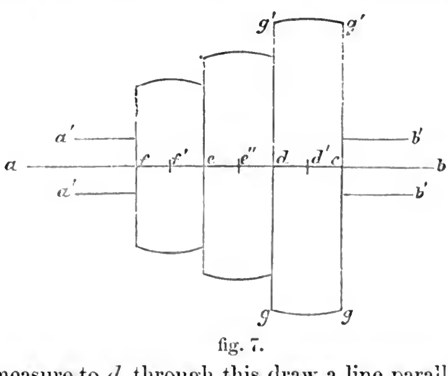


fig. 7.

g′ g. From *c* measure to *d*, through this draw a line parallel to *g g′*; measure from *c* and *d* to *g′*, *g*. Bisect the distance *d c* in *d′*; from *d′* as a centre, with *d′ g′* as radius, describe the arcs joining the lines through *g g′*, *g′ g*. In like manner, measure from *c* to *e* and *f*: the points *f′*, *e′* will be the centres of the arcs joining the lines drawn through *e* and *f*.

EXAMPLE 8, fig. 8, represents a projecting 'snug,' by which two parts may be joined by means of a bolt secured by a nut, passed through holes bored in each. Draw the line *a b*, and another at right angles to it. From *a* measure to *b*, and put in the various horizontal lines and the base; from *b* measure to *c*, and parallel to *a b* draw a line from this point. From *c* measure to *d*; from *d* as centre with radius *d c* describe the curve. From *f* measure to *e*; a line drawn from this, parallel to *a b*, gives the end-line. The centre *g* (as also *d*) is found by trial on the copy, and the points transferred to corresponding parts on the board. The line *d c* represents one method of transferring them.

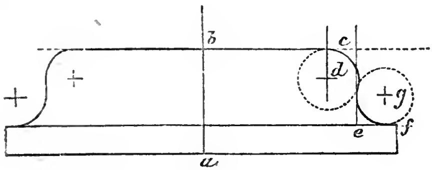


fig. 8.

EXAMPLE 9, fig. 9, represents a side view of a 'pulley,' or 'drum,' showing the arms and centre. Draw any two lines corresponding to *a b*, *c d*. From *g* as centre, with *g b* as radius, describe the circle, and also the interior circle *g′ g′*; from *g* with *g h* put in the small circle representing the diameter of the centre or eye of the wheel. From the lines 1, 1 with distance 1, 2 lay off on either side of all the centre-lines of the arms; next, from the points where the interior circle cuts these lines at the points *g′*, *g′*, lay off on each side equal to half the thickness of the end of the arm as it joins the inside of wheel. Join the points thus obtained with those previously obtained on the centre of the wheel, as 2, 2.

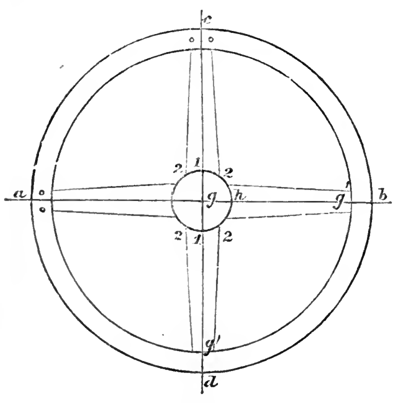


fig. 9.

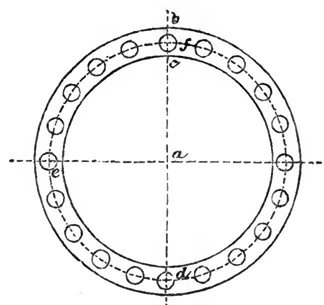


fig. 10.

EXAMPLE 10, fig. 10, represents the plan of a circular cylinder or receptacle, the small circles showing the position of the circular heads of the bolts used for attaching the cover to the main body of the receptacle. The method of finding the centres of the small circles is as follows: Draw any two lines *a c*, *b d*; from the point of intersection as centre, with radius *a b*, *a c*, describe circles; bisect the distance between these, as *b c*, in the point *f*. From *a* as centre, with *a f* as radius, describe a circle *f e d*: the centres of the small circles will be found on this line. Find the position of any two of the circles, as *f e* or *e d*; transfer these points to the board. In the copy, the centres of four of the circles will be found where the diameters *e a*, *b d* cut the circle drawn through *f d*. Count the number of circles between *f* and *e*, or *e* and *d*; divide the circular line passing through *f*, and between *e* and *f* or *e* and *d*, into as many equal parts as will give as many centres as there are circles in the copy: these points will be the centres of the circles.

EXAMPLE 11, fig. 11, represents the plan of a small thumb-wheel attached to the head of a screw-bolt, by which it may be easily moved by means of the finger and thumb. From *a* with *a b* describe a circle, draw the diameter *d b*; divide the semicircle *d b* into four equal parts in the points *e f*; from *a* draw lines through *e f*; and continue these to cut the other semicircle. From *a* measure to *n*, the centre of the circles forming the ends. With *a n* describe a circle: the points on the radial lines, as *n*,

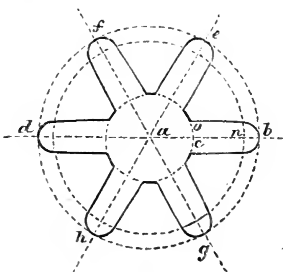


fig. 11.

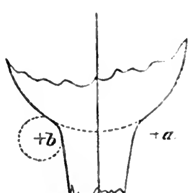


fig. 12.

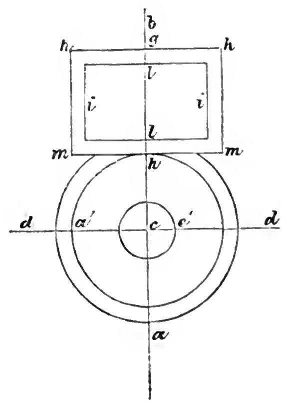


fig. 13.

where this intersects them, are the centres of the circles which terminate each radial arm. From *a* describe the small circle *a c*; from the points where this intersects the radial lines, as *c*, lay off on each side of these the distance *c o*; join the points thus obtained on the circle *a c o* with the extremities of the circular ends. Another way of joining the radial arms to the centre or eye may be understood by inspection of the diagram in fig. 12, where *a b* are the centres of the circles, part of which joins the arm with the centre.

EXAMPLE 12, fig. 13. Draw any two lines corresponding to *a g*, *d d* in the copy; from the point of intersection *c* measure to the points *h*, *g*; through these draw lines parallel to *d d*. From *h*, *g* measure to *m m*, *h h*; join *m h*; put in, in like manner, the internal parallelogram *l i l i*. From the point *c*, with radius *c e'*, *c a'*, and *c a*, describe the circles as in the copy, meeting the line *m m*.

EXAMPLE 13, fig. 14, represents plan of part of a 'valve-plate.' From any centre *a* describe a circle *a b*, and one within this, as *a c*; continue this last all round, the part from *m* to *p* being afterwards rubbed out when the drawing is finished and inked in. From *a* with *a d* put in part of a circle *e d e*. From *d* measure to *e*, *e*, and through these draw lines to the points, as *g*, on each side of the line *f*. On each side of the line *a h* measure to *p* and *m*, also from *n* to *o*; join *m o*. Put in the circles at *n* and *h*; join them as in the drawing.

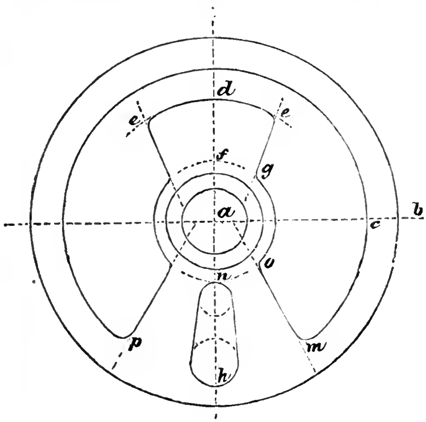


fig. 14.

EXAMPLE 14, fig. 15, represents the plan of a 'lever.' Describe the circle *a h*, draw through *a* the diameter *b a d*; from *a* measure to *c*; put in the circle *c d*. Bisect *a c* in *e*, and through this draw a line at right angles to *a d*, as *f f*. In the copy take the points *f* (where *e f* intersects the curve), *h* and *g* (where the curve *h g* touches or joins to the circles described from *c* and *d*). By means of these points (see the problem in the work on *Practical Geometry*, to find the centre of a curve, three points in that curve being given), the centre *m* will be found.

EXAMPLE 15, fig. 16, represents the method generally employed of constructing the central part of a "spur-wheel." The circles *c*, *f*, and *m* are

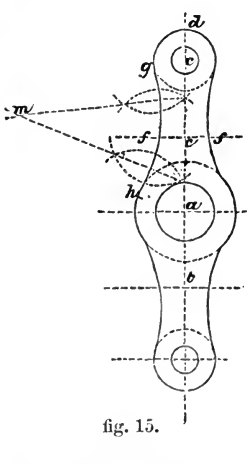


fig. 15.

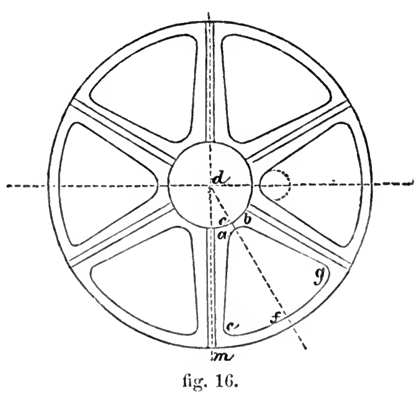


fig. 16.

described from the centre *d*; the circle *m* is divided into as many equal parts as there are arms in the wheel, any central point of these, as *m*, being adopted as the datum-point from which to take the measurements. The space between any two of these arms, as *a b*, is bisected, and a line, as *d f*, drawn. By measuring from *f* to *e*, *g*, the centres of the curves at *e* and *g* will be obtained; the centre of the curve *a b* is also on the line *d f*.

Example 16, fig. 17, represents the plan of a pulley with curved arms. The method of describing these is explained in

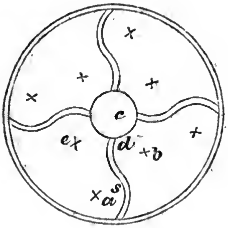


fig. 17.

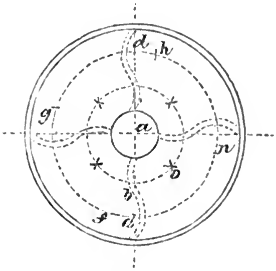


fig. 18.

Example 17, fig. 18. The first operation necessary to be done is to find in the copy fig. 17, the centres of the circles forming the curves: these must be found by trial. Next draw two lines at right angles, as in fig. 18, intersecting in the point *a* corresponding with the centre *c*, fig. 17. From *a* describe circles representing the rim and the eye of the wheel in last figure. From *c*, in fig. 17, measure to the centre *b*, from which the curve *d* is described, and from *a*, fig. 18, a circle *a o*: on this line the other centres, as *e*, fig. 17, will be found. In like manner, from the centre *c*, fig. 17, measure to *a*, from which the curve *a s* is described, and from *a*, fig. 18, describe the circle *g h*. On this will be found the second set of centres. From *d* measure to *h*, from *h* to *n*, from *n* to *f*, and from *f* to *g*: these are the various centres. Or the curves next the eye may be drawn in first, and the curves with radius *a s* be described, to meet these from the circle *g h*. In this example the arms are of uniform breadth; where they get gradually less from the centre or eye of the pulley outwards, the method of describing them may be learned from

Example 18, fig. 19. The points from which the curves are drawn must be found, and corresponding points transferred to the paper, as in last example. Two circles, as *d*, *o*, will thus be obtained, in which the centres of the various curves will be found. Put in the circle representing the eye of the pulley, and draw a diameter *a b*; draw a line in the copy corresponding to this, and measure from *b* to the point representing the centre of the circle from which the curve *c c* is drawn, as *d*; transfer this to the copy, and from *d* with *d c* draw the curve *c c*; from *c* measure to *f*, thus giving the breadth of arm at eye; from *f*, with the radius of the curve *f* taken from the copy, cut the circle *o* in *o*; from this point with same radius describe the curve *f g*. The various points denoting the centres of the curves are given in the circles, the points *e e* being those where the curves join the central circle or eye of the pulley.

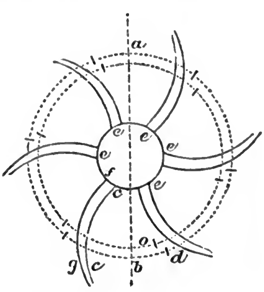


fig. 19.

EXAMPLE 19, fig. 20, represents the bottom part of foot of a cast-iron framing. Draw a line *c d*; from *c* measure to *a* and *b*; through these

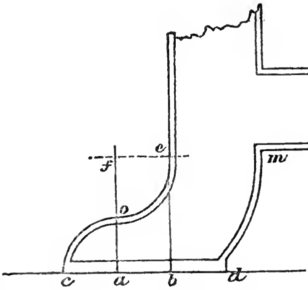


fig. 20.

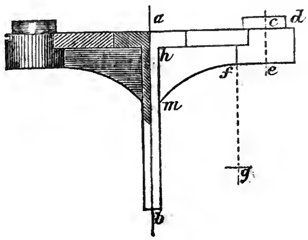


fig. 21.

draw lines perpendicular to *c d*; with *a c* from *a* describe the curve *c o*. From *b* measure to *e*. Find the centre of the curve joining *o e*, at *f*. Find by any of the methods already described the point *m*; join *m d* by the curve.

EXAMPLE 20, fig. 21, represents part of the frame-work forming the support for the bearings *c* in which vertical spindles revolve. Draw *a b*, *a d*; measure from *a* to *d* and *c*; draw *c e* at right angles to *a d*. From *e* measure to *f*, and from *f* draw to *g* parallel to *a b*; from *a* measure to *h* and *m*. The centre of the curve joining *f m* will be found at *g* on the line *f g*. The method of filling-in the drawing is shown by the other half.

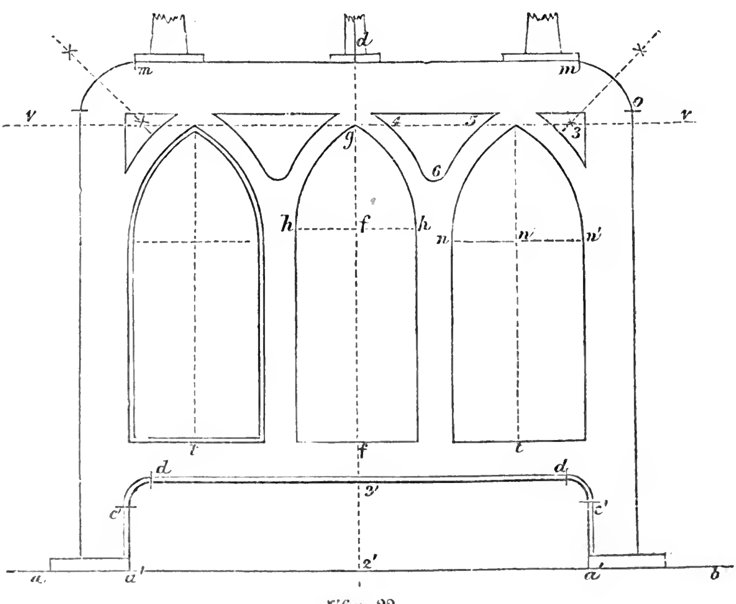


fig. 22.

Example 21, fig. 22, represents the outline of side elevation of framing. Draw the line *a b*, and at right angles to it 2′ *d*; measure from 2′ to *a′ a′*, and to 3′. Through these points draw lines *d d*, *a′ c′*, *a′ c′*; join the points *c′*, *d* by the part of the circle, as in the diagram. From 2′ measure to *f*, and draw the line *t f t*; from *f* measure to *t*, *t*; from these points draw lines parallel to 2′*d*. From *t* measure to *n*; draw *n n′*, and from *n*, *n′*, with radius *n n′*, describe curves meeting, as in the drawing. From *f* measure to *f*, and draw *h f h*; from *h*, *h* with radius *h h* describe curves meeting in *g* on the line *v v*. The curves 5, 6 and 3 are described from the centres *n′*, *n*, and 4, 6 from centre *h* on the left hand side of *f f*. The lines *m m*, *o o* are joined by curves described from the centre 3, which centre is found by describing arcs from the points *m*, *o* with any radius greater than half *m o*, and joining the intersection of these arcs by a line as in the copy.

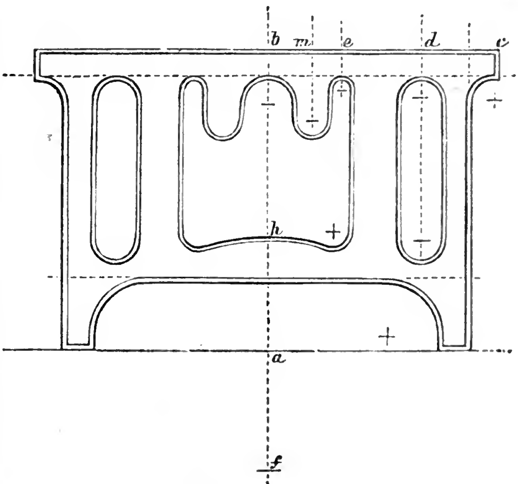


fig. 23.

Example 22, fig. 23, is another outline representing the side elevation of framing. The curve *h* is described from the centre *f* on the centre-line *b f*; the centre-lines of the other parts are at *m*, *e*, *d*, and *c*.

Example 23, fig. 24, is another form of framing. The centre of the curve *n*, joining the lines from *m*, *m*, is at *h*, on the centre-line *o h*; the centres *d*, *d* are on the line drawn through *c* to *h b*, parallel to *m m*; the centre of the circle *e* is at *g*.

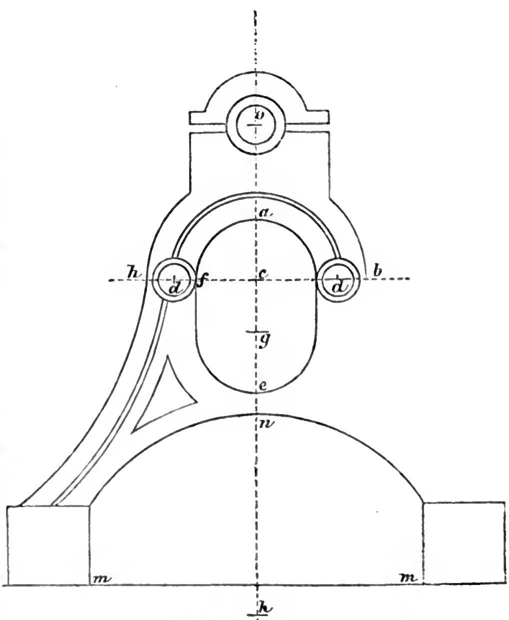


fig. 24.

EXAMPLE 24, fig. 25, represents the front elevation of a 'cross head' and 'side levers.' The centre-lines are *a d*, *e h*, *v v*. The plan is shown

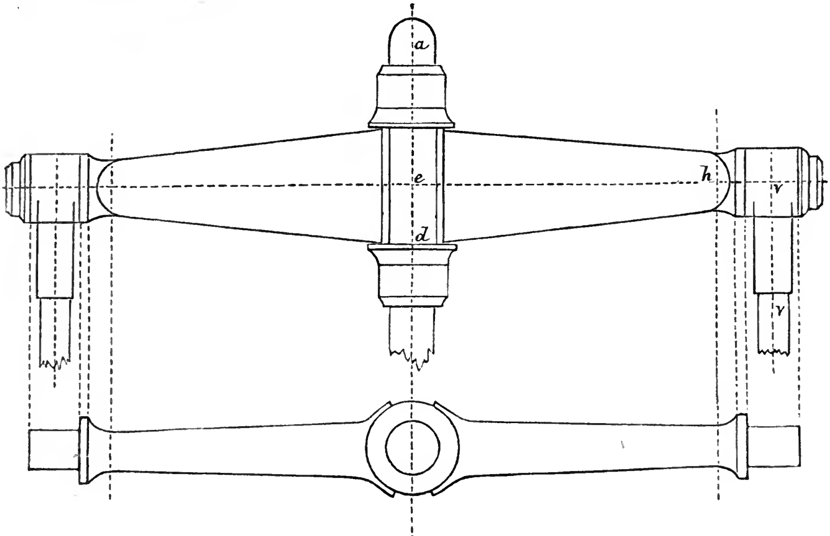


fig. 25.

below, the lines of which are obtained by continuing those of the upper figure, as in the drawing.

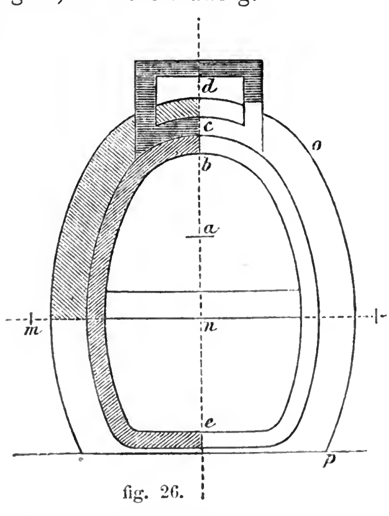


fig. 26.

EXAMPLE 25, fig. 26, represents the front elevation of the cover for a gas retort. The centre of the parts *b*, *c*, and *d* is at *a* on the line *d e*; the centre of the curve joining *o p* at *m*, on the line *n m*.

EXAMPLE 26, fig. 27, represents the 'transverse vertical section' of a boiler *a b*, and its brick 'setting.' From *a* with *a b* describe the circle *a b*; from *a* measure to *c*; draw *c d*, and from *d*, *d e*. From *d* measure to *g*, from which point a line drawn parallel to *c d* marks the point *f*, where the curve *f o'* terminates at the boiler. The point *n'* is the centre of the curve *f o'*; transfer this part from *f* to *n'*, and describe *o' f*. From *a* measure to the lines *o s*, *n m*, and draw lines through these parallel to *c d*; measure from *d* to *r* and *g*. The centre of the curve *o' h* is at *s*, and that of the curve *h r* at *m*.

EXAMPLE 27, fig. 28, represents an 'angular-threaded screw.' To copy it, proceed as follows: Measure from *a* to *d*, and from *d* to *e*, 1, 2, 3, &c.

These are the points through which the centre-lines of each thread are drawn. From *a* measure to *f*, and draw *f g*; and from *a* to *b* and *c*, and

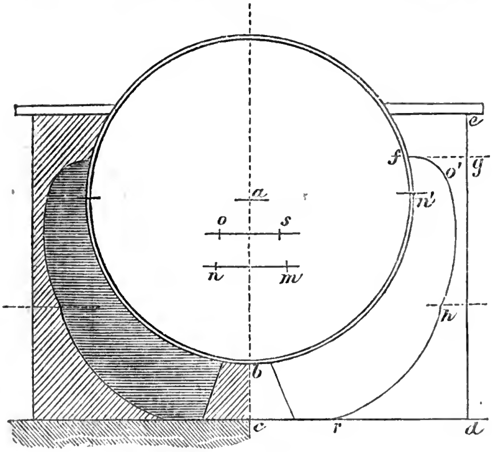


fig. 27.

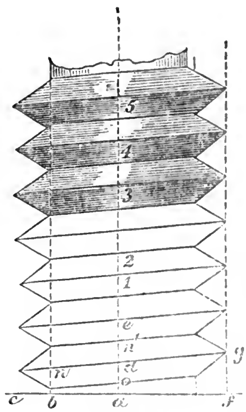


fig. 28.

draw *b n*. From *f* on the line *b f* measure to *g*, and from *b* to *n*; through *d* draw *n d g*, and parallel to this, through *e*, 1, 2, 3, &c., draw lines. Next, from *d* measure on each side of *d g*, equal to half the breadth of each thread, to *n'*. These lines terminate at the perpendicular *b n*: join the angles as in the drawing.

EXAMPLE 28, fig. 29, represents a 'square-threaded screw.' From *e* measure to *a*; *a b*, *b c*, *c d*, represent the thickness of each thread and the

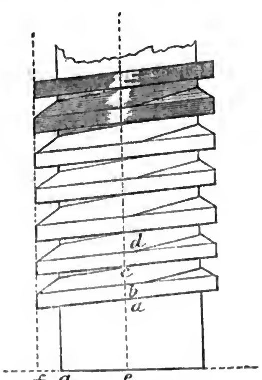


fig. 29.

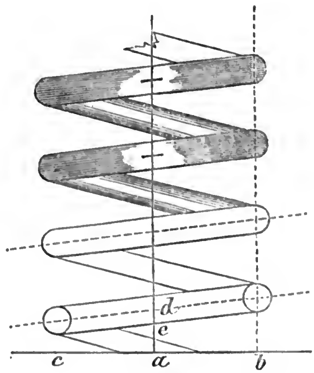


fig. 30.

distance between them; the line from *g* is the line of the inside of the screw, the line *f* the outside line of the threads. The last example shows the method of copying this.

EXAMPLE 29, fig. 30, represents a 'helix' of wire, *a d* being centre-line, *d e* being half the thickness of the coil, the lines from *c*, *b* intersecting those drawn parallel to *d*, giving the centre of the circles forming the termination of coils.

EXAMPLE 30, fig. 31, represents another form of screw.

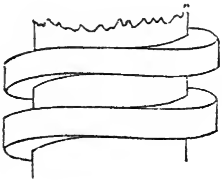


fig. 31.

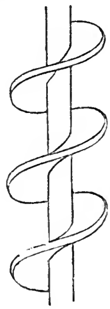


fig. 32.

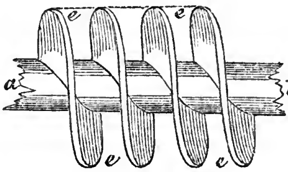


fig. 33.

EXAMPLE 31, fig. 32, represents the Archimedean, or endless screw; and another form is given in

EXAMPLE 32, fig. 33, where *a b* is the central shaft round which the helix or thread *e e* is coiled, according to a determined pitch.

EXAMPLE 33, fig. 34, shows the method of drawing-in the teeth of wheels. Let *c x* be the diameter of wheel from centre to outside of teeth.

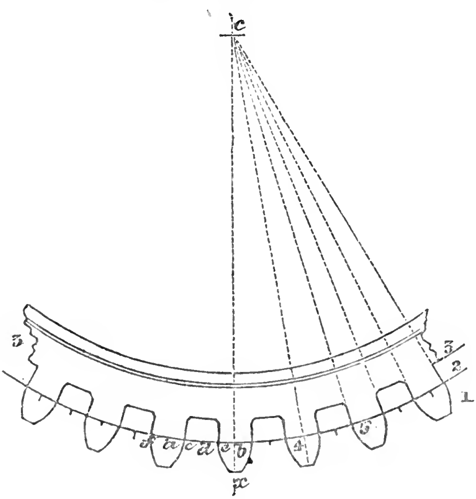


fig. 34.

The circle, of which part is shown, and of which *c b* is the radius, is termed the 'pitch-circle or line.' It is on this line that the number of teeth are marked off. Having ascertained the diameter of pitch-line, the depth of teeth, and the number of them, divide the pitch-circle into as many equal parts as there are to be teeth in the wheel, and proceed as follows: Let *a*, *b*, 4, 5, &c., be the divisions on the pitch-circle representing the centres of teeth; divide the distances between them into two equal parts, as at *d*. From *d* as a centre, with *d b* on both sides of the point *d*, describe arcs of circles as *f b*, joining the pitch-circle and the outer circle, giving the termination of the teeth as the circle *x* 1. Proceed in this way till all the arcs are made to join the circle *x* 1, 2 *d*. The bottom of the teeth are formed by radial lines drawn as from *c e* to the centre *c*, as in the diagram. The forms of teeth are various (see treatise on Mechanics in this series). For the method of describing different curves, and of setting out teeth of wheels and pinions, see treatise on Mechanical and Civil Engineering. The method of drawing the side elevations of toothed wheels may be seen in

EXAMPLE 34, fig. 35. The small dotted circles show another method of describing the form of teeth. The manner of delineating bevil-wheels

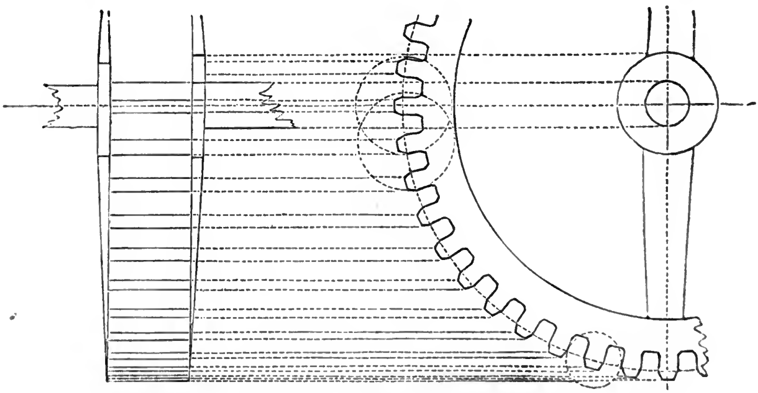


fig. 35.

(for the nature and operation of these see treatise on Mechanics in this series, at pp. 51, 52), may be gathered from the two following figures.

EXAMPLE 35, fig. 36. Let *a b* represent the centre-line of the wheel, *c d* the line of its greatest diameter or 'pitch-line,' *f* the line giving termination of teeth, *d m* being the breadth of the teeth. The teeth on the part between *c v*, *d m* converge to the point *b*; those between *k d*, *c n* to the point *a*, on the line *a h g*, *e f b*. It is foreign to the purpose of this work to go into the subject of the teeth of wheels, belonging, as it does, to a strictly technical department; we cordially recommend, however, to the pupil anxious to study this interesting and important department, Buchanan's work on *Mills and Mill Gearing*, edited by Sir John Rennie, and published by Weale of Holborn; and the *Engineers' and Machinists' Assistant*, by Blackie of London and Glasgow. Both of these works, although somewhat high-priced, abound in valuable information. We may possibly, at some future time, publish a companion to this treatise, which may serve as a guide or introduction to the sciences of Civil and Mechanical Engineering. To proceed, however, with our explanation. The method of copying the teeth of bevil-wheels may be seen in

EXAMPLE 36, fig. 37, where *a b* is the centre-line of wheel, *c g* the pitch-line, *e h* the line terminating the teeth on the back part of the wheel *e g*.

The line $x\ x$ gives the termination of the inside of the teeth, $d\ f$ that of the outside; the lines $g\ o$, $g\ f$ are projected towards points on the line $a\ b$, cor-

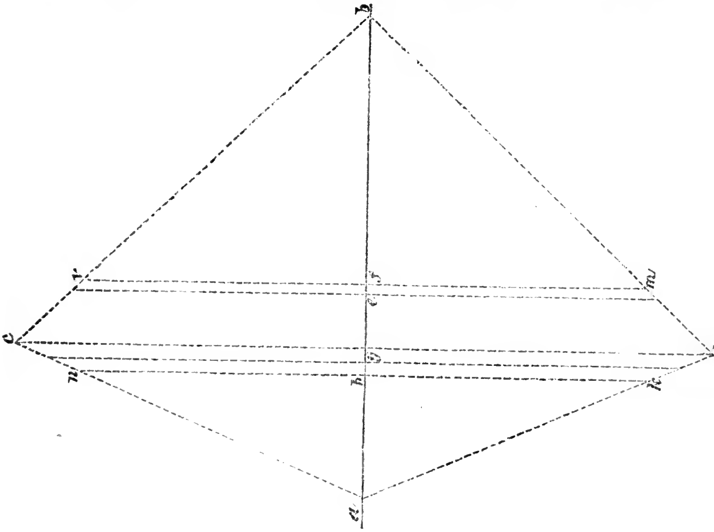


fig. 36.

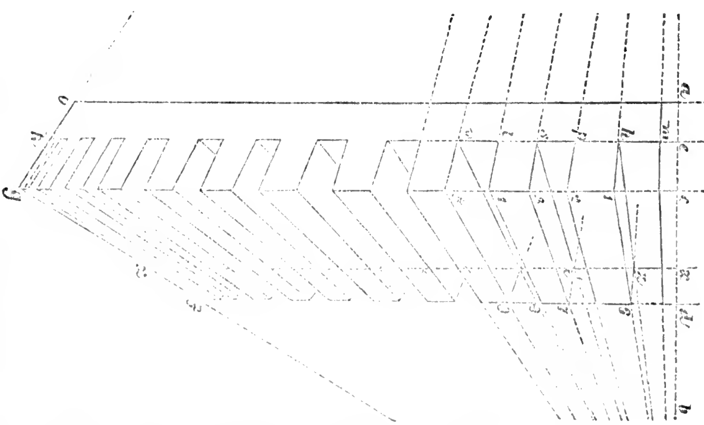


fig. 37.

responding to $a\ b$ in fig. 36. The distances between the teeth are set off on the line $e\ h$ to m, h, p, s, t, &c.; lines are drawn from these to the point on the line $a\ b$, to which $o\ g$ converges; these lines are produced to meet the line $e\ g$ in the points 1, 2, 3, 4, 5, &c. From these points, lines, as 1, 6, 3, 7, 5, 9, are drawn to the point on the line $a\ b$, to which $g\ f$ converges; these lines are terminated by the line $d\ f$. From the points h, s, v, &c., lines are drawn to the same point on $a\ b$, as 5, 9, &c., these being terminated by the line $x\ x$; the points 6, 7, 9, &c., are then joined to these, as 6 z, 2 t, &c. The pupil should put in the whole of the wheel, of which only half is here given.

Mechanical drawings are reduced or enlarged quickest by means of what are termed 'proportional compasses.' If these are not available, 'scales' should be drawn from the different figures. Thus, to reduce the drawing in

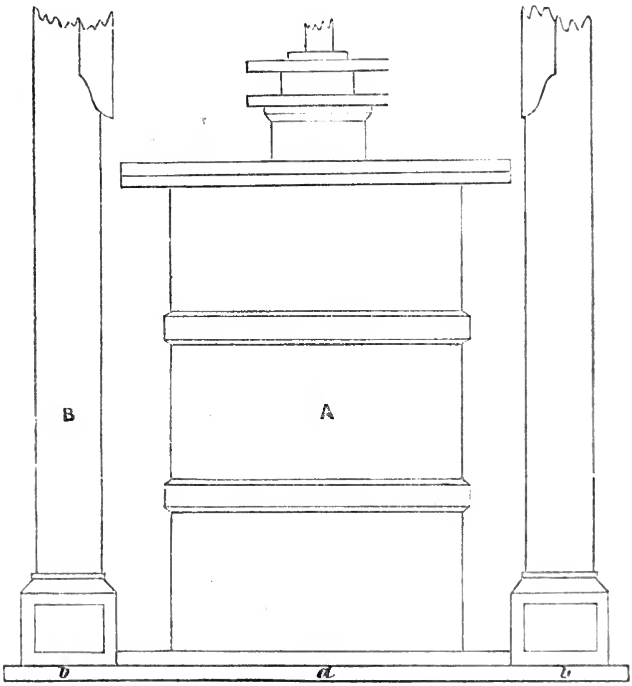


fig. 38.

fig. 39.

Example 37, fig. 38, of which the scale is given in fig. 39. Suppose the drawing is to be reduced one-half, a scale half fig. 39 is to be made, as in fig. 40; and as each measurement is taken in the compasses from fig. 38, it must be applied to the scale in

fig. 40.

fig. 39. Suppose this distance is found to be 6 feet, then the distance of 6 feet must be taken from the scale of fig. 40; and the line thus obtained must be drawn in a situation corresponding to that in fig. 38. The result will be a reduced copy, one-half of the size, as shown in

Example 38, fig. 41. To reduce by means of the proportional compasses: Having previously set them at the desired mark on the scale attached to each instrument, according to any proportion as desired, all that is necessary to be done is to take any measurement with one end; the distance corresponding to this, reduced or enlarged, is given in the other ends. This being transferred to paper, the desired distance is obtained at once. To reduce by means of the ordinary compasses, without the use of a scale as just described in figs. 38-41, is a matter requiring greater time, and accuracy of adjustment of the compasses is indispensable. Suppose *a b*, fig. 41, to be the points representing the intersection of the centre-lines

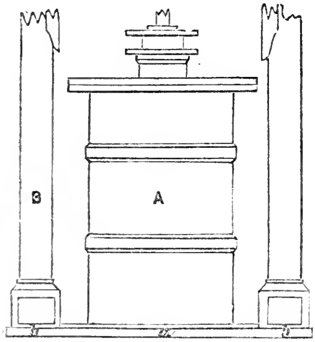


fig. 41.

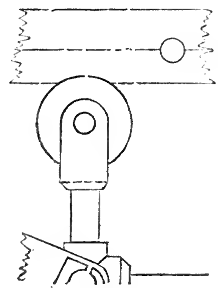


fig. 42.

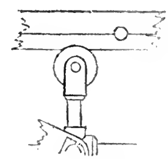


fig. 43.

of the parts A, B with the base-line *a b*, and that a line corresponding to the centre-line from *a* was drawn on paper, and that half the distance *a b* in the copy was to be transferred to the paper, half of *a b* would have to be found in the first place on the copy and transferred. By proceeding thus, a copy of fig. 41, but only half its size, would be obtained. The enlargement of figures is exactly the *converse* of what we have described in figs. 38-41.

EXAMPLE 39, fig. 42, is a drawing which is reduced half in

EXAMPLE 40, fig. 43.

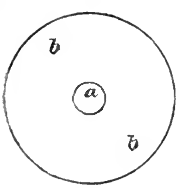


fig. 44.

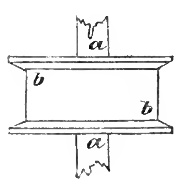


fig. 45.

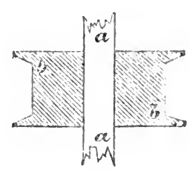


fig. 46.

Mechanical drawings are delineated in three ways; as 'plan,' shown in

EXAMPLE 41, fig. 44, which represents the 'plan' of a pulley or solid drum. In 'elevation,' as in

EXAMPLE 42, fig. 45, which is the elevation of fig. 44. Elevations may be 'front,' 'back,' 'end,' or 'side.' In 'section,' as in

EXAMPLE 43, fig. 46, which is a transverse vertical section of figs. 44 and 45. The same letters of reference denote the same parts in these three sketches. Sections may be divided into 'transverse' and 'longitudinal,' these being either vertical or horizontal.

In finished outline-drawings, shadow-lines are made use of. The light, in the generality of examples, is supposed to come from the top and left-hand side of the drawing, thus throwing the right hand and under lines in shadow. These are therefore made darker in inking-in the drawing, as exemplified in

EXAMPLE 44, fig. 47, which is the outline drawing of 'front elevation of high-pressure steam-engine,' the plan of sole-plate of which is given in

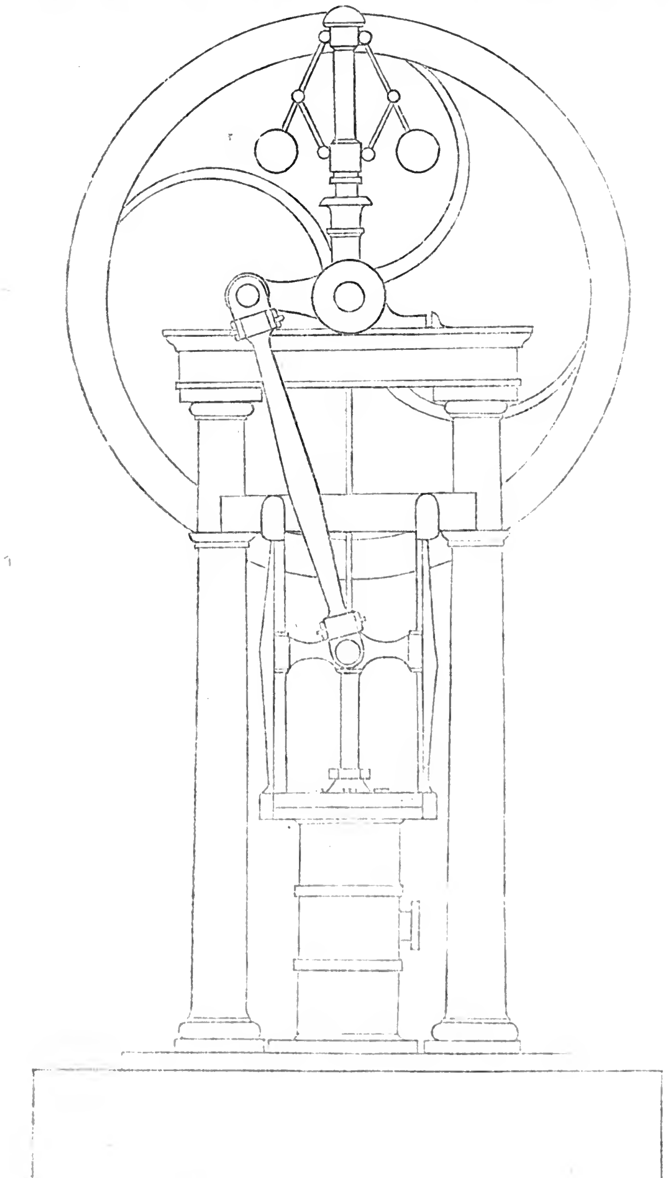


fig. 47.

EXAMPLE 45, fig. 48.

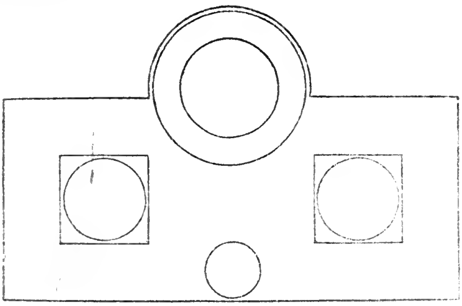


fig. 48.

We now proceed, as a conclusion to this department, to give a few examples to serve as copies to the student, in copying which he will find his operations much facilitated if he has paid full attention to the preliminary lessons. The copies given in perspective are set out by the rule given in the section on 'Perspective' in the *Illustrated Drawing-Book*, to which we refer the reader.

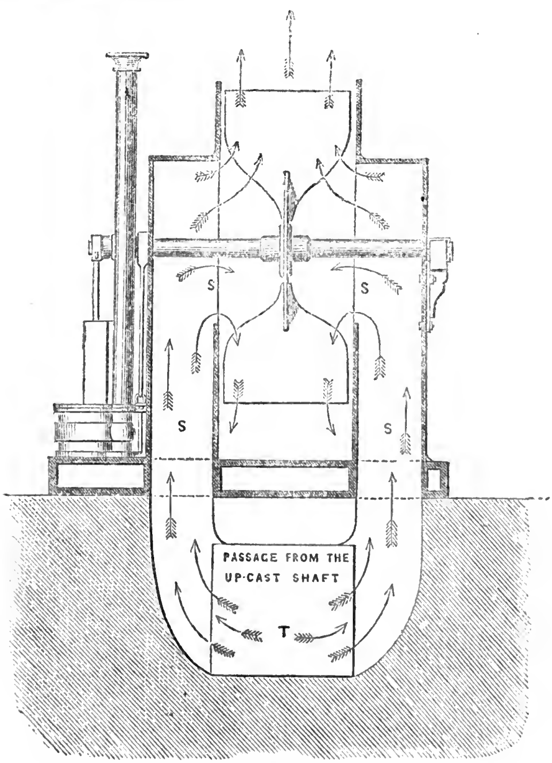


fig. 49.

Example 46, fig. 49, is a transverse vertical section of Nasmyth's steam ventilating-fan.

Example 47, fig. 50, is a longitudinal vertical section of an aerated water-machine.

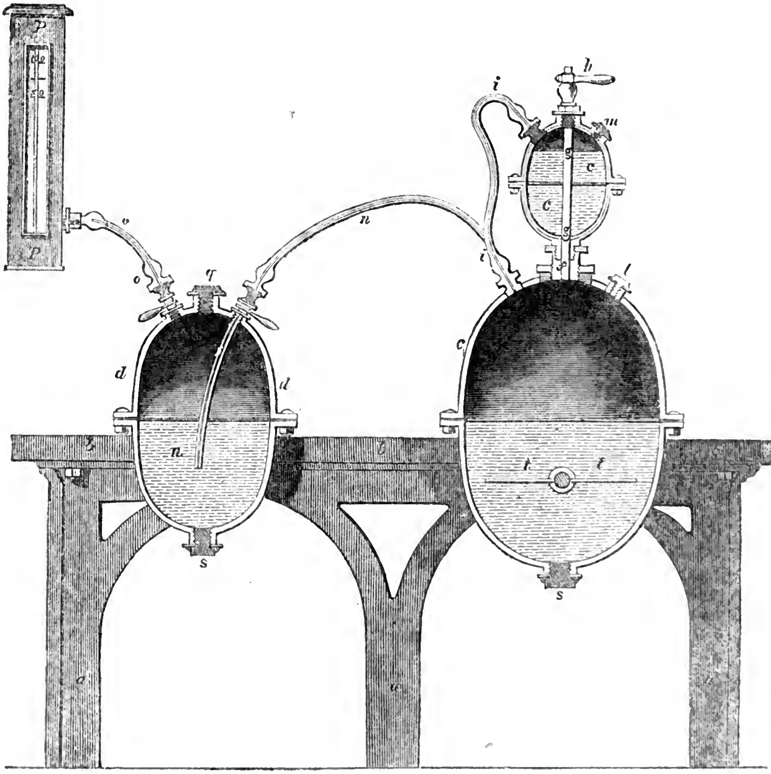


fig. 50.

Example 48, fig. 51, is a longitudinal and transverse vertical section of a smoke-burning furnace.

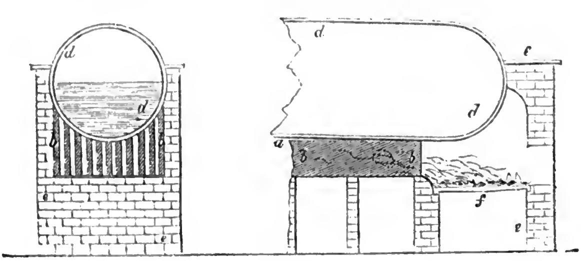


fig. 51.

EXAMPLE 49, fig. 52, is 'side elevation' and 'end elevation' of Roberts' Alpha clock.

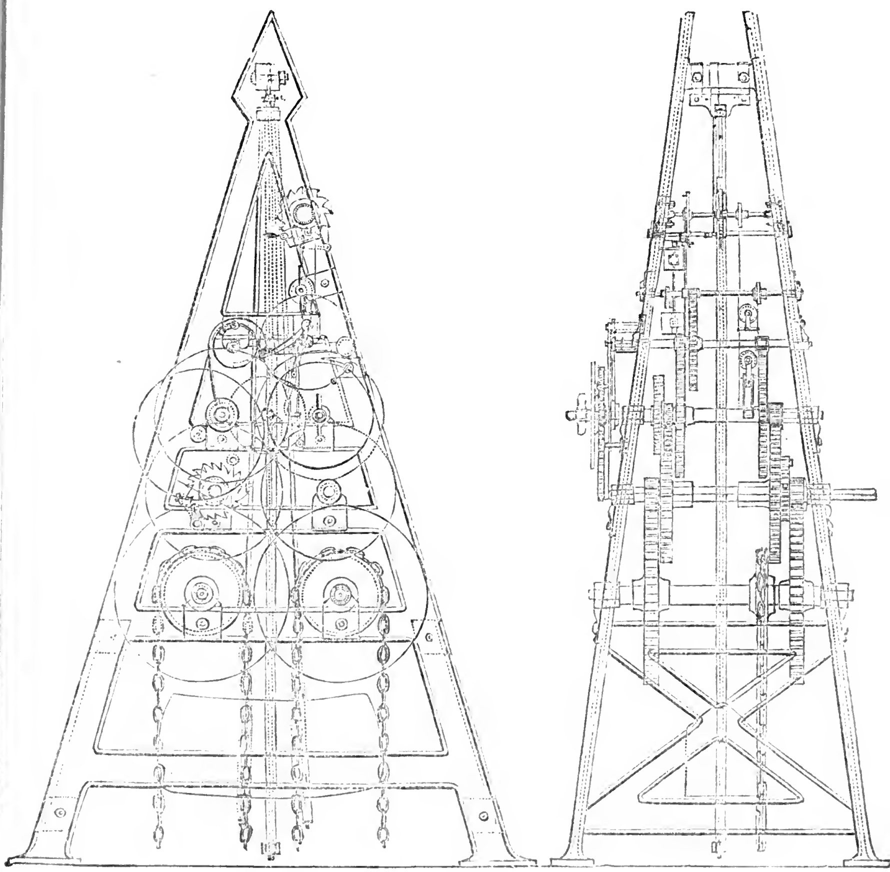
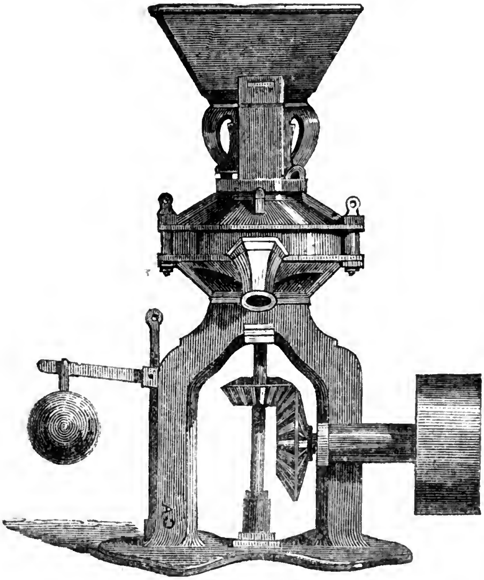


fig. 52.

EXAMPLE 50, fig. 53, represents a side-elevation of a corn-mill, with section (vertical) through the grinding-plates.

EXAMPLE 51, fig. 54, is a perspective view of another form of portable corn-mill.



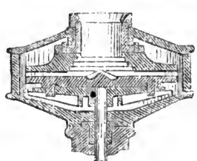


fig. 53.

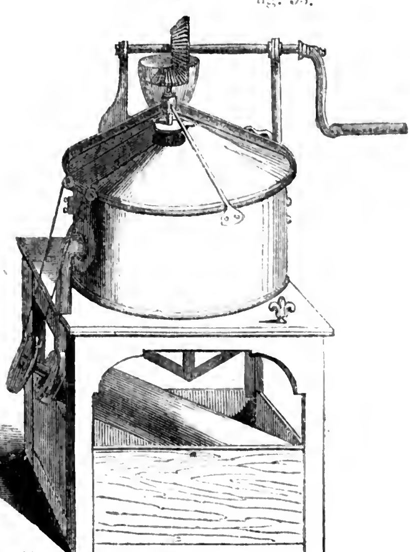


fig. 54.

Example 52, fig. 55, is a transverse vertical section of the 'patent conical flour-mill,' of which the perspective view is given in

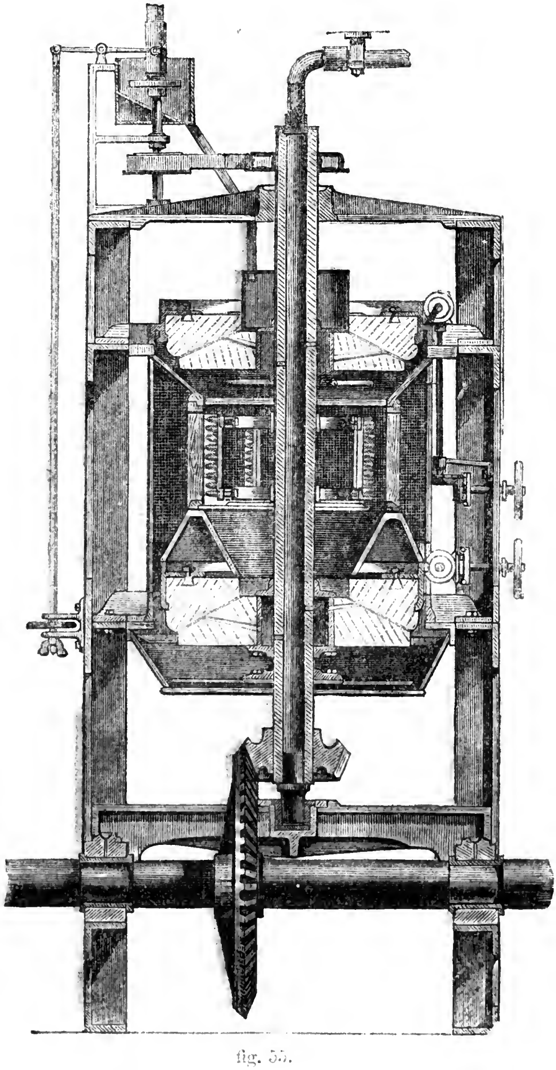


fig. 55.

Example 53, fig. 56.

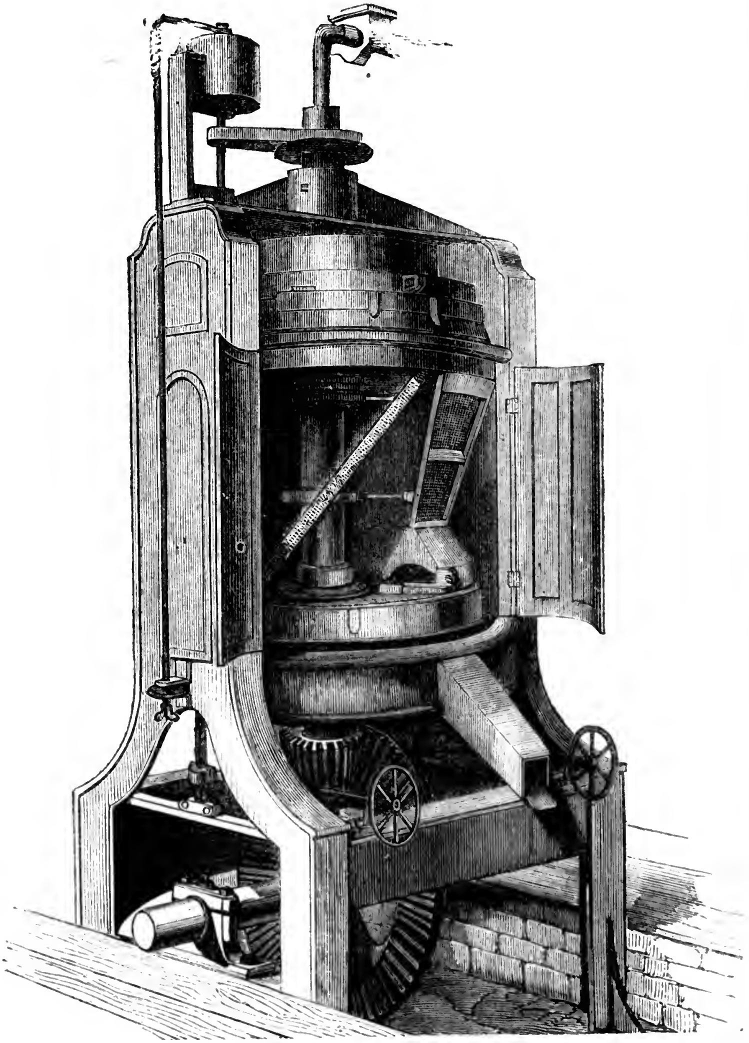


fig. 56.

Example 54, fig. 57, is front elevation of a fixed high-pressure steam-engine.

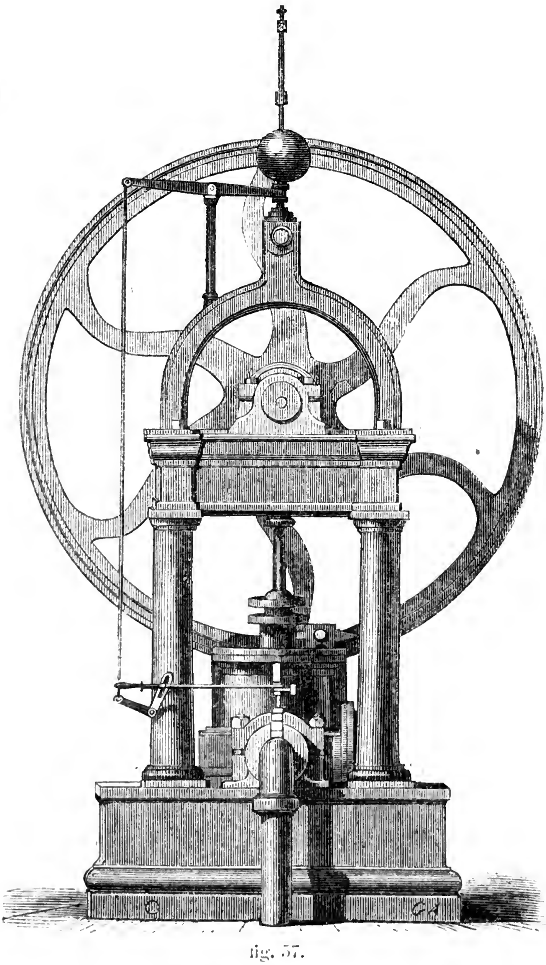


fig. 57.

EXAMPLE 55, fig. 58, is a perspective sketch of a fire-engine.

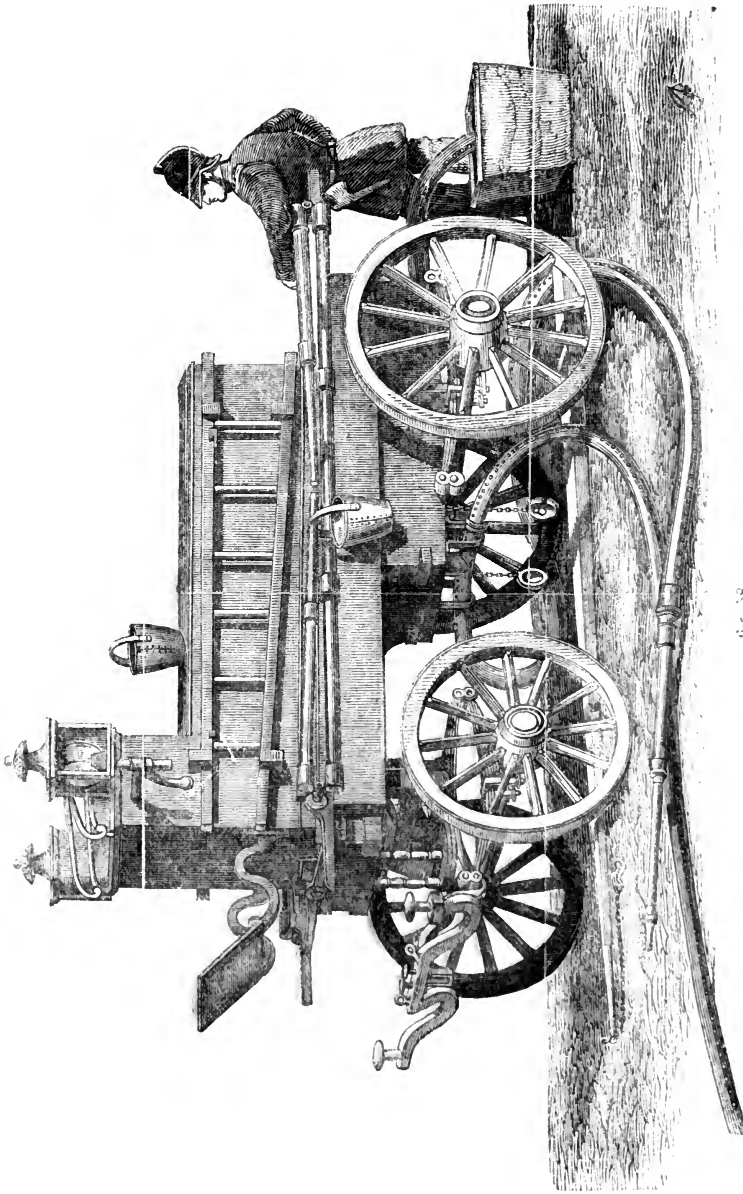


fig. 58.

EXAMPLE 56, fig. 59, is a side elevation of a 'disc-pump.'

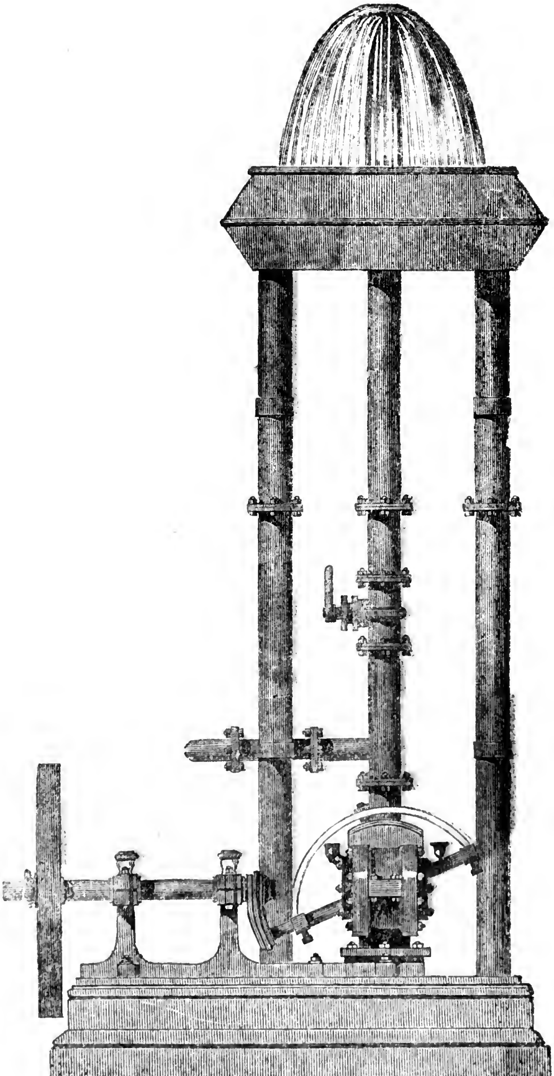


fig. 59.

Example 57, fig. 60, is a perspective sketch of a 'drug-grinding-machine.'

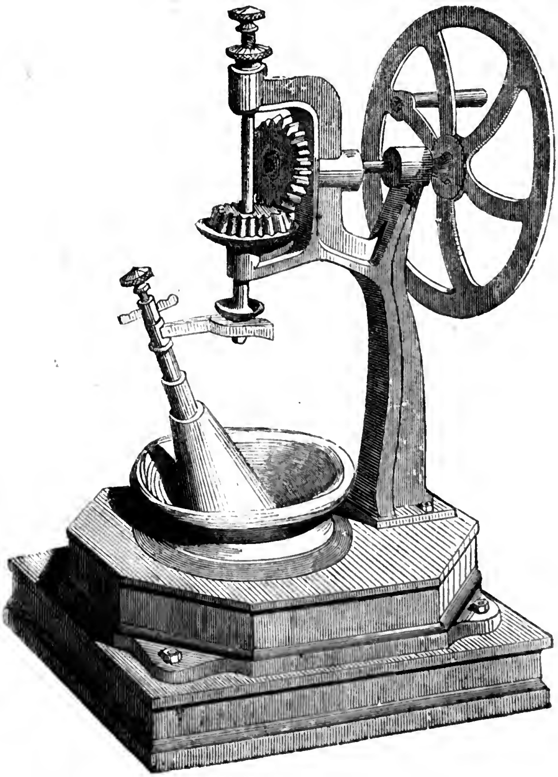


fig. 60.

EXAMPLE 58, fig. 61, is the side elevation of an 'American wood-burning locomotive.'

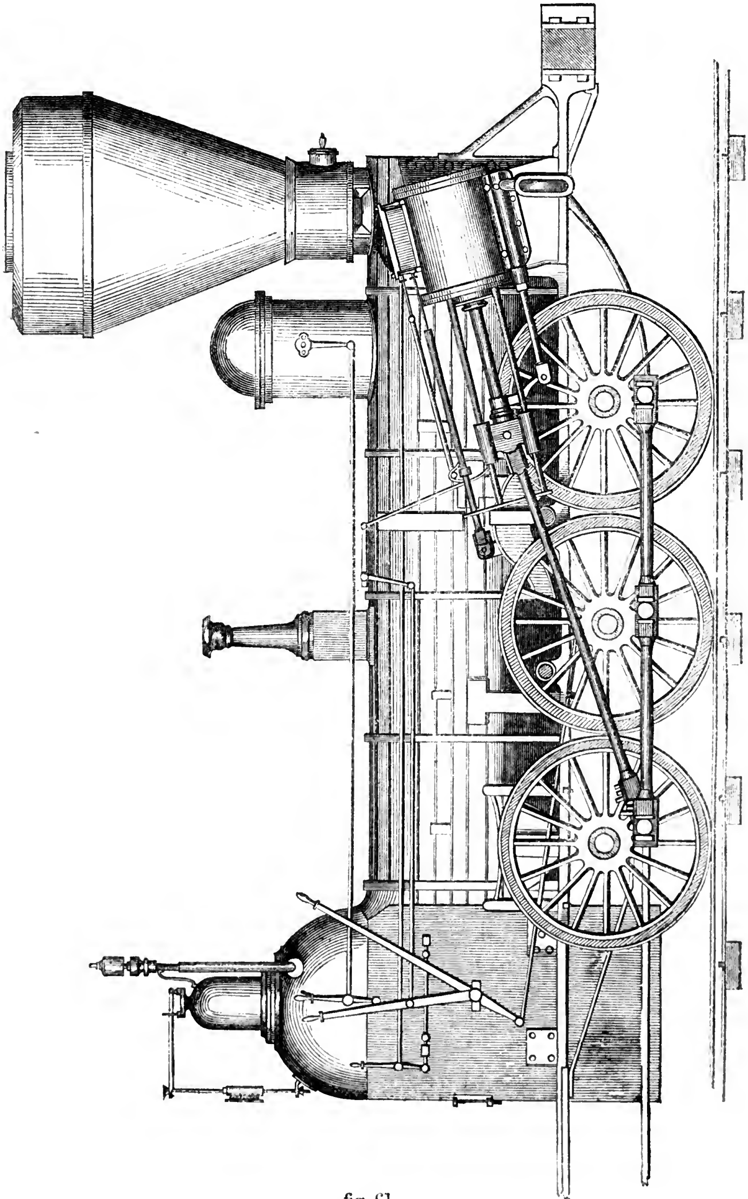


fig. 61.

In the various examples we have given, the pupil will perceive the method in which the various parts are shaded in order to represent round parts, flat, and so on. Mechanical outline-drawings may be shaded by means of lines, as in the examples we have given, thus imitating the manner in which engravers give the desired shade. When this is carefully executed in fine ink lines, regularly drawn, the drawing has a fine effect when finished, accurately presenting the appearance of roundness in some portions, and flatness in others, according as the subject requires. When this method is considered too tedious, the shades may be put in with Indian ink and a camel-hair brush, the appearance of roundness being imparted by first putting in a part of uniform depth in tint, and washing the outside line of this with a brush moistened in pure water, until the colour gradually blends into the tint of the surrounding paper. The depth of tint towards the outside part should be gradually got up to the desired point by repeated operations, the colour used being of a light shade. The addition of a little blue imparts a softness to the Indian ink, which is agreeable to the eye. Cast-iron surfaces are represented by a bluish-gray tint, malleable iron by a light blue; brass surfaces by a faint yellow, brick by a reddish yellow, faintly mottled with a shade darker of the same colour; stones by a faint yellow, with horizontal streaks of a darker tint; wood by yellow, with vertical streaks of a faint black; water by faint blue, with horizontal streaks or lines of a faint black: these look best when put in carefully with the pen and square, as in the diagram in fig. 62. These are the principal shades of colours required in mechanical drawings. The colours generally required are Indian ink, gamboge, Prussian blue, Indian red, lake, and sepia.


fig. 62.

The reader desirous of extending the range of his copies will find numerous excellent examples of machinery in the work on Mechanics in this series.

THE END.

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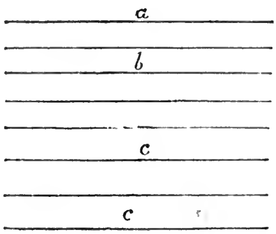
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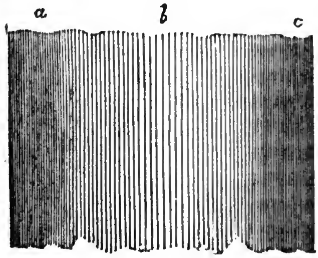
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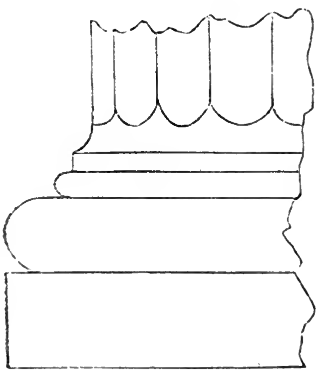

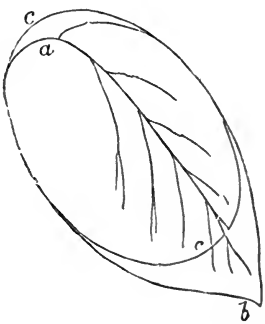
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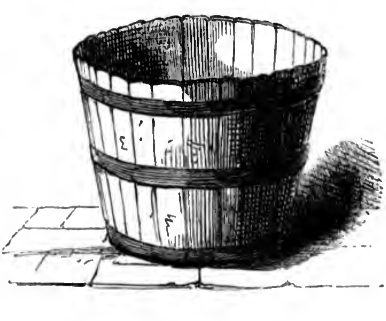
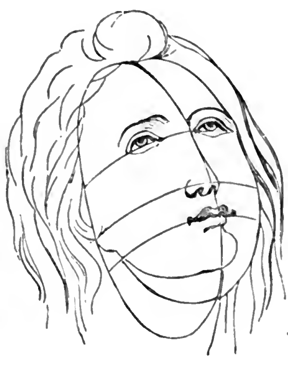




THE ILLUSTRATED
DRAWING-BOOK.

FOR THE USE OF

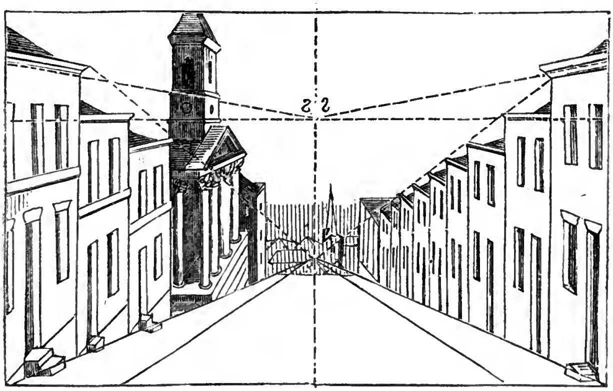
SCHOOLS, STUDENTS, AND ARTISANS.

CONTAINING

I. PENCIL DRAWING.
II. FIGURE AND ART.
III. PERSPECTIVE, &c.
IV. ENGRAVING.

WITH

THREE HUNDRED ILLUSTRATIVE DRAWINGS AND DIAGRAMS.



BY

ROBERT SCOTT BURN,

AUTHOR OF THE "ILLUSTRATED ARCHITECTURAL, ENGINEERING, AND MECHANICAL DRAWING-BOOK," "MECHANICS AND MECHANISM," "THE STEAM ENGINE," "PRACTICAL GEOMETRY," ETC. ETC.

THIRD EDITION, REVISED.

LONDON:
WARD AND LOCK, 158, FLEET STREET.

1856.

LONDON:

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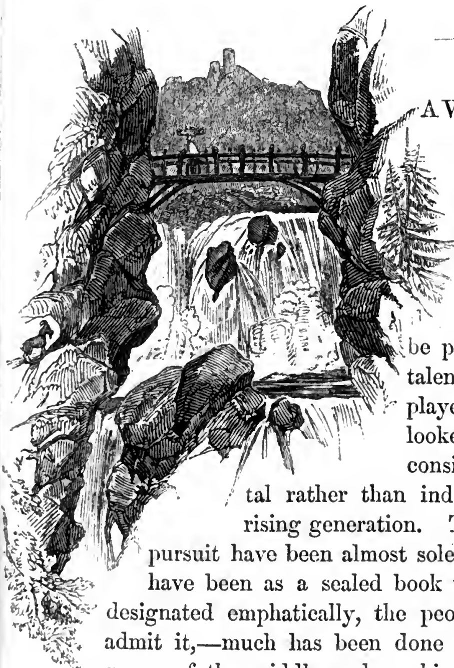
ADJOINING THE "TIMES" OFFICE.

THE

ILLUSTRATED DRAWING-BOOK.

INTRODUCTION.



HAVING long witnessed the neglect of Art in our Educational systems, the author trusts that the present work will be found in some measure to supply a means of extending its useful and beneficial influence. Imparted to many as affording a means of gratification by which time may be pleasantly occupied, or the taste and talent of the artist encouraged and displayed, Drawing has been generally looked upon as an accomplishment, not considered as an essential—as ornamental rather than indispensable in the education of the rising generation. The pleasures and advantages of its pursuit have been almost solely enjoyed by the rich; while they have been as a sealed book to the great majority of those now designated emphatically, the people. True,—and we feel glad to admit it,—much has been done of late to place within the reach of many of the middle and working classes the means of acquiring a knowledge of the art. Our Schools of Design and Mechanics' Institutes have done much in this respect; but the extent of their operations has been exceedingly limited, and by no means meets what we deem the exigencies of the case. So far from looking upon a knowledge of the art of Drawing as necessary merely to the Artist or Designer, we hold that it should form an essential part of general education—that its proper place is in the daily school, that its principles and practice should be inculcated in the daily lessons; in short, that equally with reading or writing, so should Drawing be deemed one of the branches of every-day tuition.

And that such a position is correct, we deem a matter of easy proof. We are now fully alive to the importance of cultivating what are designated "habits of taste," and the appreciation of the beautiful in art; and this chiefly—if for nothing else—from the practical value derivable therefrom in the improvement of our Arts and Manufactures. As a people, we are far behind Continental nations in practically applying to the details of every-day business those perceptions derived from a consideration and examination of the beautiful and artistic, whether as exemplified in the productions of art, or as witnessed in the ever-varied and graceful forms of surrounding nature. First among the helps to bring about another order of things in this respect is that of Drawing. By a thorough understanding of its details, an accuracy of perception and a facility for marking and retaining forms and arrangements are readily available. It is, then, of importance to place within the reach of all a means by which the Art, in its varied branches, may be easily communicated. The design of the present work is to contribute to this desideratum. We shall make our remarks as plain as possible, and as concise as the nature of the subject will admit of; and shall give unsparingly, well-digested illustrations. It is to be hoped that this union of the pen with the pencil will be of great utility in quickly imparting a knowledge of the subjects under discussion. Before proceeding to our more immediate purpose, we shall offer a few remarks elucidatory of the plan of the system by which we mean to be guided in presenting the requisite information to the student.

A knowledge of Drawing is too frequently imparted by a course of irregular and desultory lessons, aided by a laborious practice, dependent more upon empirical rules than fixed and certain principles. We are aware that there are many honourable exceptions to this rule of practice; but few, we think, will be disposed to deny that it is greatly followed. On the supposition that the pupil at the outset is utterly ignorant of the art, we commence our instructions by elucidating FIRST PRINCIPLES. As all drawings are reducible to certain lines and figures, we hold it necessary to teach the student, in the first place, to draw these elementary parts with the utmost facility; following these, by a series of examples, from the simplest up to the most complicated sketch which may be offered to him; and then, by an advance to the more intricate rules, making plain the laws of vision (the foundation of perspective), so as to enable him to delineate correctly the various views in which these are exemplified. We require the student thoroughly to understand the reason why every operation is performed as directed, not merely to give him a facility for copying any determined object without reference to principles. By dint of practice he may acquire a facility for this merely mechanical style of imitation or copying; but unless well grounded in fundamental principles, his operations will be vague and uncertain. It is, indeed, trite to remark, that the better we are acquainted with the first principles of an art, its basis or foundation, so much more intimately conversant shall we be with all the intricacies of its diversified practice, and the less easily damped by its real or apparent difficulties. Students too frequently expend much time, almost entirely in vain, from want of attention to this truth, common place as it may be deemed. In acquiring the practice of this art, they are too eager to pass from the simple rules, the importance of which they think lightly of. A sure and well-laid foundation will not only give increased security to the building, but will enable the workmen to proceed with confidence to the proper carrying out of the design in its entirety; on the contrary, an ill-laid foundation only engenders distrust, and may cause total failure. We are the more inclined to offer these remarks, being aware that students, at the commencement of a course of tuition, are apt, in their eagerness to be able to "copy" a drawing with facility, to overlook the importance of the practice which alone enables them satisfactorily to do so. It is the wisest course of procedure to thoroughly understand the details of an art, before proceeding to an acquaintance with its complicated examples.

We would, then, advise the student to pay particular attention to the instructions in their ENTIRETY which we place before him; if he be truly anxious to acquire a speedy yet fairly accurate knowledge of the Art, he will assuredly find his account in doing so. Instead of vaguely wandering from example to example, as would be the case by following the converse of our plan, copying, yet copying he knows not how or why, he will be taught to draw all his combinations from simple rules and examples, we hope, as simply stated; and thus he will proceed, slowly it may be, but all the more surely, from easy to complicated figures, drawing the one as readily as he does the other, and this because he will see in all their details, difficult, indeed, to the uninitiated, but to him a combination of simple lines, as "familiar as household words."

The following is the arrangement we have adopted in this work:—The *First Section* will be taken up with elucidating the practice of Pencil-Sketching as applied principally to decorative purposes, and as forming the groundwork of more extended practice in the higher branches of art. The *Second Section* will be devoted to the practice of Figure and Object Drawing. The *Third Section* will treat of Perspective, its principles and practice, applicable alike to the delineation of geometrical forms and of natural objects: *Isometrical Drawing* will be treated of under this section. The *Fourth Section* is designed to meet the wants of a large body of students, who are desirous of becoming acquainted with the readiest means of multiplying their sketches. Short and easy directions will be given, by which the student may be able to engrave or etch on copper or wood.

R. S. B.

1853.

PREFACE TO THE THIRD EDITION.

In preparing the Third Edition of this work for the Press, the Editor has availed himself of the opportunity to thoroughly revise every lesson; not only as regards the accuracy of the letter-press, but also the illustrations, by which the former is elucidated. In many cases where the illustrations did not convey the information intended—a result which happened in the first issue through the inaccuracy of the Engraving—they have been erased, and new ones substituted, characterised by greater accuracy and fineness of drawing. While feeling gratified at the extensive demand with which the work has been favoured, it is the earnest wish of the Editor to make it perfect in all its departments, so far as its limits will permit; and, to attain this desideratum, he has given this revisal his most careful attention.

THE

ILLUSTRATED DRAWING-BOOK.

SECTION I.

OUTLINE SKETCHING.

BEFORE the apparent forms of objects can be delineated, it is absolutely necessary that the *hand* shall be able to follow the dictation of the *eye;* that is, the pupil must by certain practice be capable of forming the lines which constitute the outlines and other parts of the objects to be drawn. Before being able to write or copy written language, the hand must be taught to follow with ease and accuracy the forms which constitute the letters; so in drawing, the hand must be tutored to draw at once and unswervingly the form presented to the eye. Thus the handling of the pencil, the practice to enable the hand to draw without hesitation or uncertainty, and the accurate rapidity essential in an expert draughtsman, may be considered as the first part of the art of free pencil sketching. It is unpleasing to see, in a sketch, the evidences of an uncertainty in putting in the lines; just as if the hand was not to be trusted, or at least depended upon, in the formation of the parts dictated by the eye. The eye may have an accurate perception of the object to be drawn, yet its formation may be characterised by an indecision and shakiness (to use a common but apt enough expression), which to the initiated is painfully apparent.

In beginning, then, to acquire a ready facility in free sketching, in which the hand and eye are the sole guides, the pupil should consider it well-spent time to acquire by long practice an ease and freedom in handling the pencil, chalk, or crayon with which he operates.

The first lessons may be performed with a piece of pointed chalk on a large black board: some of our celebrated artists have not in their early days disdained the use of more primitive implements, as a piece of burnt stick and a whitewashed wall or barn-door. The larger the surface on which the lessons are drawn the better, consistent, of course, with convenience. If a black-board cannot be obtained, a large slate should be used.* Until the pupil has acquired a facility for copying simple forms, he should not use paper and pencil; as in the event of drawing a wrong line, it is much better at once to begin a new attempt, than try to improve the first by rubbing out the faulty parts and piecing the line up. As the

* It would tend much to the general introduction of "Art lessons" in schools of the middle and lower classes, could a series of stiff and durable sheets with rough black surfaces be produced, at a cheap rate. These might be furnished at the upper end with a few subjects in different departments of the art, which the pupil could copy—these copies being capable of erasion by means of a damp sponge—chalk pencils being used. In this way the sheets would serve for a succession of pupils.

pupil must necessarily expect to make many blunders at first starting, it will save paper if he will use a board or slate, from which the erroneous lines can be at once removed, a damp sponge being used for this purpose. By this plan any number of lines may be drawn.

Having provided himself with the necessary materials, the pupil may begin by drawing simple lines. These must be drawn without the assistance of a scale or ruler, by the hand alone. The line *a*, fig. 1, will be parallel to the side of the board or slate, and perpendicular to the ends. The pupil should endeavour to make the line as regular as possible, and to run in one direction—that is, neither inclined to the right nor left. He should next draw horizontal lines, as *b*, beginning at the left and going towards the right hand. In drawing lines as *a*, the pupil should begin at the top and go towards the bottom; in a more advanced stage he should try to draw them from either end. The oblique lines *d e e* and *f* should next be drawn. In all these exercises the line should be drawn boldly, in a length at a time, not piece by piece: the hand should not rest on the board or slate while drawing, but should be free, so that the line may be drawn in at one sweep, as it were, of the arm or wrist; the latter only resting on the board, the hand being allowed free movement. Irregular or "waved" lines should next be drawn, as at *c*: this style of line is useful in drawing broken lines, as in old ruins, trees, gates, stones, &c. &c. The pupil must not content himself with drawing a *few* examples of the lines we have given. He must practise until he can at once with ease draw lines in any direction correctly; and he ought to progress from simple to difficult, not hastily overlook the importance of mastering simple elementary lessons. With a view to assist him in arranging these, and to afford not only examples for practice, but also to prove by a gradation of attempts the connection—too apt to be overlooked by many—between simple lines and complex figures, we proceed to give other lessons.

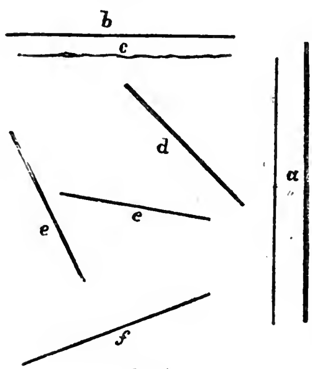


fig. 1.

Fig. 2 shows a number of parallel lines, as *a b c*; in this lesson, not only must the pupil endeavour to keep each line straight from beginning to end, free from waviness and indecision, and also parallel to one another, but another object must be kept in view; that is, the distance between the lines: hitherto he has drawn lines with no reference to this, but merely to their position and direction. No mechanical aids must be allowed to measure the distances, this must be ascertained by the eye alone; and a readiness in this will be attained only by practice. The eye is like the memory; it must be kept in constant training before it will do its work. By inspecting the diagram, it will be perceived that

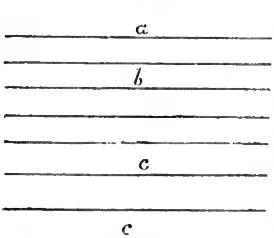


fig. 2.

the lines marked *c c* are further apart than those above. All gradations of distances should be carefully delineated; and if, after the lines are drawn, the eye should detect, or fancy it detects, any error in this respect, let the lines be at once erased, and a new trial made; and let this be done again and again, until the lines appear to be correctly drawn, both as regards boldness and correctness, and distance apart. After drawing the horizontal lines, the student may then proceed to perpendicular lines. It may here be noted, to save future explanation, that when we use the term perpendicular, we mean it to be that applied to a line or lines which run parallel to the side of the board or slate; and horizontal, those parallel to the ends: strictly speaking, both lines thus drawn are perpendicular to others which may be drawn parallel to their opposite sides. We, however, suppose the surface on which the pupil is drawing to be in the same position as this book while held open for reading; the sides to represent the sides, and the ends the ends of the drawing-board or slate. Lines are horizontal when parallel with the lines of type, and perpendicular when parallel with the sides of the page; it is in this way, then, that we shall use the terms horizontal and perpendicular. Perpendicular lines, as in fig. 3, may next be drawn, close to one another at the sides, at *a* and *c*, and further separate at *b*; they may also be drawn horizontally in the same way;—this practice will be useful in more advanced stages. As the pupil will observe, the lines thus drawn give the appearance of roundness; it is, in fact, the way by which engravers obtain this effect: the pupil will find it useful in fine pencil-drawing.

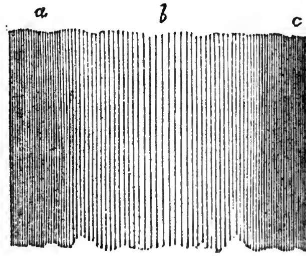


fig. 3.

The drawing of diagonal or oblique lines may next be practised, as in fig. 4. In all these examples, the board or slate should never be moved or reversed; the end forming the uppermost one should always remain so. We are aware that some have greater facilities for drawing lines in one direction than in another. Thus the majority of beginners would draw lines sloping from right to left with much more ease than in the reverse position, as in the preceding sketch. We have seen cases where, in lessons like the foregoing, the lines sloping from right to left were drawn first, the board reversed, and lines to represent those sloping the reverse way drawn in the same direction exactly; the board was then turned to its original position, when the sets of lines appeared sloping different ways, while, in reality, they were done both in the same manner. This practice is not honest either to the teacher or pupil, and should be avoided.

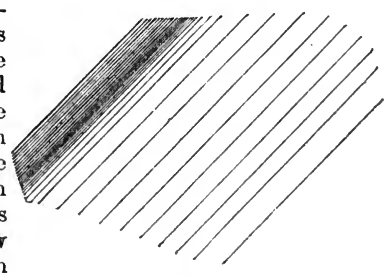


fig. 4.

The examples given have had reference only to one peculiar position of the lines to be drawn; that is, they have all been horizontal, or all perpendicular or oblique: placed in the same relative position, or parallel to one another. We now give an example where the lines go in different directions with respect to one another. Thus in drawing the lines *b a*, *a f*, *d c*, and *c e*, fig. 5, care must be taken to have the lines perpendicular to one another; that is, supposing the lines *a b*, *c d* to be drawn first, the horizontal lines *a f*, *c e* must be drawn so that the points or ends *f*, *e* shall neither be above nor below the ends or points *a c*—that is, *f* and *e* must be exactly opposite *a* and *c*. In another work in this series* we have given ample directions for erecting lines perpendicular to one another geometrically; in the present case no mechanical aid is allowable, the eye is to be the only guide. Attention should also be paid to keeping the exact distance between the lines *a b*, *a f*, and *c d* and *c e*. The pupil must not imagine that all these modifications of lines are worthless; a little patience and reflection will suffice to show him that they are, in truth, part of the groundwork, without which he can never hope to attain to perfect drawing. We now proceed to a little more interesting labour, where simple figures are to be drawn; these, however, being neither more nor less than the lines already given variously disposed. Draw the lines *a c*, *b c*, fig. 6, meeting in the point *c*; these form a certain angle: care should be taken to draw the lines as in the copy.

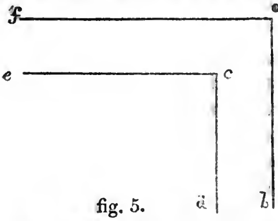


fig. 5.

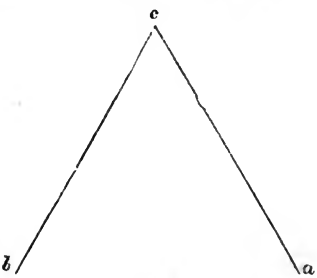


fig. 6.

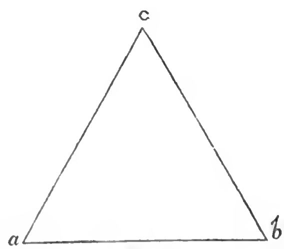


fig. 7.

Next draw the horizontal line *a b*, fig. 7, and a figure is formed which the pupil will at once recognise. Draw the horizontal line *a b*, fig. 8; perpendicular to it, from the ends *a b*, draw the lines *a c*, *b d*, taking care that they are of the same length as *a b*; draw the line *c d*, a square is at once formed. As it is an essential feature in this form that all the sides are equal, and parallel to one another, if the pupil, after drawing it, perceives that these are not attained, he should rub it out, and proceed to another attempt. Some little practice must be given to the delineation of squares, angles, &c. If a parallelogram or oblong—vulgarly called an oblong square—is wished to be drawn, it may be done by making two

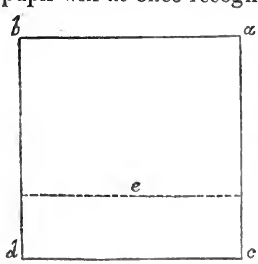


fig. 8.

* Treatise on "Practical Geometry, and its application to Architectural Drawing."

opposite lines shorter than the others: the line *e* denotes the fourth outline of an oblong, of which the side is *a b*. If two oblongs be drawn, care being taken to have the inner lines the same distance within the outer ones, by adding a narrow line outside these, as in fig. 9, the representation of a picture-frame is obtained; the diagonal lines at the corners, as at *a* and *b*, being put in to represent the joinings at the corners of the frame, the

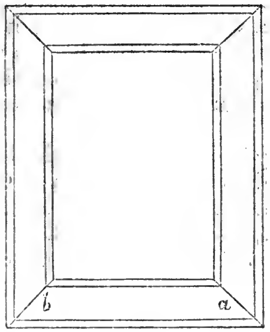


fig. 9.

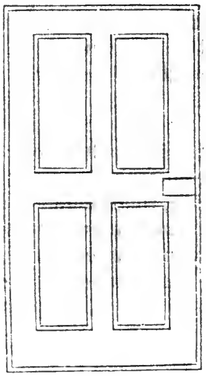


fig. 10.

"mitre" joints, as they are termed. By first drawing the simple outlines, as in fig. 10, the foundation of a door is obtained, which is finished by filling in the extra lines, as in the figure.

We now proceed to the drawing of curved lines, as in fig. 11. And as these are the basis of innumerable forms, the pupil must not rest satisfied with a few attempts at forming them; he must try and try again, until he is able, with a single sweep, to draw them correctly. They must be done

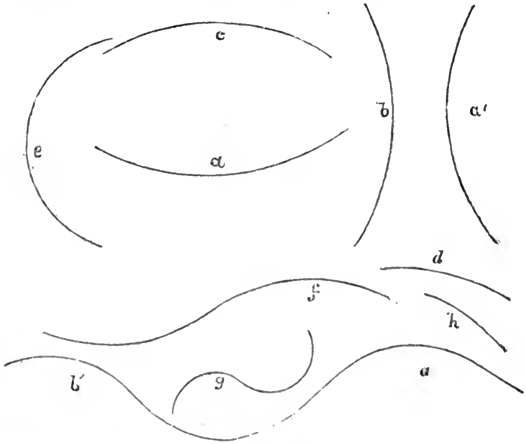


fig. 11.

in one stroke, no piecing being allowed. Let the curved line *a* be first produced; beginning at the top, bring the pencil down to the lowest part, and by another sweep of the hand, the wrist resting on the board or table, up to the other termination, so that at one operation the form may be traced; do this repeatedly, until the correct outline is attained at every trial. The pupil may next proceed to the curved lines *a b*, which are merely the line *a* in other positions; then, after repeated trials, the lines *c*, *d*, *e*, *g*, and *h* may be drawn. These curves should be attempted to be drawn in all manner of positions, beginning at the top, then at the bottom, and making the curve upwards, and so on, until the utmost facility is attained in drawing them, however placed. The curved line *s*, generally known as the "line of beauty," *f*, *a b′*, must next be mastered; it is of the utmost importance to be able to do this easily and correctly. In all these, and the future elementary lessons, the pupil must remember that when failing to draw a form correctly, he should at once rub it out or destroy it, and commence a new attempt.

Having, then, acquired a ready facility in drawing the simple elementary curved lines, the pupil may next proceed to the combination of these, exemplified in simple figures, as circles and ellipses or ovals. First attempt to draw the circle *a′ b*, fig. 12: beginning at *a′*, sweep round by the right down to *b*, then from *b* towards the left, and up to *a′*, where the circle was

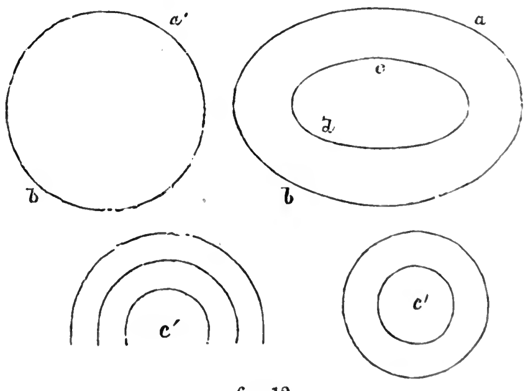


fig. 12.

first begun. The pupil may also try to draw it by going the reverse way to the above. We are quite aware that it will be found rather a difficult matter to draw a circle correctly at the first, or rather even after repeated attempts; but the pupil must not be discouraged, by dint of practice he will be able to draw circles of any size very correctly. We have seen circles drawn by hand so that the strictest test applied could scarcely point out an error in their outline, so correctly were they executed. Circles within circles may be drawn, as at *c′*; care should be taken to have the lines at the same distance from each other all round. The ellipse *a b* must next be attempted; this is a form eminently useful in delineating a multiplicity of forms met with in practice. Ovals within ovals may also be drawn, as at *c d*.

At this stage of his progress the pupil ought to be able to draw combinations of straight and curved lines, as met with in many forms which may be presented to him in after practice. The examples we intend now to place before him have no reference to picturesque arrangement, but are designed to aid the pupil in drawing outlines with facility, and to prove to him, by a progression of ideas, that the most complicated forms are made up of lines of extreme simplicity; that although in the aggregate they may look complicated, in reality, when carefully analysed, they are amazingly simple. Again, although the pupil may object to them as being easy and formal—in fact, not picturesque or decorative enough to please his fancy—he ought to recollect that, before being able to delineate objects shown to his eye *perspectively*, he must have a thorough knowledge of the method of drawing the outlines of which the objects are composed, and a facility in making the hand follow aptly and readily the dictation of the eye. These desiderata can be alone attained by a steady application to elementary lessons.

Fig. 13 is the moulding, or form known in architecture as the "echinus"

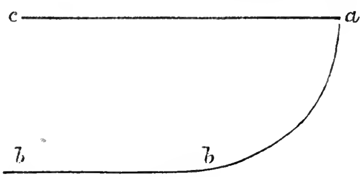


fig. 13.

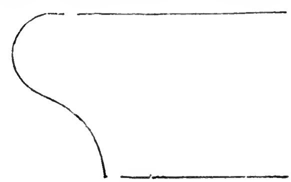


fig. 14.

or quarter-round. First draw the line *a c*, then *b b* at the proper distance; next mark with the eye the point *b* on the line *b b*, to which the curve from *a* joins; then put in the curve *a b* with one sweep. The curved portion of the moulding in fig. 14, known as the "ogee," must be put in at one stroke of the pencil or chalk, previously drawing the top and bottom lines.

Fig. 15 is the "scotia;" it is formed geometrically by two portions of a circle, but the pupil should draw the curve at once with the hand. It is rather a difficult one to draw correctly, but practice will soon overcome the difficulty.

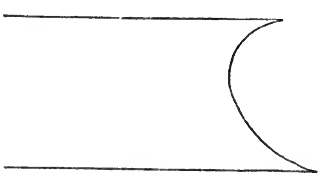


fig. 15.

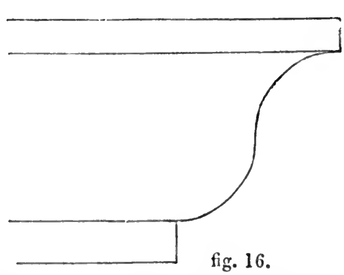


fig. 16.

Figure 16 is termed the "cyma recta;" it affords an exemplification of the line of beauty given in fig. 11.

Should the pupil ever extend the practice of the art beyond the simple lessons we have given him, he will find, in delineating the outlines of numerous subjects, the vast utility of the "practice" obtained in executing the foregoing examples. In sketching ancient or modern architectural edifices, he will find the forms we have presented of frequent recurrence.* We shall now proceed to give examples of the *combinations* of the forms or outlines we have just noticed. Fig. 17 is half of the base of an architectural order frequently met with, called the Doric. Fig. 18 affords

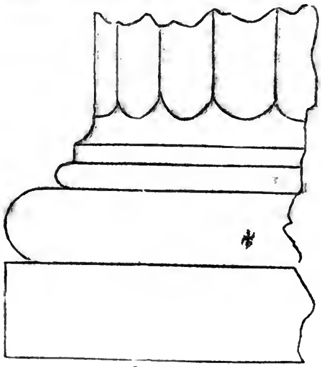


fig. 17.

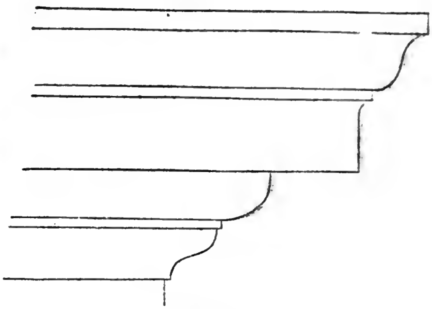


fig. 18.

an exemplification of the outline of part of a "cornice" belonging to the Tuscan order. Let us slightly analyse the supposed proceedings of the pupil in delineating this. Suppose fig. 19 to be the rough sketch as first attempted. On examining the copy as given in fig. 18, the pupil will at

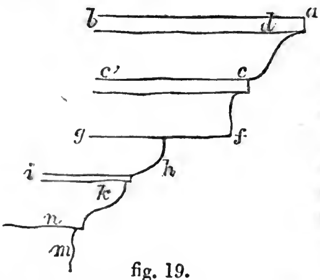


fig. 19.

once perceive that the proportions are very incorrect: thus the distance between the two upper lines as at *d* is too small, the fillet being too narrow; again the point *c*, which regulates the extent of the curve from *a*, is too far from *a*, while the line *c c'* is too near the line *d*; the space between *c c'* and the line below it is too wide, and the line *f* is not perpendicular, but slopes outwards towards *f*; the distance between the line *f g* and the one immediately above it is also too narrow by at least one-third. Again, the point *h*, where the portion of the circle begins, is too near the point *f*; the line *i* is also too near that of *f g*; the outline of the curve is not correct, it being too much bulged out near the point *h*; the line *n* is not straight, and that marked *m* is too far from the extreme end of the line, and is also "shakily" drawn. The pupil has here indicated a method of analysing his proceedings, comparing them with the correct copy, which he would do well in his earlier practice to use pretty frequently, until he is perfectly at home in correct delineation of outlines. It may be objected that this analysis is uncalled for, from the simplicity of the practice: but let it be noted that if the pupil is not able, or unwilling to take the necessary trouble to enable him to draw simple outlines correctly, when he proceeds to more complicated examples, he will be very apt to draw difficult outlines incorrectly. We hold that if a thing is worth doing at all, it is worth doing well; and how can a pupil do a thing correctly, unless from correct

* For the various kinds of mouldings, see the volume on "Practical Geometry," &c., in this series.

models or rules? and how can he ascertain whether he is following them, unless by careful comparison and examination? The works of painters and artists are often found fault with, from the incorrectness of outline and the inconsistency of measurement observable, which might be obviated by a more careful attention to the minute details, —too frequently spurned at by aspiring artists; but of which, after all, the most complicated picture is but a combination. Thus the outline in fig. 19 presents all the lines and curves found in fig. 18, but the whole forms a delineation by no means correct. If a pupil is allowed to run from simple lessons without being able to master them, his more ambitious attempts will be still more characterised by faults and crudities of execution. Correct outlining must be attained before the higher examples of art can be mastered.

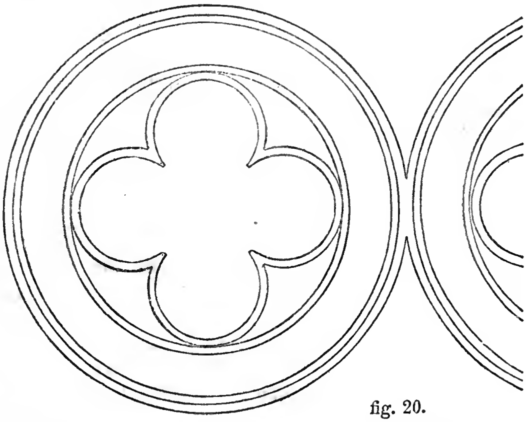


fig. 20.

Fig. 20 is an outline-sketch of the ornament called a quatre-foil, frequently met with in architectural and artistic decoration. It will be a somewhat difficult example to execute at first, but it affords good and

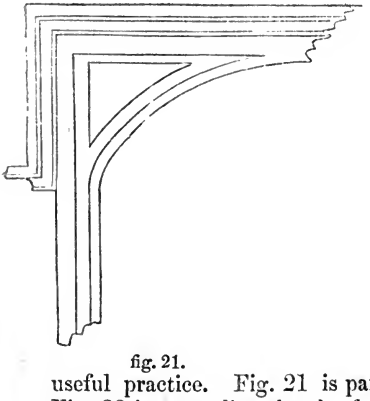


fig. 21.

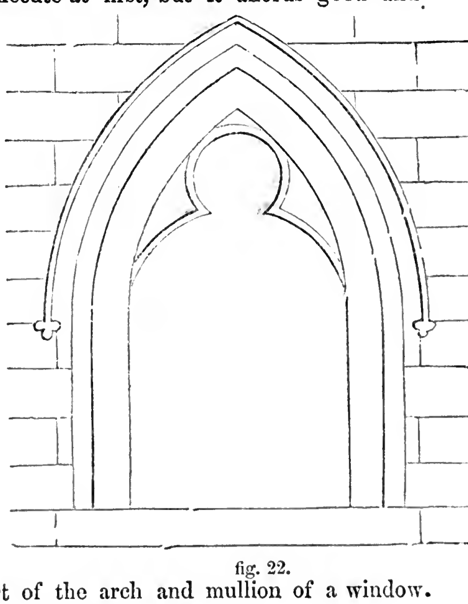


fig. 22.

useful practice. Fig. 21 is part of the arch and mullion of a window. Fig. 22 is an outline-sketch of a gothic recess in a wall.

The reader will perceive that in all these foregoing designs, although consisting of pure outline, there exists a large amount of practice, which, if he has carefully mastered, will be of eminent service to him in the higher branches of the art.

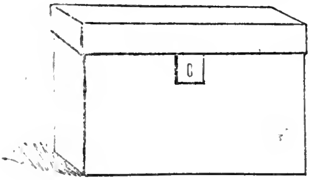


fig. 23.

The pupil may now proceed to more ambitious attempts in the art of delineation. Fig. 23 is the representation of a box supposed to be standing on a table. It is formed entirely of straight lines. He should draw the front oblong first, then the end, taking care to make the perpendicular boundary-line farthest from the eye rather shorter than the first line, in order to give the perspective appearance to the representation. In this section we do not give the rules of perspective delineation, preferring to let the pupil become acquainted therewith after he has acquired the necessary facility for copying objects as they appear presented to his eye. This to us appears the most natural course, as perspective cannot be taught unless the objects which illustrate the rules, and which are to be found in all perspective delineations, can themselves be sketched with ease. As soon as a pupil can copy an object correctly, so far as his own ideas go, he will at once perceive the *utility of an art which by stated rules will enable him to test the accuracy of his proceedings.* Fig. 24 is a free outline sketch of a pump; by drawing the lower square first, thereafter the end and top, and next the upright oblong, finally putting in the handle and spout, the delineation will speedily be effected.

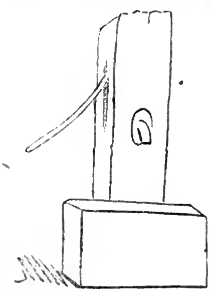


fig. 24.

The pupil at this stage should attempt to delineate the forms presented by placing boxes, square blocks, bricks, &c. in various positions. Fig. 25 is the representation of a book lying on its side; it is formed of both straight and curved lines. He should draw the horizontal lines first,

fig. 25.

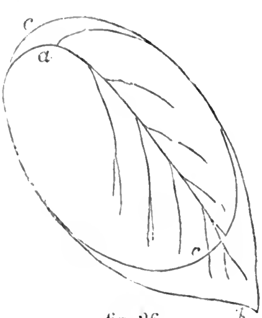


fig. 26.

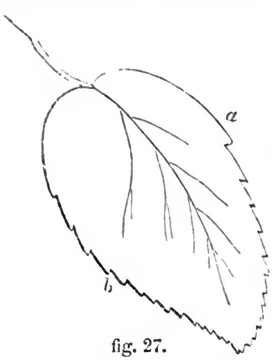


fig. 27.

then the oblique, taking care to make the two lines forming the top nearly parallel, and the others slightly to approach each other, to give the idea of distance; the under lines may be strengthened as in the figure, which will compensate for the absence of light and shade. Fig. 26 affords a good exemplification of the use of the oval or ellipse in forming leaves, &c. In the first place, a correct ellipse is to be drawn, thereafter the top *a* and the end *b* of the leaf, rubbing out the parts *c c* not required, and lastly putting in the fibres, as in the figure. The leaf is finished by putting in the serrated or saw-like edges, as in fig. 27. The

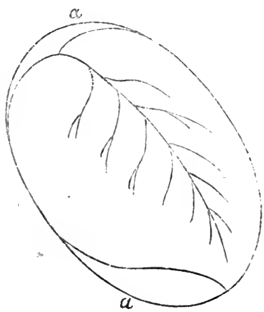


fig. 28.

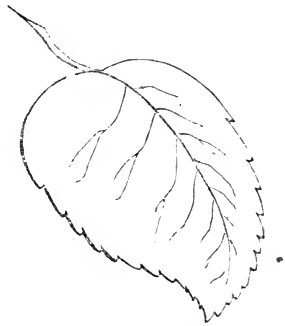


fig. 29.

next fig. (28) is formed in the same way, the only difference being, that the leaf is comprised *within* the ellipse; the parts *a a* being rubbed out, and the edges filled in as in fig. 29. Fig 30 exemplifies the use of the circle in delineating natural objects. A *pear* is drawn by first making the

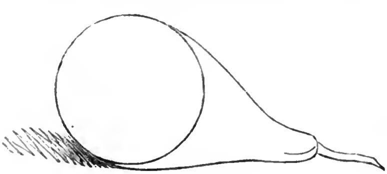


fig. 30.


fig. 31.

circle as in fig. 30, thereafter finishing it as in fig. 31. The use of the circle is further demonstrated by figs. 32 and 33, which show the method adopted in drawing an acorn. The method here indicated, of using ellipses and circles as the foundation of the outlines, is applicable to the

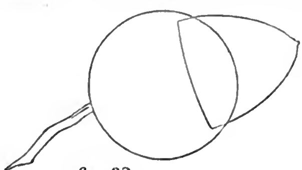


fig. 32.

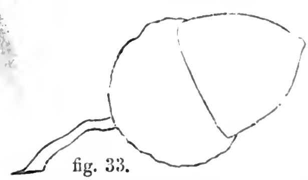


fig. 33.

formation of a vast variety of objects; thus vases and other forms can be rapidly delineated, as shown in figs. 34 and 35.

Fig. 36 shows the position of the two ellipses *a* and *b*, which form the

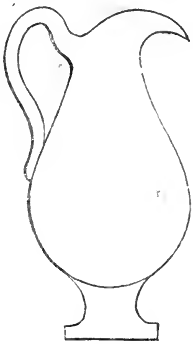


fig. 34.

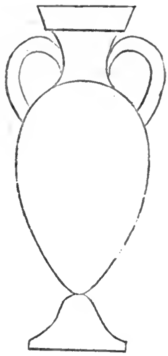


fig. 35.

bases of the ornamental sketch shown in fig. 37. In like manner, the half-ellipse, formed on the horizontal line, in fig. 38, is the foundation of

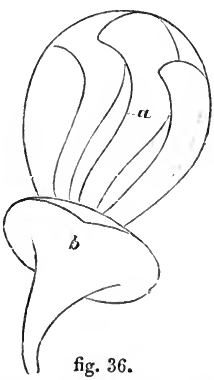


fig. 36.

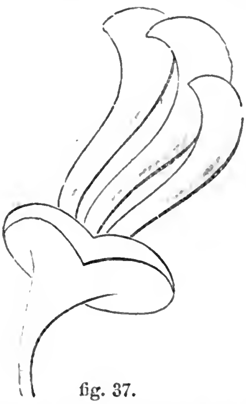


fig. 37.

the sketch shown in fig. 39. So also is the flower-petal shown in fig. 41

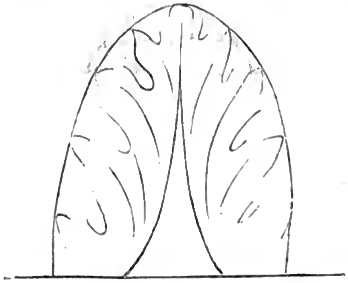


fig. 38.

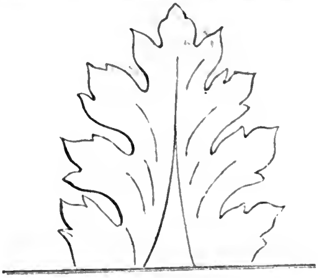


fig. 39.

made clear by the analytical sketch in fig. 40, where the preliminary forms are shown drawn. Again the ornamental scroll in fig. 42 is drawn

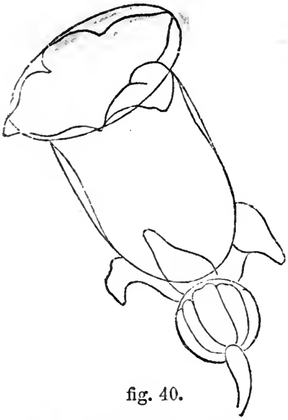


fig. 40.

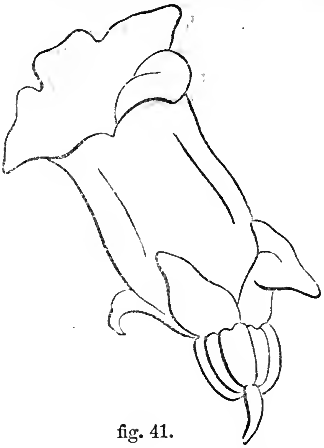


fig. 41.

by sketching a half-ellipse on the horizontal line. The convolvulus flower

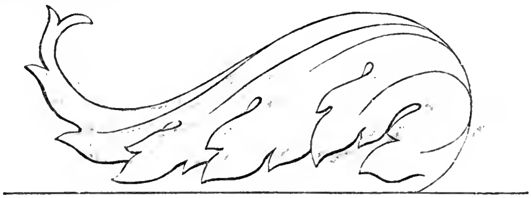


fig. 42.

and stem in fig. 43 are also drawn by previously sketching an ellipse to

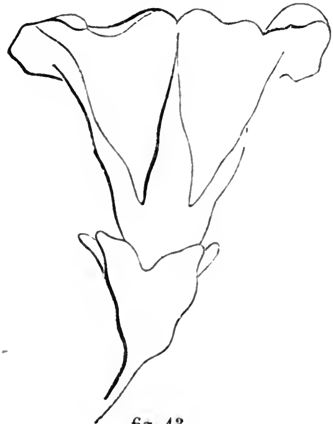


fig. 43.

fig. 44.

form the flower. In sketching the flower in fig. 44, the pupil must first draw an outline which will take in the whole figure, making it as near the shape of the sketch as the eye dictates. After the correct outline is formed, the details must be drawn. The flower, stem, and leaves of the sketch in fig. 45 should next be drawn, the form being estimated chiefly by the eye; the stem ought to be put in first, thereafter the distances between the leaves, and then filling-in the details.

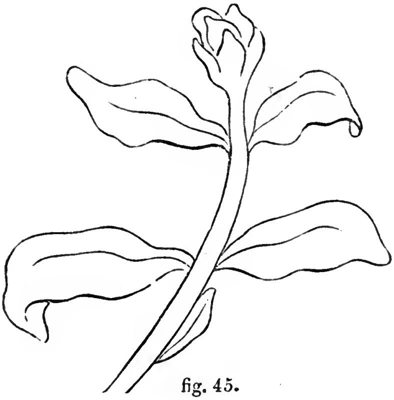


fig. 45.

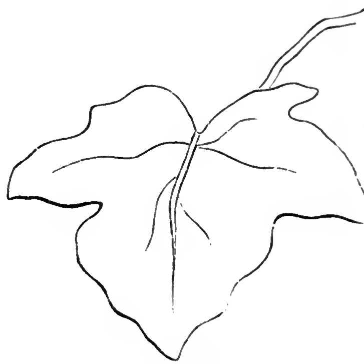


fig. 46.

The ivy-leaf in fig. 46 is to be drawn in the same way as the last. The ivy stem and leaves shown in fig. 47 should be drawn by first sketching out the length, form, and direction of the stem, then ascertaining and marking the distances between the leaves, and filling in the details as


fig. 47.


fig. 48.


fig. 49.

before. The leaf in fig. 48 and the leaves in fig. 49 should next be copied. Fig. 50 is the leaf of the common "dock;" it is to be copied by first drawing an ellipse, thereafter filling in the details. Fig. 51 is the stem and leaves of the "burdock;" the sketch may be put in at once by the assistance of the eye; it may be better, however, to draw a circle for the

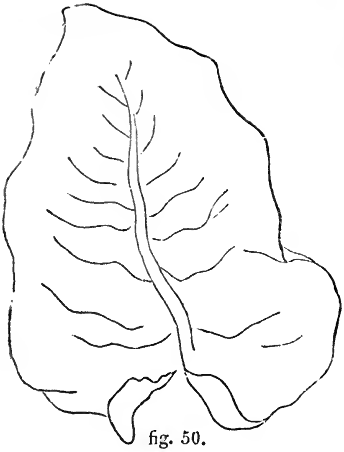


fig. 50.

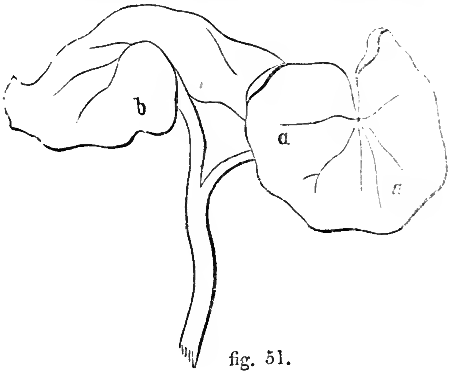


fig. 51.

part *a*, and an ellipse for that of *b*. The scroll in fig. 52 may be

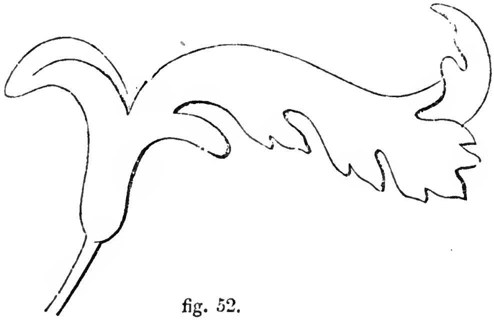


fig. 52.

sketched by drawing an outline which would touch all the parts of the design, there-

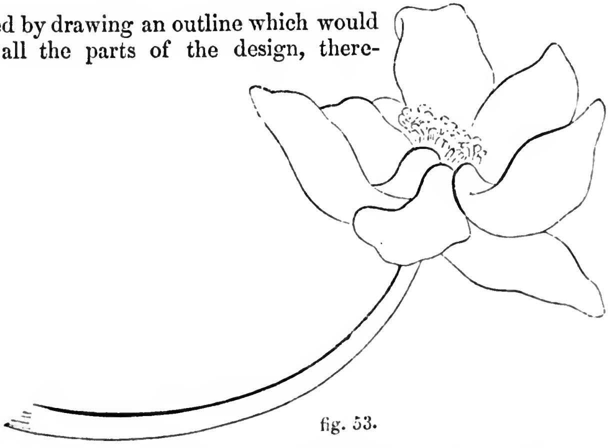


fig. 53.

after filling up the details. In drawing the sketch shown in fig. 53, the pupil will have to trust greatly to the eye: the stem should be drawn first, its length and *direction* being carefully noted; the distance of the extremities of the leaves from the stem should next be

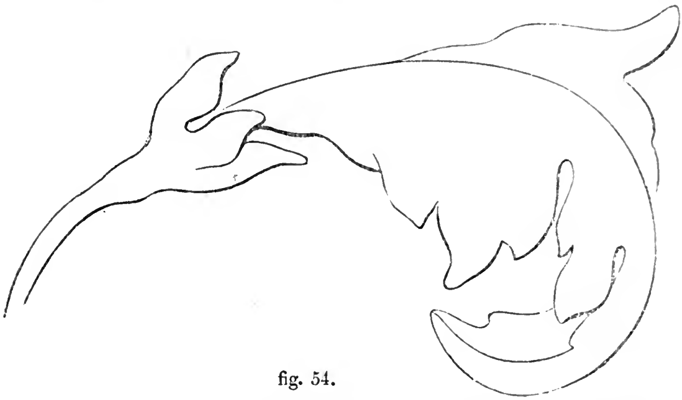


fig. 54.

marked off, then their general outline, and thereafter the details. The proportions the parts bear to one another must be attended to. The outline of the stem and the curve of the scroll of fig. 54 must first be drawn, the distances, directions, and proportions of the various parts being carefully observed. In sketching the scroll in fig. 55, the eye alone

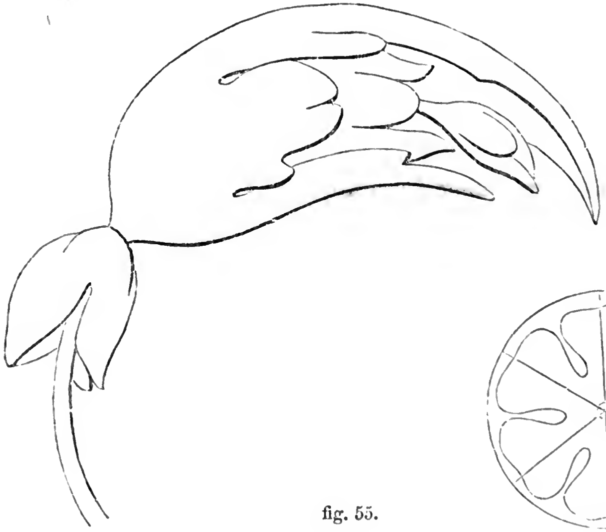


fig. 55.

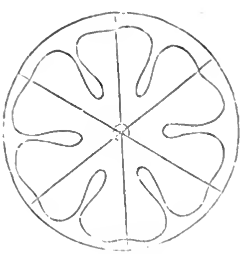


fig. 56.

will be the guide, the directions and distances of the various parts being marked off before filling in the details. The method of drawing the rosette, forming part of the scroll shown in fig. 57, is displayed in fig. 56,

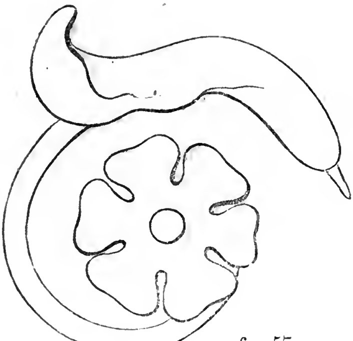


fig. 57.

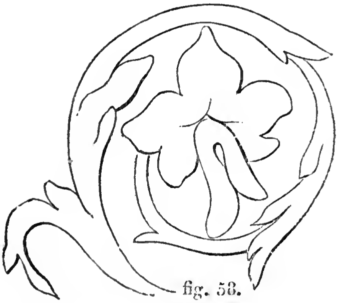


fig. 58.

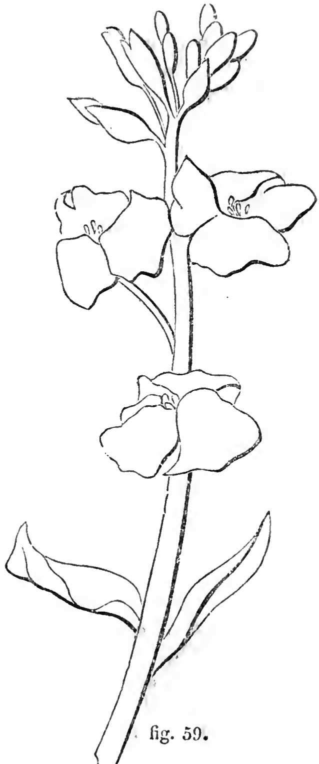


fig. 59.

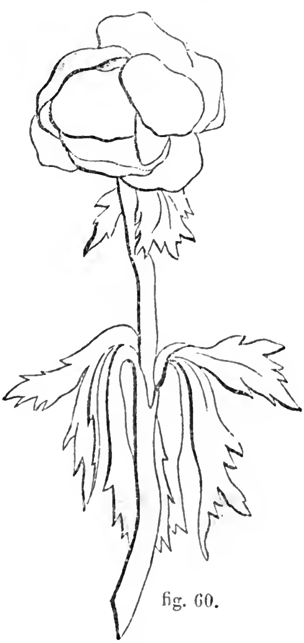


fig. 60.

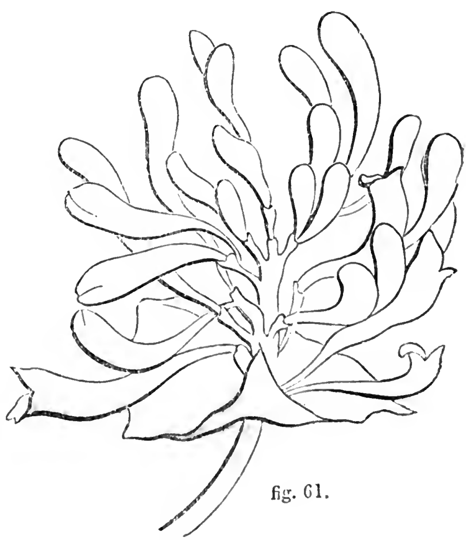


fig. 61.

the circle being drawn first. In sketching fig. 58, the direction of the curve must first be ascertained, its due proportions noted, thereafter filling in the details. The stem, leaves, flowers, and buds of the wall-flower in fig. 59 will afford an interesting example for practice at this stage of progress; the stem, its length and direction, should first be drawn, the position of the leaves, &c. marked thereon, and the details thereafter filled in. The sketch in fig. 60, which represents the stem, leaves, and flower of the yellow crowfoot, will be drawn in the same way as above. The flower of the honeysuckle in fig. 61 affords a good example for free pencil-sketching: the stem should be drawn first; then an outline made which

fig. 62.

fig. 63.

will touch all the exterior parts of the sketch, as in fig. 44 and fig. 52; the distances of the leaves should next be drawn on this, and the details put in. The pupil should endeavour to copy this example correctly: it may appear very difficult, but by a careful attention to the rules we have given, and a little determination to "try again," if perchance he should once or twice fail, the difficulties will soon vanish. The sketch in

fig. 64.

fig. 65.

fig. 62, representing a human foot, may be put in, by first drawing the general outline, thereafter finishing the details. Figs 63, 64, and 65, will be drawn in the same manner.

SECTION II.

FIGURE AND OBJECT DRAWING.

In executing the lessons in this section, we would recommend the pupil to use cartridge-paper: this material has a rough surface, which takes the pencil easily, and will bear rubbing out well; it is, moreover, cheap, which —to a pupil who is apt to make many attempts before he succeeds in making a perfect copy—is a matter of some importance. A few black-lead pencils will be also requisite; some rather hard, to make the outlines, and others soft, for shading: for the latter purpose those marked B will be found the most useful.

In executing the copies here given, and indeed in all other drawings

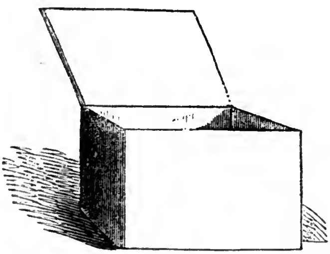


fig. 1.

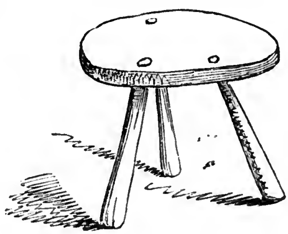


fig. 2.

which are to be shaded, the outlines must be first put in before this is attempted. The pupil should endeavour to produce the proper degree of shade at one operation, without having occasion to go over or darken it afterwards. This retouching spoils the effect of clearness and spirit which shading at one operation is calculated to give, and which all drawings should have. The drawings in figs. 1 and 2 will be easily put in. The outline of fig. 3 should be drawn in the manner explained in Section I., the shading put in at once by bold strokes from top to bottom; if done at

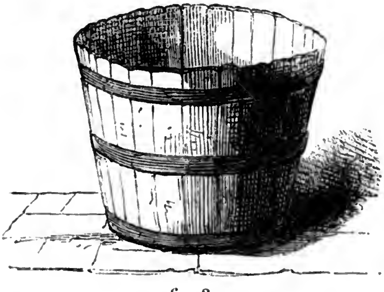


fig. 3.

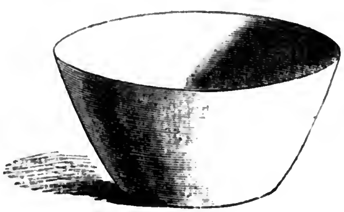


fig. 4.

two operations, a shadow might result, by which the effect would be lost;

a few cross-strokes may be next put in, which will give a little roundness to the sketch. In fig. 4 the nearest part of the oval is to be drawn considerably stronger, so as to bring it forward. Figs. 5 and 6 are examples

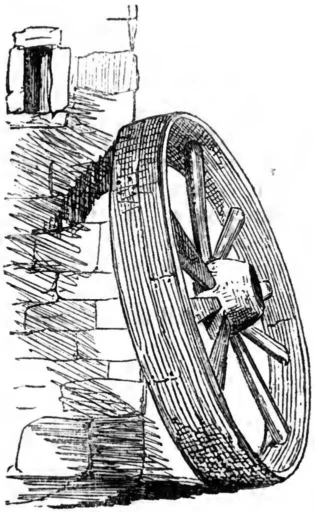


fig. 6.

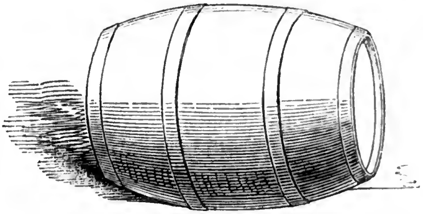


fig. 5.

in which the ellipse is distinguishable. In copying fig. 7, a nice broken outline should first be obtained; the shading being simple needs no explanation. The outline of fig. 8 is to be drawn as formerly; the indented parts of the leaf to be put in slightly, and afterwards the stronger

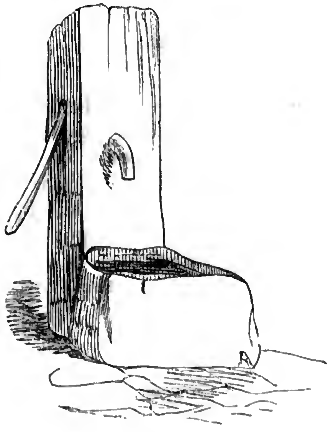


fig. 7.

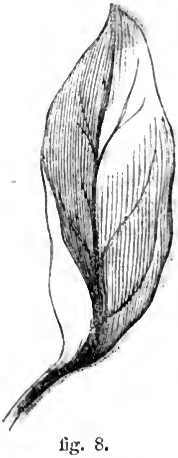


fig. 8.

shadow, which throws forward the curled edge of the leaf. In copying the annexed sketch of a grindstone, to get the outline correctly the framework should be drawn first, carefully observing the relative proportions of the parts, in order to give an idea of perspective.* Having

* In Section III. the subject of Perspective will be fully treated of. Before Perspective can be mastered, it is absolutely necessary that the pupil should be able to sketch by the assistance of the eye: hence our reason for making the Section on Perspective follow this and the preceding one.

done this, an ellipse may be drawn to represent the stone, part of this to be rubbed out afterwards. In shading the drawing, the nearer parts should be made darker than those distant; this causes the latter to recede, having the appearance of distance. In fig. 10 we give the representation of an old gate; it is so simple that it needs no explanation. Fig. 11, which is the representation of a familiar object, is treated under a very simple effect of light and shade, the shaded parts bringing forward the light ones: this effect is called *relief*. It is of the utmost importance that the pupil should have a clear knowledge of the mode of producing this effect. We would recommend him to try the experiment of placing simple objects so as to relieve each other, and to sketch them in this

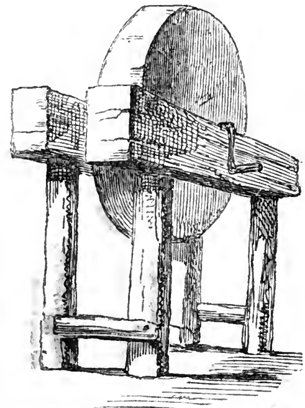


fig. 9.

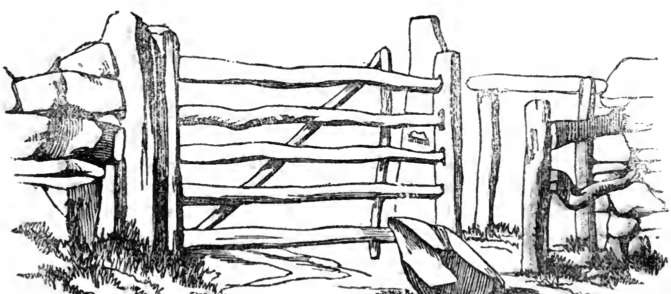


fig. 10.

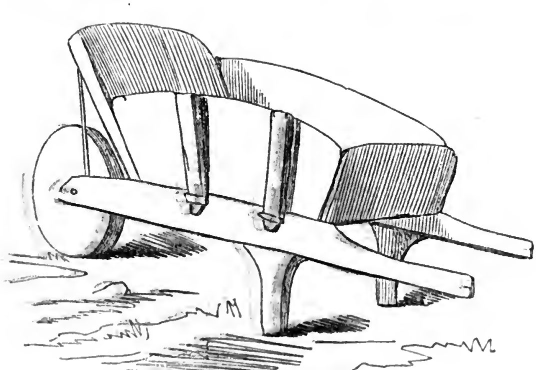


fig. 11.

manner; this practice will enable him very speedily to understand the method by which the effect may be obtained. In fig. 12 the same effect is dis-

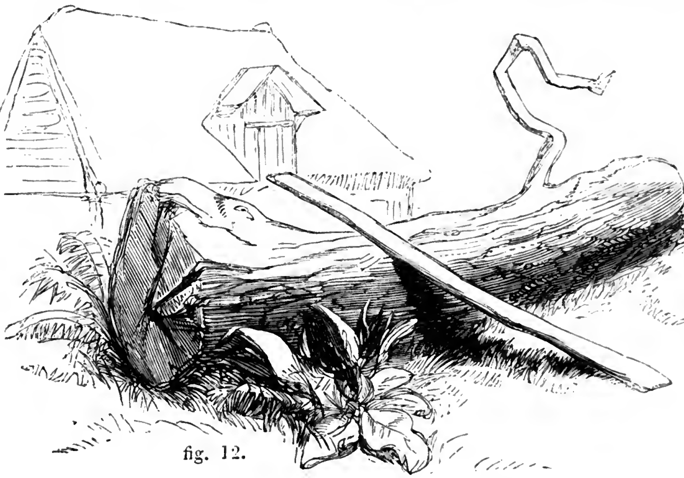


fig. 12.

played, only reversed; a mixture of light and shade throwing back the other end, which is in half tint. In fig. 13, which is the representation of a fuschia-leaf, the outline must be drawn in the manner explained in Section I.; the shading is similar to that in fig. 8. After copying this, we would recommend the pupil to get a similar leaf, and place it in various positions, so that the light and shade will be variously disposed. This will afford excellent practice, and will accustom the pupil to draw or sketch from nature. In fig. 14, which is the representation of a rural stile, the pupil will find the principle of relief shown in figs. 11 and 12 again displayed; the

fig. 13.

shading behind the stumps throwing the light parts forward, and the shaded sides of these causing the back part to recede. In fig. 15 the sketch of a flower is given; the manner of copying this will be evident from an

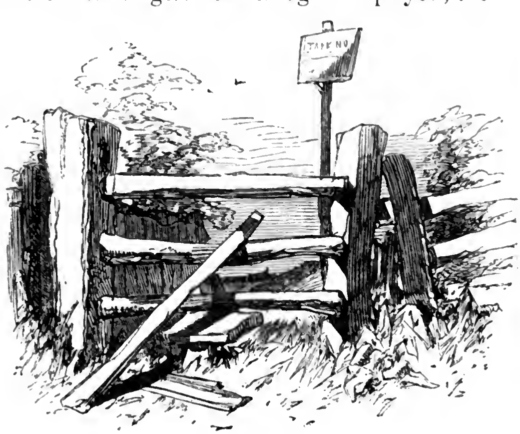


fig. 14.

inspection of the figure. In fig. 16 the effect of relief must be treated in the manner explained in fig. 8. A group of dock-leaves is given in fig.

fig. 15.

fig. 16.

17: these form an excellent study, and examples may be met with in any part of the country. After he has copied the example we have given, we would recommend the pupil to seek out a natural group and sketch it,

fig. 17.

carefully observing the relief which one leaf gives to the other; if this relief were not noticeable, the leaves would appear as if they were adhering in a mass together. In fig. 18 a slight sketch of a tunnel, with overhanging foliage, is given; it affords an example of how easily an effect may be

fig. 18.

obtained without much labour. In fig. 19 an old boat with a fisherman's basket is given; this is treated under an effect of shade, with a slight shadowing behind the light end of the boat.

fig. 19.

fig. 20.

In fig. 20 we have given another group of dock-leaves, and in fig. 21 a slight sketch, neither of which requires description. In fig. 22, representing the foliage of the elm, the pupil must put the shading in with as few strokes as possible, so as to obtain the leafy appearance of the copy. The manner of putting in the foliage, &c., of an ash-tree is exemplified in fig. 23; the strokes must be given in a quick, free manner,

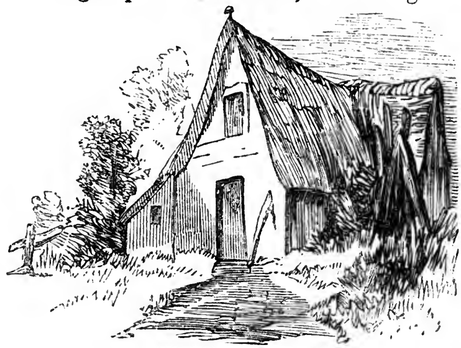


fig. 21.

fig. 22.

fig. 23.

and the branches in graceful curves. Fig. 24 illustrates the manner of delineating oak-foliage, which is done in a style very different from the former. The branches of an oak are twisted in endless variety; the foliage is

fig. 24.

fig. 25.

drawn in a more angular style than that of the ash; it must, however, be

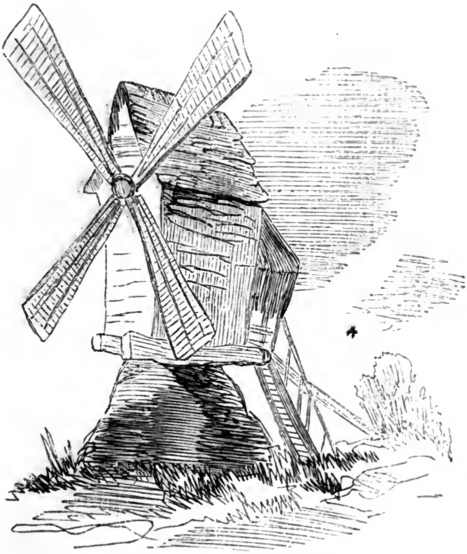


fig. 26.

kept free and loose, without formality. In fig. 25 the manner of delineating the foliage of a willow is shown; it is somewhat similar to that of the ash. In drawing the windmill in fig. 26 the outline is to be drawn in a broken

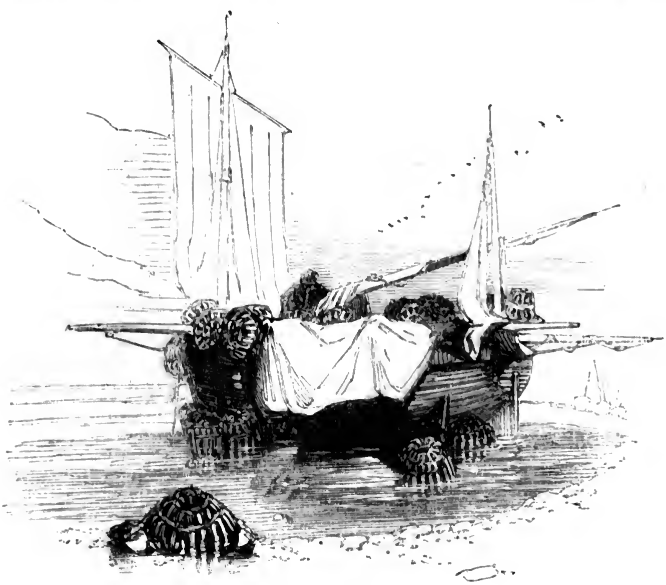


fig. 28.

manner, so as to agree with the subject; a little decided shading on the lower part will give an effect, and the grass to be executed in a rough manner. The sketch in fig. 27 to be carefully outlined, and the shading done with care; the dark parts to be put in last. The sketch of a ship in fig. 28 is given with a view of showing the reflection of objects in water. Water in a perfectly quiescent state reflects the objects placed

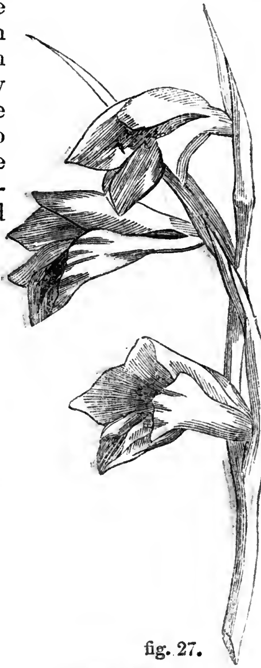


fig. 27.

fig. 30.

fig. 29.

in it almost as distinctly as the objects themselves, only a little darker; the darker the water is, the less distinct will the lights be. The sketch in fig. 29 must first be carefully outlined; the shading to be begun at the top, proceeding downward, to keep the marks from being smeared. In drawing the curled leaves, the pupil must be careful to give them the necessary relief. An inspection of the sketch will show how this is done; where the leaf is light, the curled part is thrown into shadow, which brings it forward. In sketching the stem and flower of the wallflower, given in fig. 30, the pupil must proceed as in the last. In drawing the sketch in fig. 31, the pupil must put in the stumps and stones first, then the direction of the branches in the tree; the outline of trunk must be done next, in a free manner, carefully avoiding any formality, as the *outlines* of a tree give a *character* to the whole. The shading should, if possible, be done at once, avoiding the necessity of having to go over it again, as this takes away the clearness. It will be seen how the stumps are relieved by the mass of shadow behind them. In the sketch of the old farm-house given in fig. 32, the light falls on the gable-end and the grass in front; the foreground is kept in shadow, so as to bring it forward. This part must be

fig. 31.

fig. 32.

kept either light or dark, according to the character of the objects which it is to relieve; but in all cases it must be the most forcible part of the drawing. In the sketch of an old oak given in fig. 33, the weeds and small patch of foliage are kept in shadow, so as to support the tree; if these were kept light, the effect would be lost. The sketch in fig. 34 is treated under a broad effect of light, the upper part relieved by the foliage in the background, the old fence on either side being kept dark. The pupil will do well to look out for an object in the fields similar to this,

fig. 33.

and sketch it from various points of view. The moss-rose in fig. 35 must be drawn in the same manner as the other flowers. Fig. 36 is a scroll from the antique. In the first place, the outline must be carefully put in; the shading of the ground next done as flat and as even as possible; next, the details of the leaves; and lastly, the shadows and the broken part round the whole. In sketching the copy in fig. 37, the circular part of the bridge should be drawn in first, then the upper part and the outline of the whole; thereafter the foliage at the top, taking care not to make it too dark, as it should appear to recede from the eye. It may be taken as a general rule, that in distances shadows become lighter on account of the atmosphere, the dark parts being

fig. 34.

fig. 35.

fig. 36.

the first to lose their distinctness. The copy here given is treated with a broad effect of light. The few strongly-marked weeds give an effect to the whole; the reflections in the water are indistinct, in consequence of its

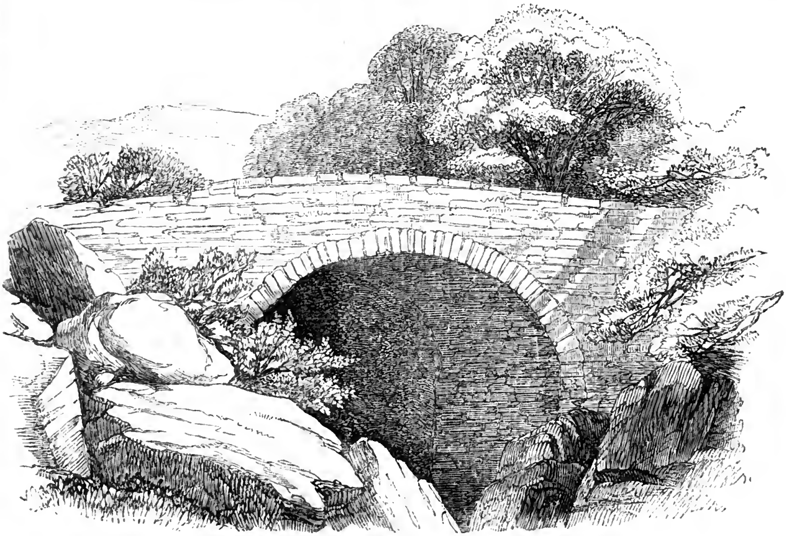


fig. 37.

being a running stream. The ass sketched in fig. 38 must first be carefully outlined, then pencilled in a vigorous manner, so as to give the rough effect.

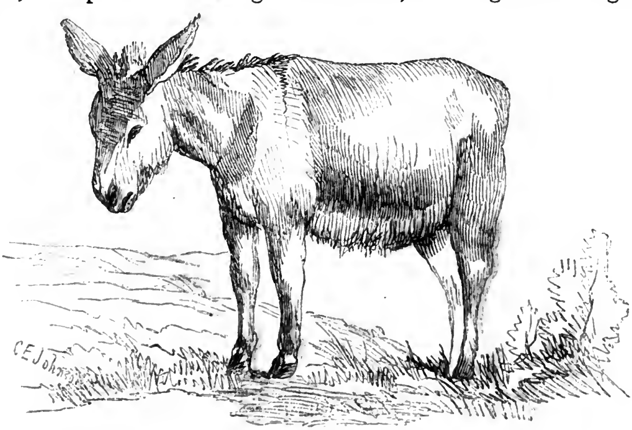


fig. 38.

In a former sketch we have given a specimen of the mode of delineating the foliage of an oak-tree. We now give another in which the tree is the principal object (fig. 39). The further branches are made darker, which brings out the nearer ones. The pupil will see from this sketch how the effect of water is given with very little trouble. The drawing in fig. 40 will

fig. 39.

require very careful outlining before any of the shading is put in. The pupil should begin to shade the head first, then the neck, which fore-

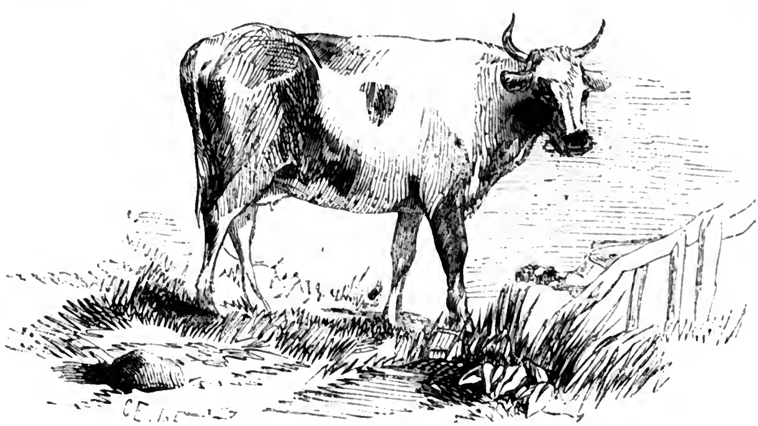


fig. 40.

shortens it. The weeds and grass should be put in in a bold manner, with some very dark shadows to give effect to the whole. The drawing in fig. 41 must first be carefully outlined; then the details of the trees put in, as the branches and the character of the foliage; the house should next be

fig. 41.

finished, and the more distant parts; thereafter finishing the trees and the dark foliage which relieves them; and lastly, the foreground and water. In copying the vase from the antique given in fig. 42, the pupil will find the rules given in Section I. of infinite use. A line must first be drawn down the centre, an ellipse thereafter formed, marking the distances on each side correctly from the centre line. It would be advisable to try the drawing of the outline, in the first place, without filling in the details; attempting it several times, at each trial adding a little more from the copy, until competent to draw the whole correctly.

Having gone thus far in drawing from objects, we now conclude the section. Having laid before him the rudiments or basis of the art, we leave it to the perseverance of the pupil to make further progress.

fig. 42.

Part II.

PROPORTIONS OF THE HUMAN FIGURE.

We have deemed it best to treat separately from the other department, of the proportions which different parts of the human frame bear to each other, according to the acknowledged standard of beauty, as derived from measurements from the antique. We trust that the student will find the lessons here given of great assistance in enabling him to draw from casts. We should advise him to habituate himself to this practice, as it will lay a foundation for attaining with ease a correctness of proportion, which constitutes the chief beauty in drawings of the human figure. He must not, however, suppose that beauty is always attained by attention to these rules, correctness being the principal point they have in view. There are many styles of beauty, the qualities of some consisting in a slight deviation in some point or other from the *established* proportions.

We first begin with the various parts of the human "head divine"—the seat of the soul, as some term it. The mouth, of which a sketch is given

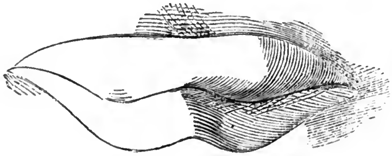


fig. 1.

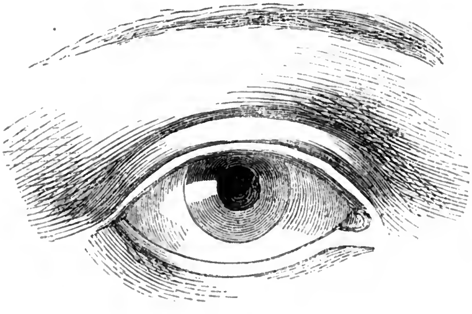


fig. 3.

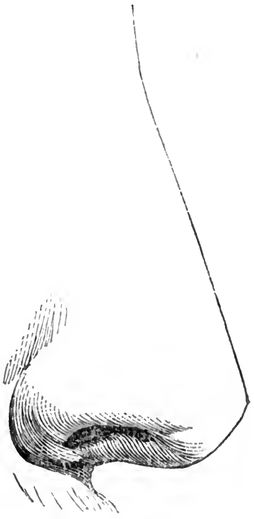


fig. 2.

in fig. 1, is equal in width to the length of one eye and a half, and the height to one-half. The mouth in profile is exactly the same height, but only half the width; the upper lip projects less than the lower one. The nose in width is equal to one eye, and the height to two eyes, measuring parallel to the eyebrows (fig. 2). The eye is composed of the ball, the sight, the lachrymal point (which is the point nearest the nose), the upper and lower

fig. 4.

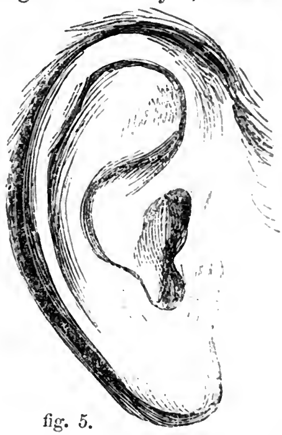


fig. 5.

eyelids, and the eyebrow (fig. 3). The ball, when seen in front, is an exact circle, with the sight in the centre; the height is equal to half the length, and the eyebrow is situated above the eyelid about one-third the length of the eye. The eye in profile is half the length and exactly the same height as when seen in front; the eyeball forms an ellipse, and the sight is always in the centre (fig. 4).

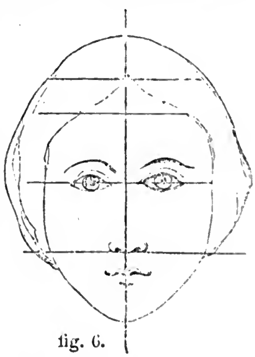


fig. 6.

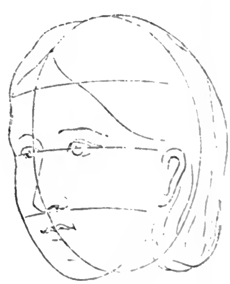


fig. 7.

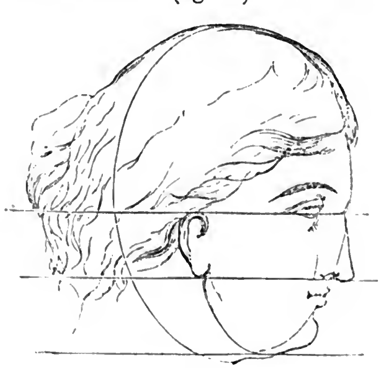


fig. 8.

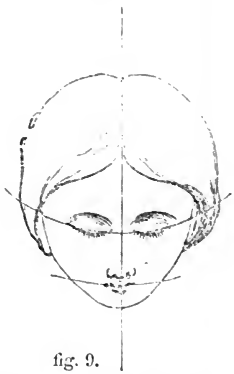


fig. 9.

The ear in width is equal to one eye, and its length to two eyes (fig. 5). In fig. 6 a front view of a face is given. In order to obtain a correct proportion, a perpendicular line must first be drawn, and then divided into two parts by a horizontal line drawn across the centre of it, which will give the point for the height of the eyes. After drawing the outline of the face, the perpendicular line must be divided, as in the sketch: the lower point will give the place for the lower part of the nose; the mouth is situated about half an eye lower than this; the ear is exactly the same length as the nose; consequently these are on a level. The same proportions are observable in the figures 7, 8, 9, and 10. The hand is the same length as the face, and its width is equal to one-half (fig. 11). The side view of a hand is the same length as when seen in front (fig. 12). The foot in profile is nine eyes in length and three in height (fig 13). Figures 14 to 17 inclusive are examples of hands, arms, &c. &c. The generally received proportion

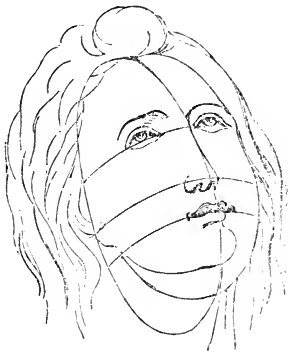


fig. 10.

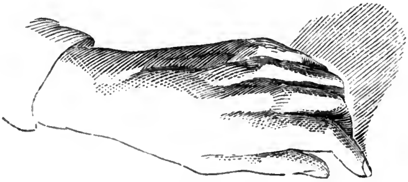


fig. 12.

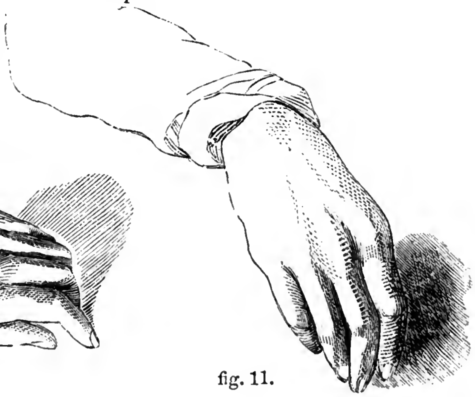


fig. 11.

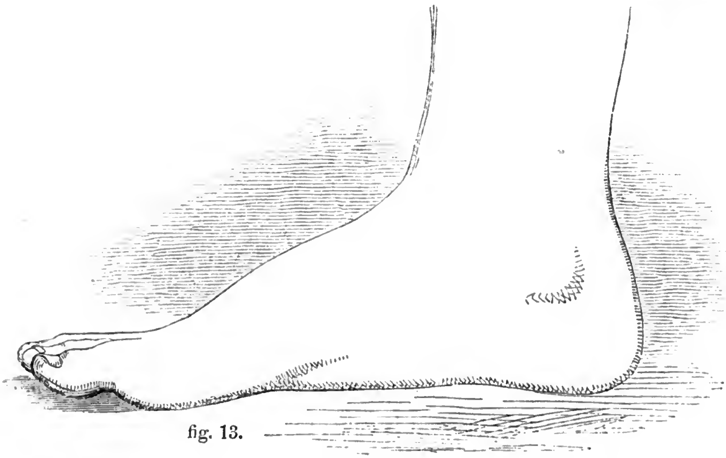


fig. 13.

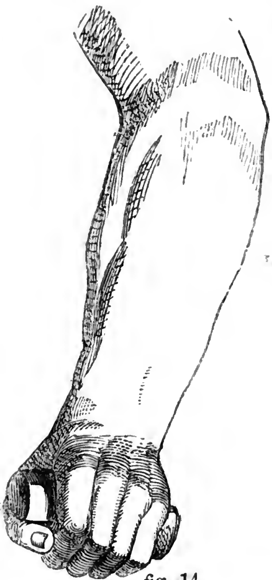


fig. 14.

of a man is ten faces in height; by extending the arms horizontally their full length, the same proportion is obtained. The length of two noses gives the width of the neck when seen in front. Two heads give the width of the shoulders when seen in front. The length of the fore-arm

fig. 15.

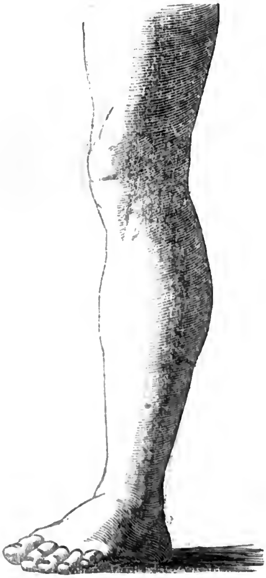


fig. 16.

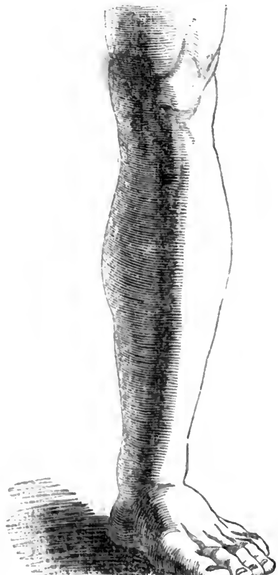


fig. 17.

to the extremity of the fingers is equal to seven noses and a half. The width of the wrist as seen in front is equal to a nose and one-third. When seen in front, the width of the knee is equal to two noses; but in profile it is a degree less. The length of the leg from the knee to the heel is equal to three faces. When viewed in front, the width of the leg near the ankle is equal to a nose and a half, but it is less when viewed in profile. The annexed (fig. 18) is a sketch of a leg foreshortened, and the following (fig. 19) that of a bust. In figures 20 and 21 are given examples of figure-drawing, which the pupil would do well to copy.

fig. 18.

At this stage of his progress the pupil should procure a plaster cast of the human form, or part of it. The materials he will require are, a drawing-board on which to fix his paper, a few sticks of black chalk, a leather stump, a small quantity of charcoal, and a port-crayon; it would also be well if he obtained a quantity of the crayon paper, which is slightly tinted, and takes the chalk well.

fig. 19.

The light should be allowed to fall on the sketch from the left hand. (It is from the right in fig. 19.) In order to catch the proper effect of the parts sketched, the pupil should sit so as to throw back the head as far as possible from the drawing. A correct outline of the bust or figure should first be drawn with the charcoal, which may be erased by slightly brushing it with a silk or other light handkerchief; this is better than rubbing the lines out, as the friction destroys the surface of the paper. After a correct outline of the subject is obtained, the pupil should trace it with the black chalk as faintly as possible, then, by means of the handkerchief, remove the charcoal, which will leave a beautifully clear outline; after this he may begin the shading. He must first scrape a little of the chalk on a paper as fine as possible, and rub the leather stump among it; taking this, he must rub in the shadows; these will by this means be soft and beautiful, and will prepare a good ground for the finish.

fig. 20.

Having rubbed in the shading as like that of the model as possible, carefully observing the different strength of the shadows, he must point or sharpen his chalk, and begin to put in the details. He should patch over all the shading with the fine point of his chalk; this, when done in a proper manner, gives a very beautiful effect. In shading, the pupil must observe that there are two kinds of shadows; one is called the *shadow of incidence,* the other the *shadow of projection:* the shadow of projection is always defined, having a sharp decided edge; the shadow of

fig. 21.

incidence is always soft, having no defined edge, but softening imperceptibly into the lights. The pupil must be careful to leave no hard edges; for although the shadow of projection is decided, the edges are not hard; moreover, the deepest shadows are always nearest the highest lights. The drawing of the bust or figure will require a slight background to detach it from the paper. If any mistakes are made in sketching, a little stale bread will remove the defective parts.

SECTION III.

PERSPECTIVE DRAWING.

Part I.

INTRODUCTION—PRINCIPLES AND TERMS EXPLAINED.

The aspect under which the art of drawing in perspective has usually been presented to the student has not been of a kind calculated to induce him to enter upon its pursuit, much less to inspire him with feelings of ardour in its acquirement. The repulsive and formal array of theorems, demonstrations, and corollaries, however convincing to those who will be at the pains to master them, are calculated rather to disgust than to allure the general reader; and the youthful learner of either sex turns with dismay from their strictly logical pages, and seeks a premature escape into those more flowery fields of drawing in which the hand and the eye are the sole, but often the fallacious guides.

That the study of perspective should thus be frequently avoided as a dry and scholastic problem, or an inexplicable chaos of lines and angles, is not so much the fault of the art itself, as of the uncouth garb in which it is often clothed. Divested of this, its principles are more easy of acquirement than those of many other arts which are sought after as recreations, and are quite as pleasing in their development. To take an example, for instance, from the study of music: even to those whose natural taste and skill give them great facilities in the latter pursuit, the mental labour and manual application it demands are infinitely greater. The study and practice required before an approach to a pleasing effect can be produced from any musical instrument, are unquestionably much greater than those which are necessary for the ready handling of the pencil and T square: the compasses are more easily managed than the violin or piano; and the mazes of intersecting lines are less intricate than the perplexing varieties of crotchets, quavers, dots, and spaces. And when those beautiful laws by which objects arrange themselves, so to speak, before the human eye, in forms varying according to their positions relatively with the spectator, are once understood and reduced in the mind to principles of order, the pleasure obtained from their contemplation is of the same nature as that which we derive from listening to the performance in correct time of an elaborate musical composition.

Though, therefore, the art of correct delineation is more easily acquired than that of correct musical performance, its effects are not on that account the less pleasing. Pleasurable sensations affect the mind through the medium of the senses; and there seems to be no reason why those which obtain access through the eye should be of a less exalted character than those operating through the medium of the ear. The comparative sensibilities of these organs in different individuals will in each case decide which organ is most acutely sensitive to such emotions in that particular case; but as we know that with the deaf the eye, and with the blind the ear, is chiefly the medium through which such sensations enter the mind, and as persons thus deprived of different senses appear equally sensitive to them, we may safely conclude, as a general rule, that the pleasure derivable from contemplating a pictorial representation correctly delineated is equal to that obtained from listening to a piece of music correctly performed; and *per contra*, that the want of that correctness which a knowledge of perspective rules alone can impart to the draughtsman, is as unpleasing a defect in him as the perpetration of discord, or a defalcation in time, would be in the musical performer.

But the pleasures of perspective are not restricted to the beholder, any more than those of music to the listener. They are enjoyed, perhaps, in a higher degree by the artist himself, when he sees the objects he wishes to represent gradually emerge from his labyrinth of lines, and assume those fair and exact proportions in which the mirror of nature presents them to his view. Secure in the certainty of a truthful representation, and charmed as he proceeds with the beautiful simplicity of the process by which that truth has been attained, he contemplates the accurate counterpart of his original with the delightful consciousness of a success achieved—a success which, less transient than that of sounds which die away as soon as heard, remains permanently inscribed in his drawing, and excites new pleasure whenever reviewed. When it is added, that this elegant source of enjoyment is open to either sex; that its pursuit is attended with no expensive adjuncts; that the art may be agreeably acquired within the limits of the family circle, and does not lead to the relinquishment of home,—it will not be necessary to adduce much that might yet be said to recommend its more general adoption, both in the instruction of youth and the amusement of the more mature.

But its value as an innocent gratification is even a smaller recommendation than its great utility in the practice of the arts, to most of which it is increasingly valuable. To the architect, its acknowledged worth requires no comment; for though the plainer representations of plan, section, and elevation convey his ideas to the mind of the building artificer, the portraiture of the future structure, exactly as it will appear from some given point of view, is often necessary to satisfy the judgment of the employer. To the pictorial artist it is indispensable, for the scenes which he has to depict must often be impressed only on his memory; and he will therefore be at fault, without a knowledge of the rules which regulate the forms under which they appear. To the engineer it is frequently highly useful in conveying correct impressions of his viaducts, his tunnels, or his bridges; to the machinist, who would present an accurate likeness of wheels, rollers, and other mechanical complications; to the upholsterer, whose chairs and tables require to be shown in various points of view; to the decorator, who must pre-inform the mind of the occupant as to the effect of his mural ornamentations; in short, to the practitioners of almost every art, and to the makers of almost every article of daily use. The preposterous violations of perspective that may frequently be met with in commercial books of patterns, whereby the effect of the drawing is injured, show that its rules are not sufficiently known; and the neglect of them, which spoils the highly-finished paintings of some of the first masters of the old Flemish school, excites regret that the art of drawing was with them so far behind that of colouring. The unpleasing effect of the incorrect drawing beneath such elaborate colouring is a forcible plea in favour of every representation being depicted on the infallible basis of correct perspective.

It is important that the learner, before commencing the necessary instructions in this pleasing art, should have a correct idea of the critical meaning of the word Perspective, and of the purpose which it is more immediately intended to effect. Its *meaning* is, the exact appearance which objects assume when viewed from any given point or station; its *purpose*, the representation of such objects on a plane surface, as a sheet of drawing-paper, in exact accordance with such appearance.

In the work on Practical Geometry, instructions have been given how to describe squares, circles, and various other regular and irregular figures. But those instructions refer exclusively to their *geometrical* representation, as they would appear on a plane surface at right angles with the line of vision, that is, placed directly opposite to the eye. If, however, they be not exactly opposite to the eye of the spectator, they will assume different outlines, according as they may be situated above it, below it, towards the right hand, or towards the left. Now, in a view embracing a considerable number of objects, one only of those objects can be situated exactly opposite to the eye; the remainder will all be viewed more or less at an angle, according to their respective positions. Therefore one only of those objects, if truly represented exactly as they appear, can present a geometrial outline; the others will all have *perspective* outlines, presenting two or more of their sides to the view at the same time. This will be obvious after consulting the accompanying illustration, which

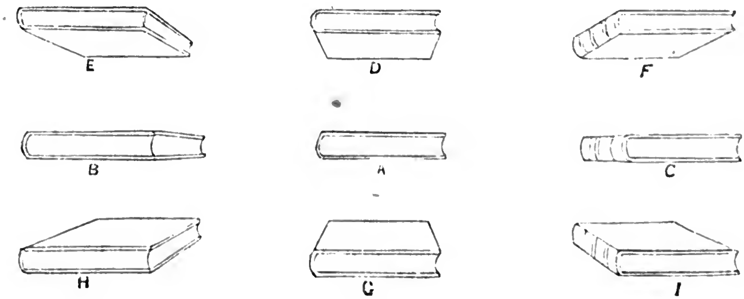


fig. 1.

gives a series of correct perspective representations of a thick book, which the reader is supposed to hold in his hands in various positions consecutively. If he hold it up level, with one of its edges opposite to his eye, its form and appearance will be that shown at A, in which he will see nothing but a geometrical view of that edge; if, keeping it at the same level, he move it towards the left, a second edge will come into view, as at B; if towards the right, the last-named edge will disappear, but the back of the book will be seen, as at C. If he now bring it back to the first position A, and elevate it somewhat, the front and back edges will both disappear, and the lower side will be seen, as at D; by moving it at the same level towards the left, three of its surfaces will come into view, as at E, or towards the right, as at F, the lower side being in both these cases seen as well as the two edges. Let the book now be held, at G, as much below the eye as it was previously above it; its lower side has now disappeared, and the upper side becomes visible; and by moving it to the left (H), or to the right (I), three surfaces again become visible, as when the book was held at E and F; with this difference, that the upper side of the book is now visible instead of the lower. It will be observed that, in each of these nine positions, a comparatively *slight change of position* has effected a *material change in the outline* of the figure presented by the book; its boundary-lines assuming different slopes, and different sides or edges coming into view or disappearing, according as it has been shifted upwards or downwards, to the right or to the left. The main object of perspective is to discover and apply the rules which regulate these varying slopes and inclinations of the boundary-lines of objects, by which the draughtsman may be enabled to transfer to paper a faithful delineation of them exactly as they appear.

The student is recommended to go through this simple exercise with any thick book; taking care, as he brings it into its successive positions, and observes the outline presented, to keep his head steady, so that his eye may retain its original level and position. A writing-desk, chess-box, or any object of similar shape that may be at hand, will answer the purpose quite as well; and by thus making his observations, and exercising his thoughts upon simple and familiar objects, he will easily acquire a clear idea of the change of outline produced by a change in the position of the object relatively with the spectator. This branch of the art is denominated Linear Perspective, inasmuch as it refers exclusively to the lines which constitute the boundaries of objects and determine their form. And as form is the basis of correct drawing or painting, which determines the position and extent of each of the various colours to be superadded to give increased effect to the form, the principles and practice of linear perspective will be first treated of. The latter part of this section will discuss the more advanced subject of Aërial Perspective, which refers entirely to the various degrees of depth or force of colour and shadow, by which various distances can be more naturally and effectively denoted than is possible by mere diminution of size. The knowledge of this is essentially necessary in every case where it is proposed to superadd to a correct copying of natural forms, those increased effects which result from the further imitation of nature, by adopting her gradations of colour and shade.

Standing at the end of a long straight street, and looking along it observantly, the line of the curb-stones, which separate the pavement from the road-way, and also those lines of the pavement which run in the same direction as the curb-stones,—that is, along the street,—appear to draw nearer to each other as they recede from the spectator; and, if the street be a very long one, they will approach each other so nearly as almost to meet in a point. If he look at the curb-line and other lines of pavement on the other side of the street, he will perceive in them a still greater inclination, all apparently tending towards the same point, and which point will appear to be somewhere in front of him. Turning his eye upwards, he will remark the same curious effect in the cornices of the houses; which, with the window-sills, the tops of the railings, the lintels of the doors, and the lines of the shop-fronts, all manifest the same tendency to approach each other, and meet at some remote point at the end of the street. He will observe, further, that lines on or near the ground all point rather upwards; those about as high as his own head are tolerably level; while those which begin much above his head, such as the cornices and heads and sills of the upper windows, all incline downwards; also, that the higher the latter are at any point near him, the greater is their slope downwards as they recede from him (fig. 2).

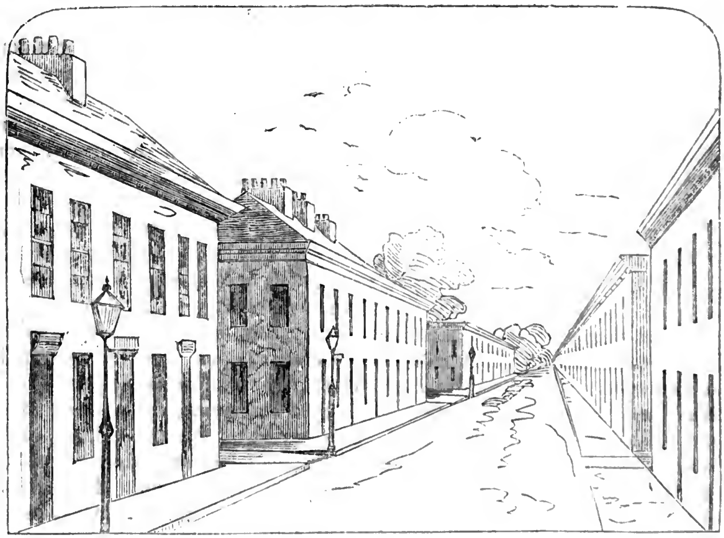


fig. 2.

A similar effect may be observed by any person standing at the end of a long avenue of trees, and looking along it. The convergence of the lines of the feet of the trees, the commencement of the foliage, &c., is almost equally manifest (fig. 3).

fig. 3.

If, again, the observer walk on till he arrive at a crossing where the street is intersected by another, and then cast his eye diagonally across it, so as to face the corner opposite to that at which he makes his observation, he will perceive a totally different result. None of the lines of the first-named street appear to meet in *front* of him, though they still manifest a tendency to approach each other, and meet in some distant point far away *on one side;* while those of the second street which has come into view appear all to tend towards some second point *at the other side.* This effect will be recognised with the aid of the street view in fig. 4, the position of the observer being at *a*.

The same effect may be observed in any room. Let the learner stand at the end of an apartment, and note the direction of the lines of the ceiling, walls, and floor. He will find that those lines which are as high from the floor as his head are level or horizontal; those of the ceiling,

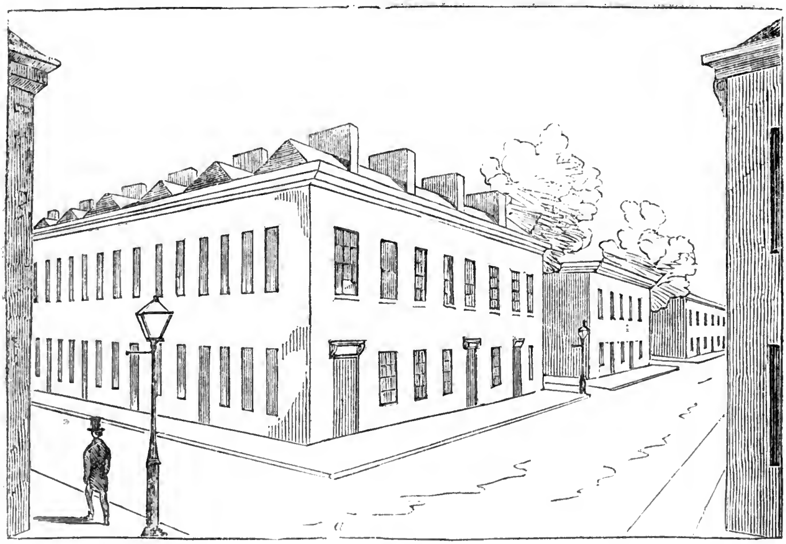


fig. 4.

which are above it, slope downwards as they recede from him; those of the floor, which are below it, slope upwards. The degree of this slope or inclination increases near the ceiling and floor, and continues to do so till, at one part of the room, the lines assume a vertical position; thus showing that they all appear to converge towards some unknown point, though well known to be all in reality parallel and horizontal.

Now, since flat or plane surfaces are bounded by lines, it follows, that changes in the direction of such boundary-lines cause corresponding changes in the form of the planes which they enclose. The ceiling, floor, and sides of the room are planes, whose perspective appearance and form are determined by the lines at which they meet each other; and such plane surfaces will seem to converge just as lines do. In the street view (fig. 4), for instance, the sides of the houses form such converging planes.

After lines and planes, comes the consideration of solids. As planes are denoted by lines representing their external configuration, in like manner solids are denoted by planes representing the forms of their various sides. A house, a book, or other object composed of straight lines, may be looked on as a solid body whose external form is an arrangement of various planes; and the true perspective representation of such solid will be composed of perspective views of such of these planes as can be seen at once by the spectator from any given station. Thus in fig. 1, the sides and edges of the book are planes, of which one, two, or three, according to its position with respect to the spectator, are seen in perspective at once. And as the perspective appearance of planes is changed by any change in the direction of their boundary-lines, so is that of solids changed by changes in the outlines of their constituent planes. And having shown that lines and planes change their appearance according to the position from which they are viewed, it follows that the *point of view* has a corresponding effect on the outlines and appearance of solids.*

It will next be our object to arrive at the rules by which the exact appearance of lines, planes, and solids, from any given point of view, may be laid down on paper; to which end, we must first ascertain the exact points towards which, as has been already explained, the lines of such objects converge, and at which they would meet if produced. These imaginary points are called *vanishing-points;* because if a plane were long enough to reach as far as the sight could extend, its top and bottom lines would meet at such a point, and the plane would seem to terminate or vanish at that point. These vanishing-points are of the greatest importance in perspective, and the most important of them all is the *point of sight,* which will, therefore, be the first explained.

The *point of sight* is the point in a picture which is exactly opposite to the eye of the beholder, and is always situated somewhere on the line of the horizon. The height of this *horizontal line,* and therefore of the point of sight, is dependent on the height from which the spectator is supposed to take his observation, which shows the horizontal line varying according to the height of the eye (fig. 5). In copying any scene from nature, it will be seen that the line of the horizon always maintains the same level as the eye of the draughtsman. If he takes a

fig. 5.

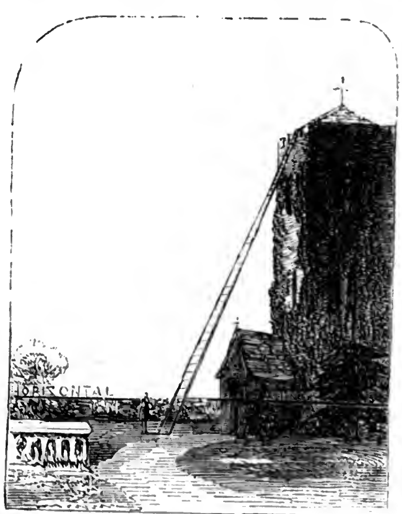


fig. 6.

view standing on level ground, the horizon will seem low (fig. 6), and the view will embrace but a limited field; if from any considerable elevation, the horizon will be higher (fig. 7), and a wider range of objects will be visible; and from a still greater height, such as the top of a hill or of a tower, the horizon still maintains its level with the spectator, and the field of vision is correspondingly extended (fig. 8).

* The attention of the reader is particularly directed to the foregoing paragraph, as containing much that is of importance in the demonstration of the principles of Perspective.—Ed

The space comprised between the horizontal line and the base of any picture, whether it consist of land or water, or both, is called the *ground-plane;* which will represent a space more or less extensive according as the

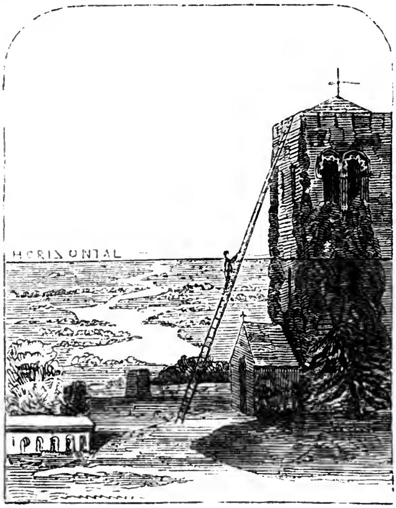


fig. 7.

fig. 8.

spectator's position, and consequently the horizontal line, may be elevated, as in fig. 9, or of lower altitude, as in fig. 10.

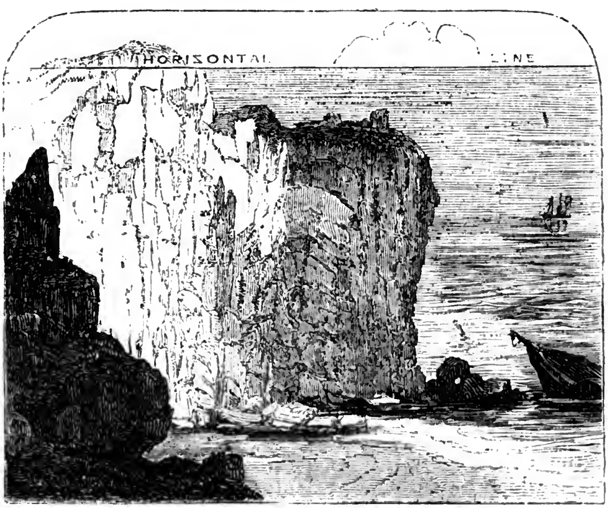


fig. 9.

The spectator's position is termed in perspective the *station-point.* In many cases, where objects, as trees, houses, &c., intervene, the view of the horizon will be intercepted, and it *will* therefore be invisible from the station point. The horizon still existing, however, though not visible from

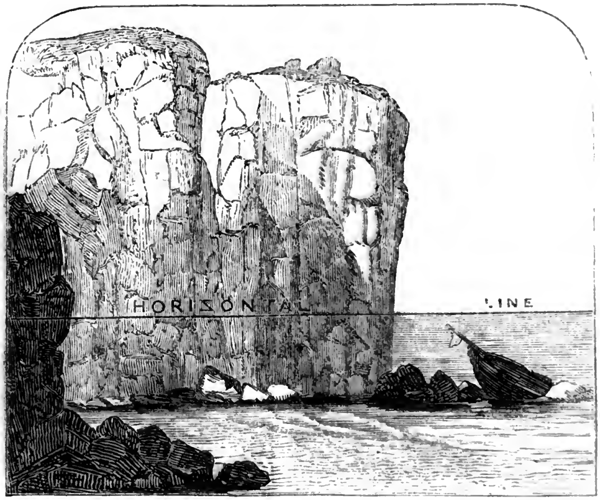


fig. 10.

the station, its position must be denoted by an imaginary, dotted, or occult line extending across the drawing, as on it will be found the proper situations of the point of sight and other vanishing-points.

If, when looking through a window, we could trace, with some instrument on the surface of the glass, the lines of the objects seen through it, such lines would constitute a true perspective representation of those objects. Now, a window is a plane surface perpendicular to the ground-plane of such representation, and as a window represents, so any picture in its frame is supposed to represent the objects shown therein, exactly as they would appear if the frame were glazed, and the objects beyond it were marked upon the surface of the glass. The space included by the frame, and here supposed to be filled with a flat sheet of glass, is called the *plane of delineation*, or, by some draughtsmen, the *plane of the picture*.

If a sheet of glass be set up on its edge on a flat table, with some object (say the pentagonal figure shown in fig. 11) on one side of it, and the eye of an observer on the other, it will constitute a plane of delineation, and the line *a b* at which it rests on the table (which will represent the ground-plane) will be the *base-line of the picture*. When the eye E is directed towards the object, rays of light will proceed in straight lines from every point of the object towards the eye. These are called *visual rays;* and the points at which these visual rays intersect the plane of the picture are the true perspective positions of those points as they appear from the station E. When the perspective places of any two points are found, a right line connecting those points will be the perspective representation of the corresponding line in the object. Thus, the five visual rays E 1, E 2, E 3, E 4, E 5, proceeding from the points 1, 2, 3, 4, 5 of the object, intersect the plane of delineation at the points similarly numbered, and the lines con-

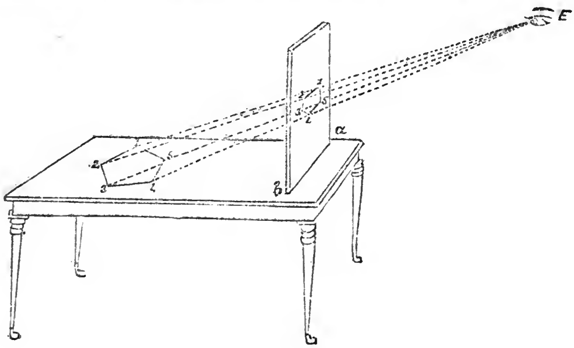


fig. 11.

necting those points with each other will be the representation of the figure on the table, transferred in perspective to the said plane, as seen from E.

The *plane of the picture,* then, is an imaginary transparent plane, supposed to exist somewhere between the spectator and the object, and the picture itself is a copy of the view that would be seen through such plane.

It was just now stated that rays proceed from every point of an object towards the eye. They also diverge from any radiant point in every direction. It is not necessary for our purpose to enter into a minute explanation of the beautiful mechanism of nature by which representations of objects are conveyed to the mind through the medium of that organ, but a glance at its principal parts may assist the reader to comprehend what is to follow. Transparent bodies of various forms are called *lenses,* and it is known to opticians that rays of light passing through any lens undergo certain changes in their direction, according to its form and density. Thus the tendency of a convex lens, *a,* figure 12, is to concentrate parallel rays passing through it, and bring them all to one point or focus; whereas that of a concave lens, *b,* fig. 12, is to disperse them, by throwing them wider apart from each other. The density of the lens or transparent medium effects similar changes. A ray passing from a rarer to a denser medium, as from air into water or glass, is said to be refracted, which means that it is bent from its straight direction, an effect which must have been observed by the student fond of aquatic amusements in the bent appearance of an oar when dipped into water. These properties of lenses are turned to useful account by opticians in their endeavours to assist defective vision. The glasses of the spectacles which they provide for the weak-sighted are lenses, the curvature of which is adapted to the defect to be remedied. If the individual have not a distinct perception of *distant* objects, owing to

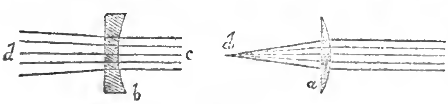


fig. 12.

extreme fulness of the curve of his eye, a concave lens interposed between it and those objects counteracts the detrimental effect produced on the vision by the excessive convexity. If, on the other hand, flatness of the ball of the eye impairs his perception of objects near him, the interposition of a more convex lens compensates for the deficiency. These ingenious contrivances are, however, only imitations of those more perfect arrangements adopted by nature in the eye, to enable it to perform its function of conveying to the brain or sensorium correct ideas of the forms, colours, sizes, and distances of objects. Any set of rays diverging from a point is called a *pencil of rays;* the central ray of any pencil is called its *axis* (*c d*, fig. 12); the axis of any pencil in passing through a lens undergoes so little divergence or refraction, that it may practically be said to continue a straight line; and lastly, with a double lens equally convex on both sides, the distance of the *focus* will be equal to the radius of the curve. These optical facts being premised, let us examine the operation of such a lens (A B) when rays from any object (C E) pass through it. (Fig. 13.)

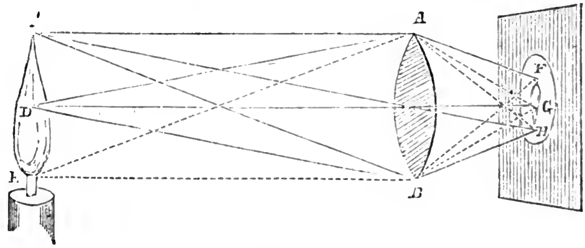


fig. 13.

From any three (C, D, E) of its innumerable radiating points, imagine three pencils of rays (A, C B, A D B, A E B) to fall upon the lens. From the nature of a convex lens, as just explained, the axis of each pencil will pass straight through the lens, but its diverging rays will be collected on the axis in a focal line (F, G, and H) at a distance beyond the lens equal to its radius. If all light be carefully excluded except what passes through the lens, and a sheet of paper be placed at the focal distance, the rays from the object will present an inverted image of it on the paper. This may be easily proved in a dark room, by holding an ordinary convex spectacle-glass, suitable for old people, between a lighted candle and a sheet of paper, taking care that the paper is at the proper focal distance from the lens, which will be known by a clear but inverted image of the candle being visible on the paper.

Now this is but an imperfect imitation of what takes place in the human eye, of which fig. 14 is a diagram. Its principal apparatus is a double-convex lens, called the *crystalline humour,* consisting of a clear liquid contained in a transparent bag or membrane, and protected externally by a transparent coat, D, called the *cornea.* Between these, and surrounding the crystalline humour, is a membrane having a circular hole, P, called the *pupil,* furnished with a muscular provision, by which its opening may be enlarged or diminished. In the back part of the eye is an expanded net-work of nerves lining the enclosing membrane, and called the *retina,* which is connected by means of the optic nerve with the brain.

The visual rays from objects pass through the pupil to the convex lens, which produces their inverted image on the retina, whence the optic nerve communicates their impression to the brain or sensorium. In the candle experiment, just mentioned, the spectacle-glass represents the cornea and crystalline humour, and the sheet of paper the retina. There is at the back of the eye a muscle attached, by which it may be moved towards either side, so as to direct the opening of the pupil and the face of the crystalline lens towards any desired object; but as perspective drawing only embraces such objects as can be seen at one time without moving the eye, further notice of this muscle is unnecessary here.

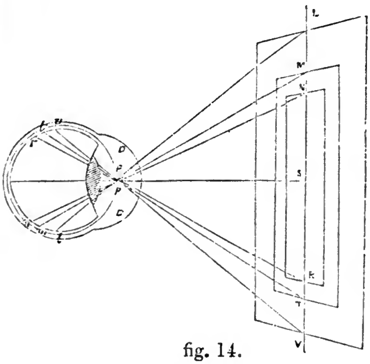


fig. 14.

A slight consideration of this diagram, elucidating the structure of the eye, will suffice to show the reason why the range of vision towards either side of the spectator is limited; that is, why he can only see a certain number of the objects before him at once, and why he must turn his eyes either to the right or left before he can clearly perceive more of them. A line passing directly through the eye at right angles with the retina, as the line S P in fig. 14, is called the axis of the eye; and it is demonstrable that in proportion as visual rays are parallel to or coincide with such axis, so will the image they form on the retina be clear and distinct. A visual ray entering the orifice of the pupil in an oblique direction, as the line L l in fig. 14, will also fall on the retina obliquely; and if this obliquity exceed a certain degree, the image of the object on the retina becomes indistinct or invisible. If the object be viewed from a point too near it, the visual rays from its extremities will enter the eye at too great an obliquity, and it cannot, therefore, be all viewed at one glance (fig. 15); but if it be removed to a greater distance, the obliquity of the rays from its extremities will be diminished (fig. 15), and its entire width will come within the convenient range of vision at one view. Now it is found that the greatest obliquity of the extreme visual ray which will permit a comprehensive view of the whole object, or set of objects, at one glance, without turning the eye, is when that ray forms with the axis, *a b*, fig. 15, of the eye an angle of 30°; and as objects are visible at an equal distance on both sides of that axis, the angle formed by the two extreme visual rays *a c*, *a d*, from both sides of the object, should not exceed 60°, which is, therefore, denominated *the angle of vision*, as *a c d*. The diagram, fig. 16, gives a correct idea of this angle, and of several others useful in the practice of perspective drawing. An angle of 60° is found by taking a line of any length, and with a pair of compasses set to that radius at each end, forming an intersection, as in fig. 17.

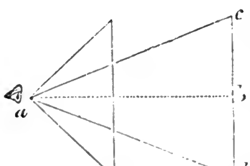


fig 15.

This angle of 60° is the largest that should ever be chosen in fixing the position of the eye with reference to any object to be drawn; and where many objects must be included in the drawing, it is a very good

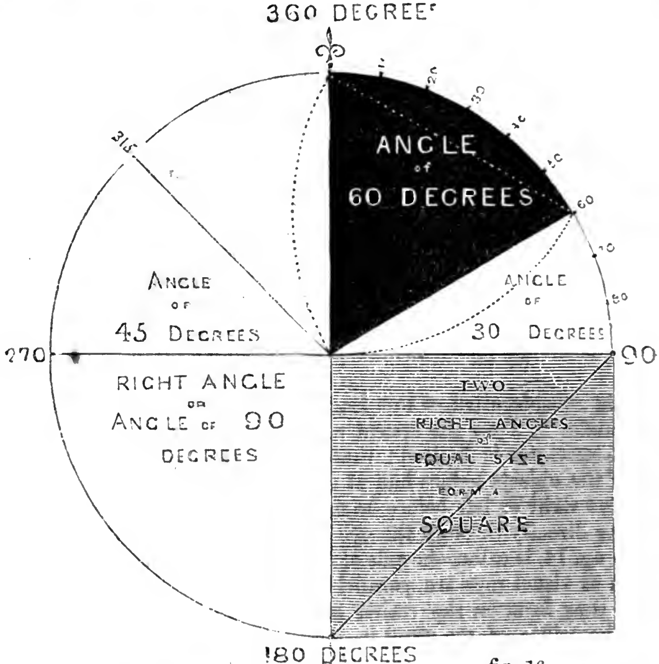


fig. 16.

one to adopt; but when it is not desirable to take in many objects, a smaller angle will often be advantageous, as shown in plan, fig. 18, where the adoption of a smaller angle, *d f e*, excludes the two objects *a* and *c* from the width embraced by the picture.

From what has been stated, it will be apparent that the width of the plane of delineation, that is, of the picture, and the lines which form the angle of vision, constitute a triangle, the apex of which is the station-point. It is important to have a clear conception of this, as it regulates the *distance of the spectator* from the plane of the picture, and this distance exercises an important influence in determining the forms of objects in perspective.

We have seen in the street-view, fig. 2, how objects of equal height and width diminish in their perspective *height* and *width* as they recede from the eye. A similar diminution takes place in their perspective *lengths*; and these diminutions, by which their apparent bulk is reduced, depend on their respective distances from the spectator. The rule for determining dimi-

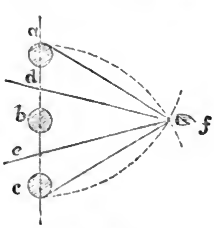


fig. 18.

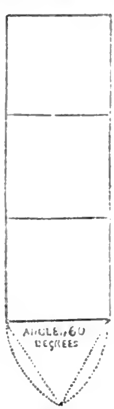


fig. 17.

nutions in the lengths of objects is obtained by the assistance of a point on the horizontal line, the distance of which from the *point of sight* (for definition of this term see p. 56) represents the distance of the spectator from the *plane of delineation* (see definition, p. 58), and is therefore called the *point of distance*. In the ground-plan, fig. 19, the position of the eye and its distance from the point of sight in the picture are denoted by the line

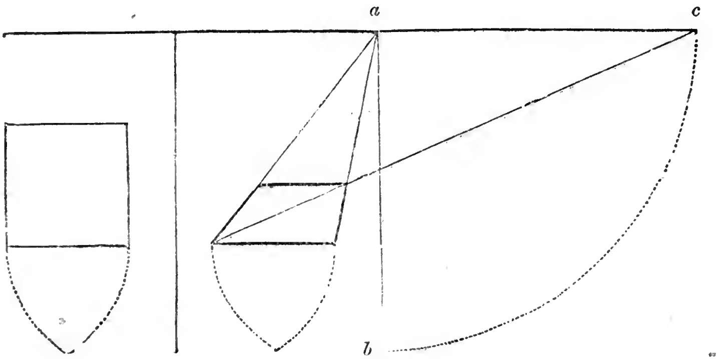


fig. 19.

drawn between them; and if a space be set off upon the horizontal line to the right or left of the point of sight (a) equal to the distance so denoted, a b, the point c at the end of that space will be the true distance-point.

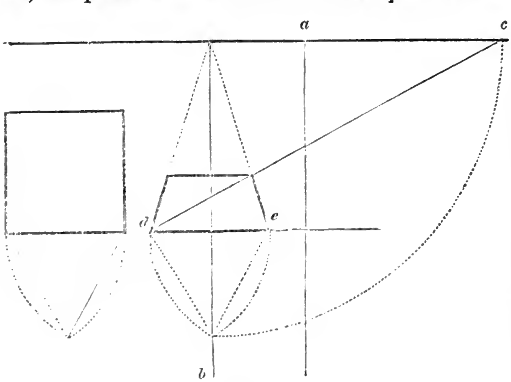


fig. 20.

This will determine the *perspective lengths* of receding objects, by rules to be hereafter laid down. This is further explained in fig. 20, which contains a ground-plan of a square on the left, while the right shows the same square in perspective, and the mode by which the point of distance is obtained. One leg of the compasses is to be placed at the point of sight a, and the other extended to the station point or position of the eye b; then with the point of sight a as a centre, and the distance between it and the station-point b as a radius, an arc of a circle from the station-point will intersect the horizontal line at a point c, which is the distance-point required. A line drawn from the corner of the square d on the base-line to this distance-point gives the perspective diagonal of the square; and the square terminates at the intersection of the diagonal d c, with the visual ray e drawn to the point of sight c. The same mode of obtaining the distance-point is shown in fig. 19.

The diminishing effect of distance, palpable though it is to the eye, at every glance embracing objects more or less remote, may be made still more obvious by simply applying the eye to one end of any straight tube. In this case the end of the tube near the eye is on the plane of delineation, A B (fig. 21); and though its further end is known to be of the same size exactly, yet its image C D on that plane is not half the size; and the longer the tube, the smaller will that image be. The respective apparent sizes of the two ends are shown in the end view at E, which gives the exact appearance of such a tube to an eye so situated. A sheet of paper rolled into a tubular form will illustrate this diminution.

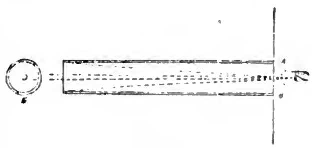


fig. 21.

The same effect may be observed on a larger scale by a person looking through a straight railway-tunnel from one end; the tunnel being, in fact, a large tube. If it be a long one, the apparent diminution caused by the distance of the further end will be very remarkable, although the two ends are known to be exactly the same size.

The objects of perspective drawing, its connection with the functions of the eye, its general principles, and the principal terms used in its practice, having now been attempted to be explained, the student is advised to study and make himself master of the figures and descriptions elucidating these before proceeding further. A good understanding of them will save him infinite trouble hereafter, and will greatly conduce to his pleasure as he proceeds; and it is hoped that the delay occasioned by examining and understanding these principles, before dashing into practice, will be found to be compensated by the increased facility with which it will enable that practice to proceed.

PART II.

PARALLEL PERSPECTIVE—SQUARES—RECTANGLES—DIAGONALS—PARALLEL PLANES—SOLIDS—CIRCLES—PYRAMIDS—OTHER FIGURES—POSITION—OBLIQUE PERSPECTIVE—INCLINED PLANES—HEIGHTS, WIDTHS, DISTANCES—SCALE—AERIAL PERSPECTIVE.

AN object may be seen in two different points of view: the one being when one side of it is parallel with the plane of the picture, and therefore at right angles with the axis of the eye; the other, when none of its sides are so circumstanced, and it must therefore be viewed at an angle, or obliquely. To the representation of objects thus differently circumstanced, different rules apply; one set of rules being those applicable to *parallel perspective*, the other to *oblique perspective*—these being the two divisions of linear perspective. The difference lies chiefly in the management of the vanishing-points; the point of sight, horizontal line, base-line, plane of picture, and some other details, being common to both. As being the most easily learned, and forming an appropriate introduction to the least simple of these two sets of rules, those of Parallel Perspective will be first treated of.

Let a square, each of whose sides is equal in length to the line A B, fig. 22, be shown in parallel perspective. Draw the horizontal line, and on it mark the *point of sight* S; which, as we shall first suppose the spectator to stand directly opposite the square at the *station-point* V, must be perpendicularly over that point, as denoted by the line S V. From S, with the radius S V, set off the *distance-point* D on the horizontal line, by drawing the arc D V. Draw the visual lines S A, S B, forming two sides of the square. Draw a line from A to D, which will give the perspective diagonal of the square, and from the point C, where A D intersects S B, draw E C parallel to A B. The figure A B C E thus formed will be the perspective view of the square as seen from the station V.

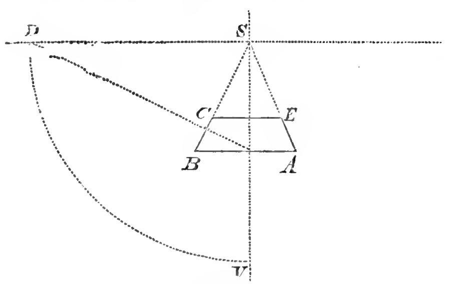


fig. 22.

Now, suppose this station, instead of being directly opposite to the side A B of the square, were situated towards the left of it, as in fig. 23. The effect of this will be, to remove the point of sight also to the left, which will produce a corresponding change in the direction of the visual lines S A, S B. Find, as in the last rule, the distance-point D¹ on the horizontal line, making S D¹ equal to S V; with this difference, that in this case it will save space and paper if the distance-point be taken to the right of the point of sight, instead of the left as in the last example. Proceed as in the last example, drawing E C, from the point of intersection E, parallel with A B.

In this figure two distance-points D^1 D^2 are taken, in order to show that it matters not on which side of the point of sight the distance-point is chosen, except as regards the convenience of the draughtsman and the size of his paper. The distance-point D^2 gives the other perspective diagonal AC of the square, which will serve just as well for finding the true position of the line EC as the first diagonal EB, which has been found with the aid of the distance-point D^1.

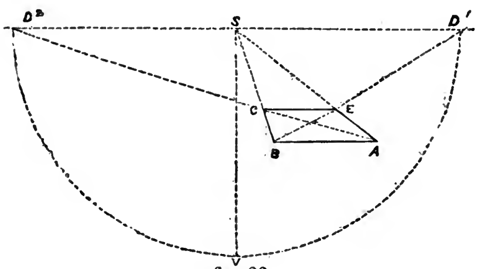


fig. 23.

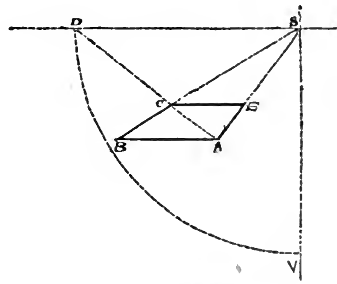


fig. 24.

Let us now suppose the station V to be removed to the right, instead of the left, of the line AB, fig. 24. In this case, the point of distance may be chosen to the left of the point of sight, to save space and paper. Set off SD equal to SV; draw the visual lines SA, SB, and the diagonal AD; the point of intersection C denotes the position of the further side EC of the square, which must be drawn parallel to AB. The figure ABCE is the perspective view of the square as seen from V in this third position.

It may be well here to explain that lines merely drawn for the temporary purpose of obtaining other lines, and not forming part of the object to be shown, are dotted in these figures, and are called imaginary or occult lines. In actual drawing, they are usually executed in pencil, and when the figure has been obtained by them and inked in, they are to be obliterated by india-rubber, in order to avoid the confusion arising from numerous lines.

It will not be necessary in future to draw the arcs VD of the last three figures. They have been given here for the sake of perspicuity, but in practice it will suffice to obtain the distance SV by compass, and mark the point D in its proper place with the pencil.

The three last figures should be carefully worked out, and compared with figs. 19, 20, Part I. Such a study will greatly assist the learner in understanding the perspective of planes, and how it is affected by changes in the spectator's position.

Having shown how one square is represented in parallel perspective, the study may be extended to numerous squares, as in a pavement. This is easily done by making AB equal to the width of the pavement, and dividing it into as many equal parts as there are squares in one side. Fig. 25 represents the plan and perspective of such pavement. The visual lines S 1, S 3, S 5, &c., represent the divisions of the pavement; the perspective diagonal AD to the point of distance, at its intersection with the visual line SB, gives the further corner of the pavement; from which the line EC, as before, drawn parallel to AB, completes its perspective outline. This diagonal also intersects every one of the visual lines S 1, S 3, &c. A line parallel to AB, drawn through each intersection, completes the perspective outline of every square.

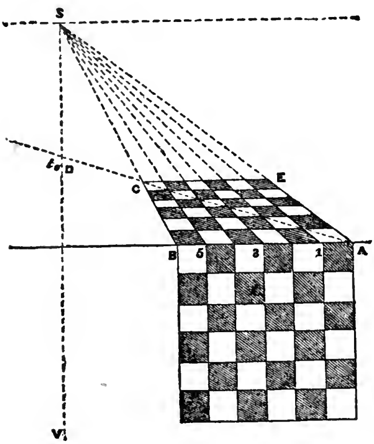


fig. 25.

This example may also, for practice, be worked out with various station-points and distances, but care must in all cases be taken that the horizontal lines parallel to BA be correctly drawn through the intersections of the visual lines with the diagonal, or an erroneous representation will result.

When only one row of squares is to be drawn, as in fig. 26, a diagonal must be drawn to the distance-point from the opposite front corner of each square; such diagonal, by its intersection with the other side of that square, will denote the back corner and position of the line EC, representing its further side; which line will form

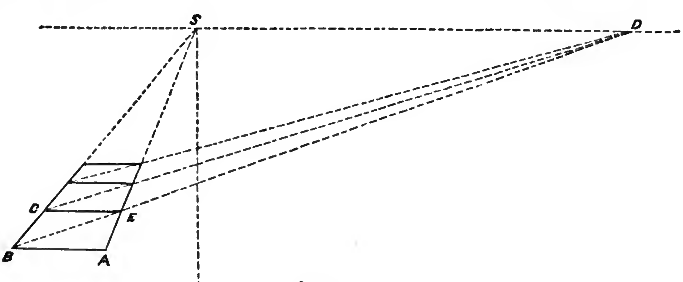


fig. 26.

the front side of the next square, and so on for any number of squares.

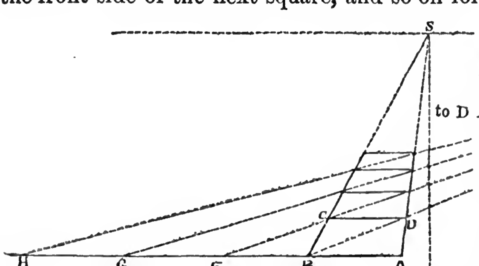


fig. 27.

The same object may be accomplished by prolonging the base-line on the *side opposite the distance point*, and setting off on it the width of each of the proposed squares, as B F, F G, G H, fig. 27; a diagonal from each of the points F, G, H, to the distance-point, will, by its intersection with the visual line SA, denote on that line the lengths of the sides of the respective squares.

The correctness of this rule may be proved, and another rule for the same object obtained, by prolonging the base-line to the right instead of the left, and marking off on the horizontal line to the left of the point of sight a distance-point D 2, fig. 28, making S D 2 equal to S D; the width of the squares set off in this line, as at *l*, *j*, *k*, and connected with the distance-point D 2 by diagonals, will denote the sides of the respective squares; and on comparing the figure thus obtained with fig. 27, the two will be found to be identical.

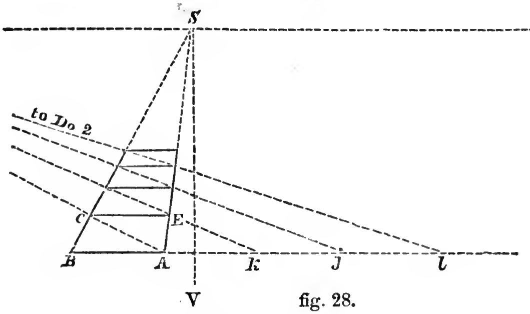


fig. 28.

The same rule is applicable to finding the perspective sides of parallelograms. Thus, for a perspective view of the parallelogram A B C E, the distance from the station-point to the plane of delineation being assumed equal to S D, and set off accordingly on the horizontal line, fig. 29, set off R F on the base-line produced, equal to the side B C on the plan; a diagonal from F to the opposite distance-point D, intersecting the visual line S B at C, denotes the perspective length of the side B C. The same object may be attained by using the visual line S R instead of S B, marking off R G equal to B C on the plan; and drawing the diagonal D G, intersecting S R at E, when R E will be the perspective view of that side on the plan.

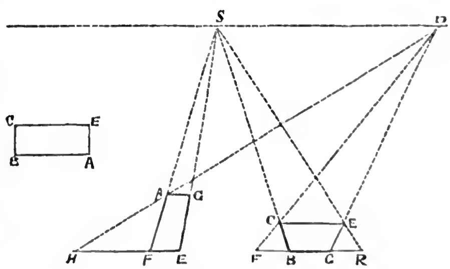


fig. 29.

But suppose the parallelogram is to be represented with its short side A E towards the spectator. Set off the length of that side on the base-line, H E, draw the visual lines S F, S E (left hand, fig. 29), set off on the base-line F H equal to the long side, draw the diagonal D H from the distance-point, and its intersection at A with the visual line S F will denote the perspective length of the long side; complete the figure by drawing A G parallel to E F.

These rules will apply to the drawing of right-lined figures in parallel perspective, under every variety of arrangement. Thus, to draw in perspective a square enclosing two rectangles, as in the plan fig. 30, the spectator being opposite to the point S, and at the distance S D: first, find the perspective view of the square A B C E, fig. 30, by preceding rules; produce the sides of the rectangles till they intersect those of the square at 1, 2, 3, 4, 5, 6 on the plan; set off those points on the base-line of the perspective view; draw the diagonals D 1, D 2, D 3, D 4; the points of intersection with S B will denote the perspective positions of the points 1, 2, 3, 4 on the side B C. Draw lines from these points across the perspective square, and parallel with A B; these will give the longer sides of the rectangles. Draw the visual lines S 5, S 6 to the point of sight, which will give the shorter sides of the rectangles, and complete the figure.

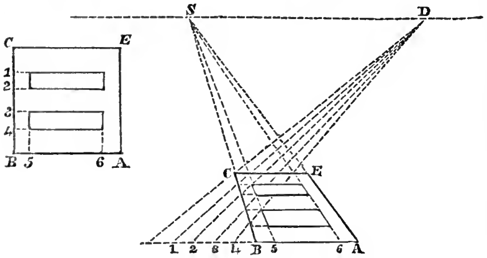


fig. 30.

The outline of a square being drawn in perspective, its perspective diagonals are obtained by simply drawing them from corner to corner. If a smaller square be inscribed in a larger, its centre and diagonals will be identical with those of the larger; and one visual line will suffice for determining the perspective of the smaller square. Thus, in fig. 31, the square A B E C being obtained in perspective by preceding rules, draw its perspective diagonals; produce one side G H of the inscribed square in the plan, intersecting A B at 1; set off the distance B 1 on the base-line of the perspective square, and draw the visual lines S 1, intersecting the diagonal E A at F, and the diagonal B C at G; from these two points draw H I and G F parallel to A B; draw lines connecting H G, F I; and the perspective view of the inscribed square F G H I is complete.

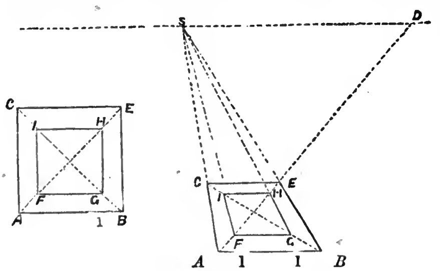


fig. 31.

From these examples we may deduce the important rule in perspective, that *the proper distance and position of any point* in a visual line terminating at the point of sight *may be found by setting off its distance on the base-line, and drawing a diagonal* from such distance to the distance-point on the horizontal line; the intersection of the diagonal with the visual line being the point required.

As a practical application of these rules, an example is here given (fig. 32) of the mode of drawing a chair in perspective. The distance-point is ascertained as before, by setting off the distance between the station-point and the point of sight upon the horizontal line. The seat of the chair is a square figure, found in the manner just described; and the lines from one of its feet to the other form also a square, put into perspective by the same process.

Thus far, squares below the level of the eye have been alone treated of; but the same rules apply to squares and rectangles situated above that level, such as the ceilings of rooms, the upper windows of houses, &c. This is exemplified in a view of that useful article of furniture called a

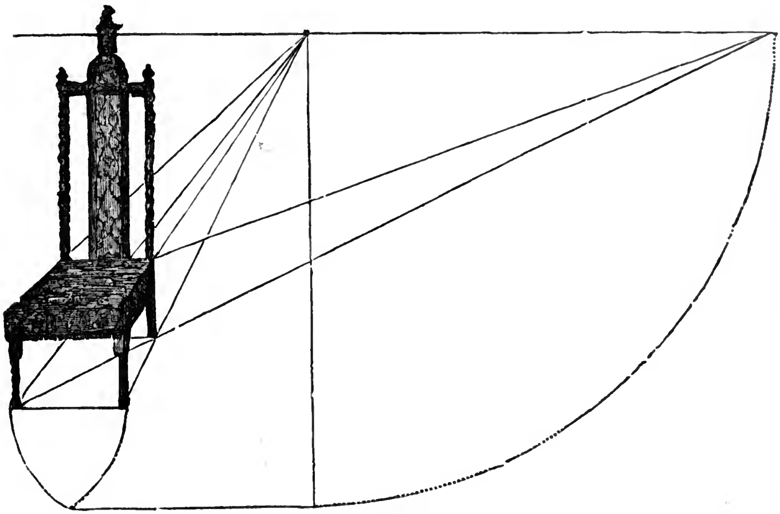


fig. 32.

"what-not," supposing it to be raised so that its upper shelves are higher than the eye (fig. 33).

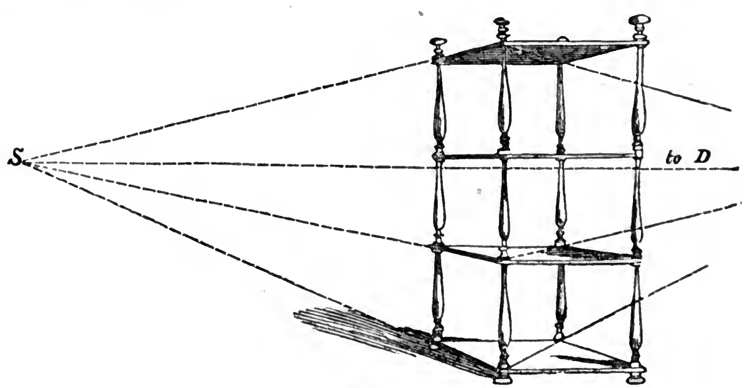


fig. 33.

The figures for which rules have been given thus far have been all supposed to be horizontally on the ground-plane, or parallel with it; but such figures frequently stand on their edges, that is, in a vertical plane. Of this kind are the sides of a room, of a house, and of many solid figures. Their perspective form is determined on the same principles, by finding the point in the visual line at which they terminate. Thus, let such a figure as is shown in fig. 30, plan, be shown edgewise in perspective, instead of flat, and let B C be the edge on which it is to stand. Draw a line A B, fig. 34, the exact length of A B on the plan, and perpendicular to the base-line of the picture. Draw the visual lines S A, S B, which denote the upper and lower edges of the figure. Set off from B on the base-line a distance B G equal to B C on the plan; the diagonal D G intersecting S B will denote by the point C the extremity of the figure; then draw C E parallel to A B, and the figure A B C E completes the perspective square. Next, set off on the base-line other points 1, 2, 3, 4, taken from C B on the plan fig. 30; and connect them with the distance-point by diagonals. From their respective intersections with B C draw lines parallel to A B, which will give the longer sides of the inscribed rectangles. Next, set off on A B the points 5 and 6, their distances from A and B being taken from the plan. Draw visual lines S 5, S 6, which, by their intersections with the vertical lines 1, 2, 3, 4, will denote the shorter sides of the rectangles, by which the whole figure is completed.

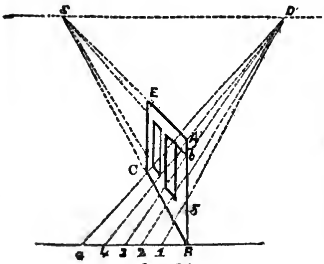


fig. 34.

This rule is applicable to all vertical planes, and is very useful in drawing panels of wainscoting for interior views, and in showing the positions of doors and windows in the fronts and sides of houses. The places of the doors and windows, and also of the cross streets, shown in fig. 2, Part I., were found in this manner.

By the combination of horizontal with vertical planes, we arrive at the perspective delineations of rectangular solids. Let it be desired to show

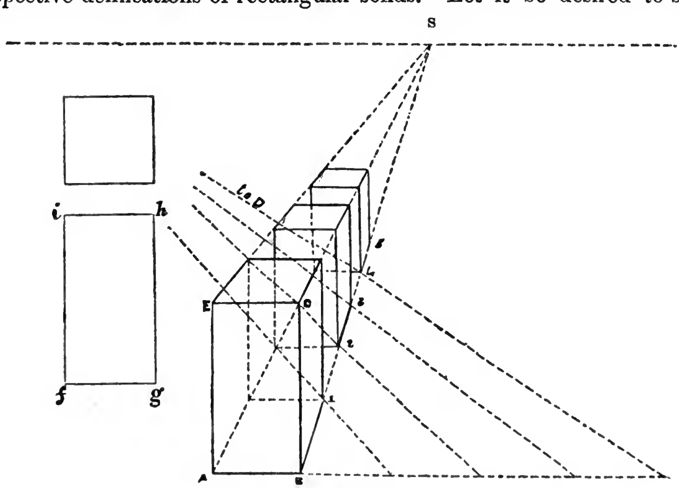


fig. 35.

in perspective a row of three square pillars of equal size, a plan of their bases being given in fig. 35, also an elevation of their sides; and let the distance between them be equal to one of their sides. With the width of the base, on the base-line, draw by preceding rules three square horizontal planes representing the bases of the three pillars, and shade them for the sake of distinctness. On the base A B erect perpendiculars A E, B C, equal to *f i*, *g h*, which connect at the top by E C parallel to A B. Draw visual lines S E, S C; at the points 1, 2, 3, 4, 5, erect perpendiculars parallel to B C, meeting the visual line S C; and from their intersections with that line, draw lines to S E parallel to E C. These lines, in connection with the visual lines S E, S C, will denote the *horizontal* planes forming the tops of the pillars; and the perpendiculars B C, 1, 2, 3, 4, 5, in connection with the visual lines S C, S B, will denote the *vertical* planes forming the sides of the pillars.

The same rule will apply to the forms of houses, boxes, and numerous other objects, whose external shapes may be considered as simple rectangular solids. On observing an object with a view to its perspective representation, the student should consider what geometrical figure it most resembles, and treat it accordingly. As he may now be supposed to have become sufficiently familiar with the parallel perspective of squares and rectangular figures, he may therefore proceed to that of other regular figures; and may first be introduced to *the circle.*

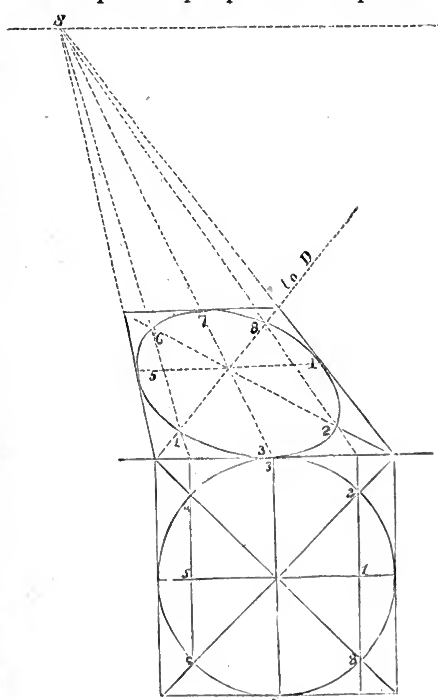


fig. 36.

Every circle may be inscribed in a square (fig. 36), touching it at four points, 1, 3, 5, 7, of the circumference, and cutting its diagonals at four other points, 2, 4, 6, 8; and if the perspective positions of these eight points be found, a moderate proficiency in drawing and command of hand will enable the learner to draw such a figure through them as shall represent the perspective circle. These points are found by the method shown in fig. 36. The diagonals 2 6 and 8 4 are drawn on the plan, and also the diameters 1 5 and 3 7. The two lines 4 6 and 2 8 are also to be drawn through the points at which the circle intersects the diagonals; and the square with its lines may now be put into perspective by preceding rules, by which means the perspective positions of the points 1, 2, 3, 4, 5, 6, 7, 8, through which the circle must pass, will be found at the intersections of the corresponding lines. The squares, diagonals, diameters, and other lines, being only drawn in order to obtain by their assistance the points 1, 2, 3, &c., may be obliterated as soon as the perspective circle is inked in. The above eight points will, in drawings of ordinary size, be sufficient guide to the hand in drawing circles; but for circles of very large dimensions, the principle may be extended, and twice the number of points easily found by doubling the number of cross-lines, 2 8, 4 6.

The last figure gives the perspective circle in a horizontal plane; the same rule applies to its projection on a vertical plane, with this difference only, that in the latter case it must be squared against the side of the picture, instead of against the base-line (fig. 37). This rule being highly use-

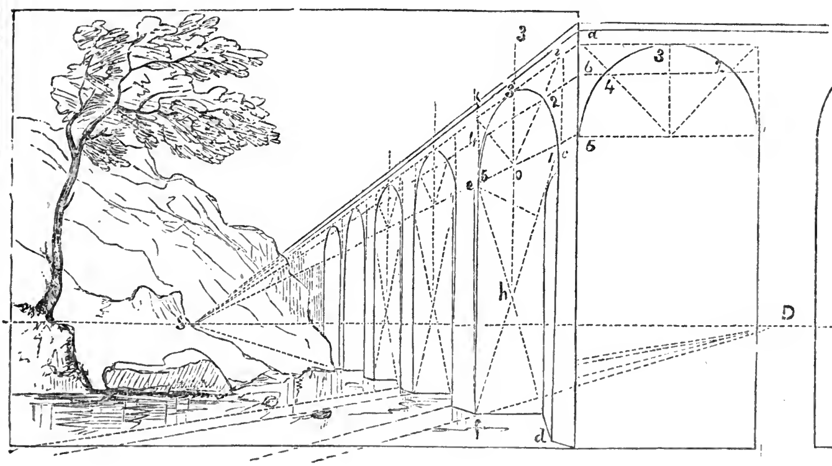


fig. 37.

ful in drawing bridges and viaducts with semicircular arches, an example is given, with a description of the process. The arches in the annexed viaduct being semicircular, the upper part only of the circle is to be squared by diagonals, diameters, and cross-line, as in fig. 36, by which means five points in the semicircle are obtained. Find the perspective lengths of the arches and piers by setting off the real lengths on the base-line, and drawing diagonals to the distance-point intersecting the visual line SD. At the intersections erect perpendiculars to the base-line denoting the piers. At the side of the picture set off *d c*, the height of the piers to the springing of the arch; draw the visual lines S*a*, S*b*, S*c*, and the others denoting the top and bottom lines of the viaduct. To ascertain the perspective point representing the top of each arch, draw the diagonals *e d*, *c f*; their intersection will be the perspective centre of the vertical plane *c d f e*, through which *g h*, drawn parallel to the side of the picture, will cut the visual line S *a* at the top of the arch. Produce the two sides of the rectangle *cd fe*, to meet the line S*a*, at *i* and *k*. Draw the lines *io*, *ko*, intersecting S*b* at 2 and 4. The perspective semicircle may now be drawn through the points 1, 2, 3, 4, 5, thus obtained. Proceed in the same manner with each of the arches, using the same visual lines S*a*, S*b*, S*c*, by which, with the aid of similar diagonals, they may all be completed.

Gothic arches of pointed form may be drawn in perspective by the same rule, varied only to suit the change in their form. The object of squaring the semicircle in the last figure was to obtain certain points of its outline which, drawn in their respective positions, would guide the hand in forming the perspective outline, and points in any other curve will in like manner denote the perspective outline of such curve. In fig. 38 the elevation of the arch is drawn against the sides of the picture as before, and points are

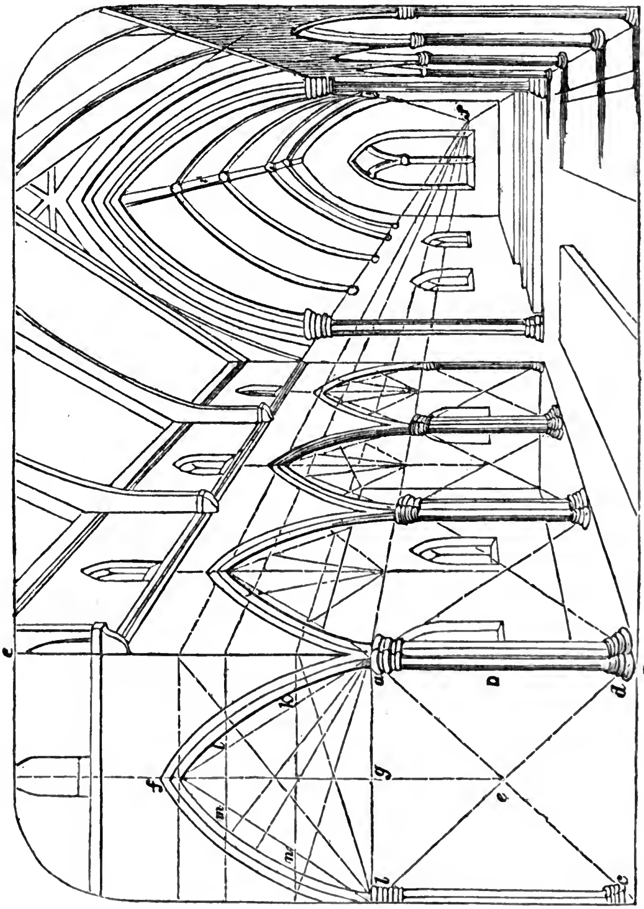


fig. 38.

found in its outline by a similar process. First join the two lower corners by a line *ab*, draw the diagonals *ac*, *bd*; from their intersection draw *ef*, passing through the centre of *ab* at *g*. Draw *fa*, *fb*, divide each of them into three parts, and through each division draw lines from *a* and *b* to the opposite side of the arch; seven points, *aklfmnb*, will thus be found. Produce *lm* and *kn* to the side of the picture. From the points thus obtained at that side, draw visual lines to the point of sight S; find, as before, the perspective point, f, of each arch by diagonals; draw the perspective lines fa, fb, divide each of them into three parts, through the divisions draw lines from g, intersecting the visual lines at points which will give the direction of the perspective curves.

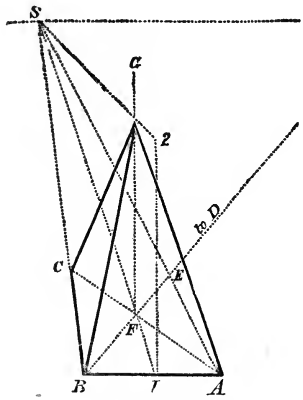


fig. 39.

The perspective centres of the vertical plane of the arches were found in the last two figures by the intersection of their diagonals. The perspective centres of horizontal planes may be found in the same manner, which is short, and often very useful. For instance, to find the apex of any pyramid or cone (fig. 39), find the perspective of the base, which we will suppose to be a square, A B C E, and at the intersection of its diagonals erect a line F G perpendicular to the base of the picture. The perspective height of the pyramid or conical object is found by drawing a visual line S 1 from the point of sight through that intersection to the base-line, and there erecting a perpendicular on which to set off the height 12. A visual line S 2 will intersect the central line of the pyramid at the required apex, whence lines drawn to its base complete the figure. The same rule will apply, whatever be the form of the base and number of sides. In architectural drawings the spires of churches are easily drawn by this rule. If the base be a circle, find its perspective centre by drawing the circumscribing square with its diagonals, whose intersection will be the foot of the central perpendicular line. In this case a single line from the apex to each side of the base will complete the figure.

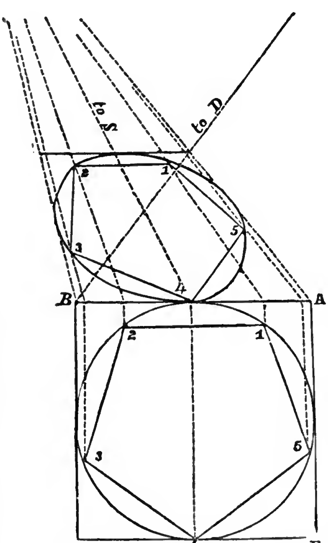


fig. 40.

Since all equilateral figures, whatever the number of their sides, may be inscribed in a circle, and touch its circumference at their angles, it follows that, having found such circumscribing circle in perspective, and the points in its circumference touched by the angles of the figure, we have only to connect those points by right lines to obtain the perspective view of that figure. One illustration of this with the pentagon, which after the square is the simplest many-sided figure, will show also the application of the rule to hexagons, octagons, or other polygonal figures.

Let the pentagon 1 2 3 4 5 (plan, fig. 40) be shown in perspective.

First circumscribe it with a circle, and that circle with the square A B C E. Square the circle, as previously shown (fig. 36), and draw its perspective view, the points of sight and distance being given. Ink in the square, circle, and pentagon in the plan, and the square and circle in perspective, and obliterate all the lines by which they were found, to avoid confusion. Proceed then to insert the perspective pentagon. From its points on the plan, 1, 2, 3, 4, 5, draw perpendiculars to the base-line, and from their intersections with that line draw lines to the point of sight cutting the perspective circumference at the points correspondingly numbered. Connect the points thus found with each other by lines, and the result will be the perspective pentagon required.

The same mode of proceeding will apply to all regular equilateral figures. *Irregular figures* are shown in perspective by finding their points or angles by means of visual lines and diagonals to the distance-point. An example of one such figure will sufficiently explain the mode of proceeding, to comprehend which, however, the mode of finding any point in perspective must first be shown.

Let B H C E, fig. 41, be the plane of the picture, S D the horizontal

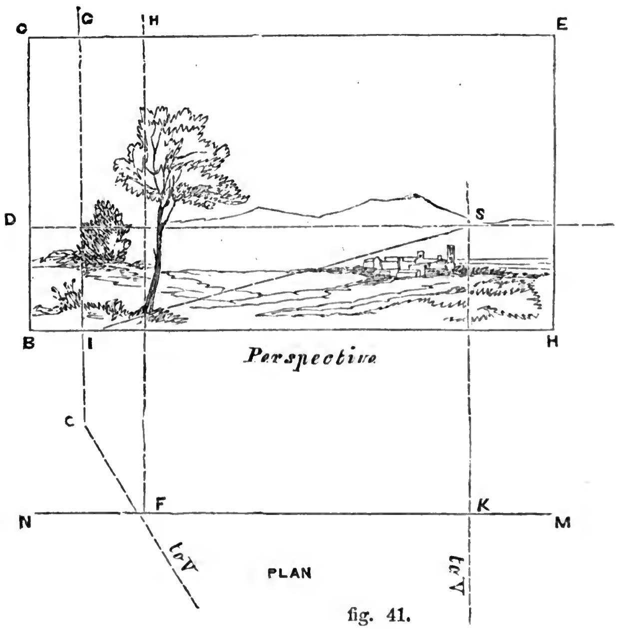


fig. 41.

line, B H the base-line, S the point of sight, V the station, and D the point of distance; S D on the picture being equal to K V on the plan. Let M N be the position of the plane of delineation on the plan, and C that of any object (say a tree) beyond that plane. Required the perspective position of such object.

Draw the visual ray V C, intersecting M N at F. From C and F draw C G, F H, both perpendicular to M N and H B. Draw the perspective visual ray S I, which is a perspective view of V C. Its intersection with F H is the required point, representing the position of the object.

The same result may be attained in another way. In the following figure (42), the same letters refer to corresponding points as fig. 41. But

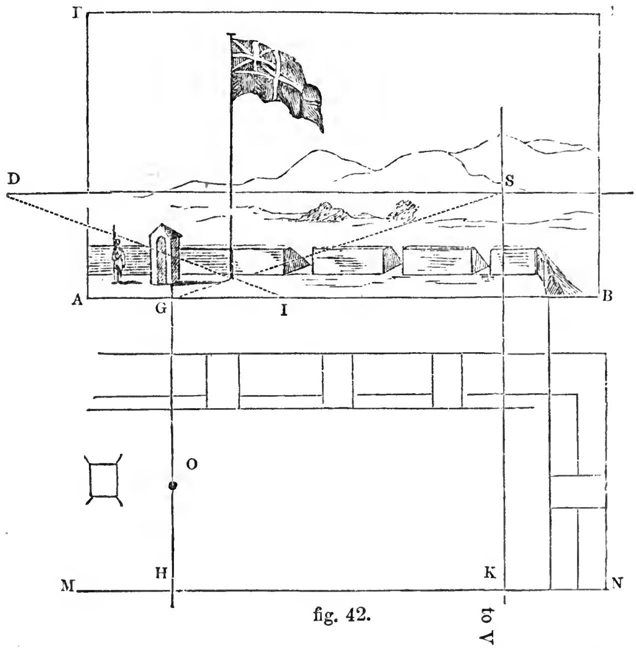


fig. 42.

the point of distance is now made use of, as in the perspective drawing of squares; its distance D S from the point of sight being made equal to K N. From the position or place of the object O (in this case a flag-staff) draw O G perpendicular to M N, intersecting it at H. From G, with the radius O H, describe an arc intersecting A B at I, and making G I equal to O H. The diagonal D I will intersect a visual line G S at the required perspective position of the object.

In drawings made on this principle, in which a plan of the object is first laid down, with the positions of the station and plane of delineation, paper more than twice the size of the proposed picture is required, which is sometimes inconvenient. This objection may in many cases be removed by inverting the plan, and making the base-line of the picture serve the double purpose of the base of the plane of delineation and of its position on the plan. In this case, the station-point of course is placed above the drawing instead of below it, and the plan of the object is shown inverted, below the drawing. By this means paper equal to the height of the picture is saved, as in fig. 43.

Having described two modes by which the proper positions of points may be found in perspective, the learner will easily perceive how irregular figures, whose plan is given, may be shown in perspective by finding the places of their points or angles in the picture. Thus, let *a b c d e f* (fig. 43) be a plan of a block of building, to be laid down in perspective previous to erecting thereon a view of them. From the station V draw a line perpen-

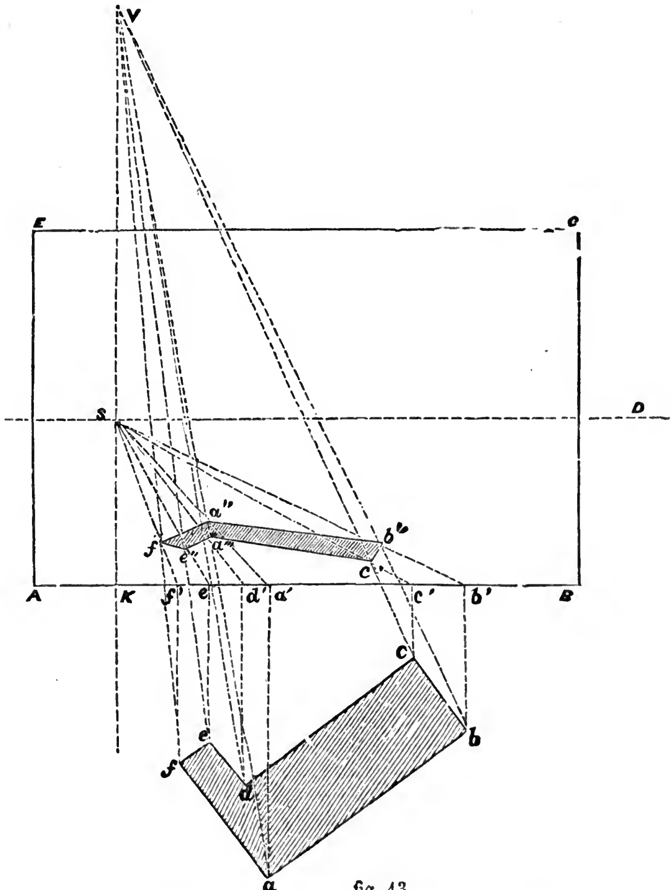


fig. 43.

dicular to the horizontal line, intersecting it at S, which will be the point of sight. On the *horizontal line* set off D S equal to K V, which makes the space between the points of sight and distance equal to that between the station and plane of the picture. Draw visual lines from V to every point of the object in plan as V *f*, V *e*, &c. Draw also from every point of the object a perpendicular to the line A B, *b b′*, *c c′*, and from the points of intersection with that line draw perspective visual lines to the point of sight S, which will intersect the visual lines of the plan at points *a′′ b′′ c′′ d′′ e′′ f′′*; these will be the perspective positions of the corresponding points in the plan; connect these points by lines, and the perspective figure will be complete.

When the size of the drawing, as compared with the extent of the paper or drawing-board, will not admit of the plan being drawn at all on the same sheet, it may be drawn on a separate sheet, with the station, position of the plane of the picture, and visual lines in plan, laid down thereon. The intersections on the line denoting the position of the picture may then be transferred to the base-line of the drawing by the compasses; or an easy mode may be arrived at by placing the edge of a sheet of paper on the plan against the line of position, and with a pencil marking points on the edge of it corresponding with the intersections. The same edge being then applied to the base-line of the drawing, the points may be easily transferred by corresponding marks on the base-line. If there be many points to be transferred, it will facilitate and prevent confusion to number them consecutively, 1, 2, 3, 4, &c., marking similar numbers on the edge of the transfer-paper.

By the foregoing rules, the position of any point, the direction of any line, and the figure of any plane in parallel perspective may be found. But there is a class of cases yet to be spoken of which may be dealt with more simply than by any rules yet given. They are chiefly those in which objects are viewed angle-wise, and which therefore are called *oblique perspective.*

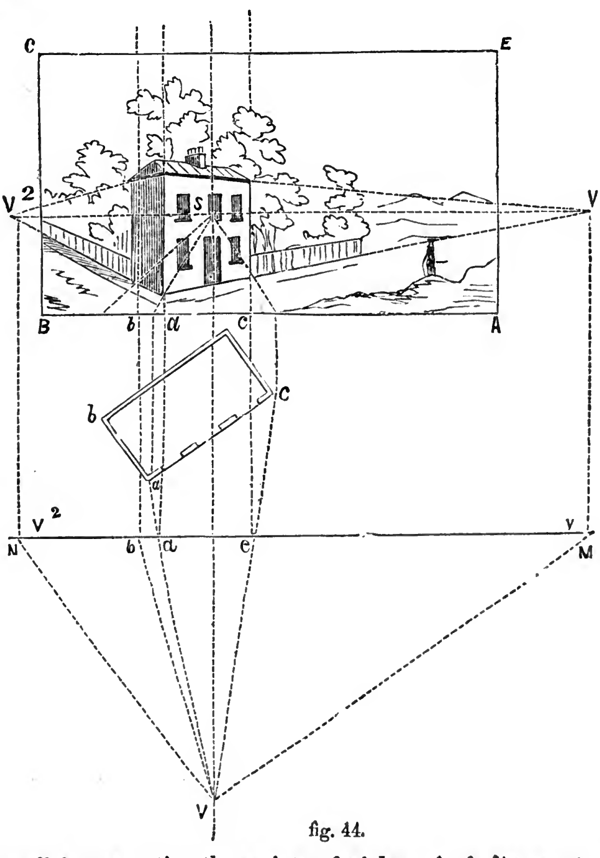


fig. 44.

In parallel perspective the *points* of *sight* and of *distance* have been those chiefly made use of for determining outlines; but in oblique views they are of comparatively little use, and the sizes and forms of objects are chiefly regulated by *vanishing-points*, the rules for finding which will now be explained. In the street view, fig. 2, and in all views in which lines and plane surfaces are in plan at right angles with the plane of the picture, the point of sight is the vanishing-point of such lines and planes; but in angular views, such as that in fig. 4, the vanishing-points of the various sides of objects will lie to the right and left of the point opposite to the eye; and those of most objects will be found somewhere on the horizontal line. In the oblique view, fig. 44, the vanishing-points for the sides of the cottage are found in plan by drawing lines V V, V V^2 from the station to the position of the plane of delineation parallel with those sides; thus, V on the plan is the vanishing-point of the long side, and V^2 that of the short side of the cottage. These points are transferred by perpendiculars to the horizontal line of the picture. The angles of the house, sides of door and windows, &c., are then connected with V, the station, by visual lines intersecting the plane of the picture, and from those intersections transferred by perpendiculars to the base-line of the picture itself. From their respective points on this line they are taken to the point of sight S as a vanishing-point, and by their intersections with the last-named perpendiculars give the outline of the cottage at its lower part or base. To find the lines of the upper part, assume a height on the perpendicular line denoting its front angle, and from the assumed point draw the upper lines of the long side to the vanishing-point V, and those of the

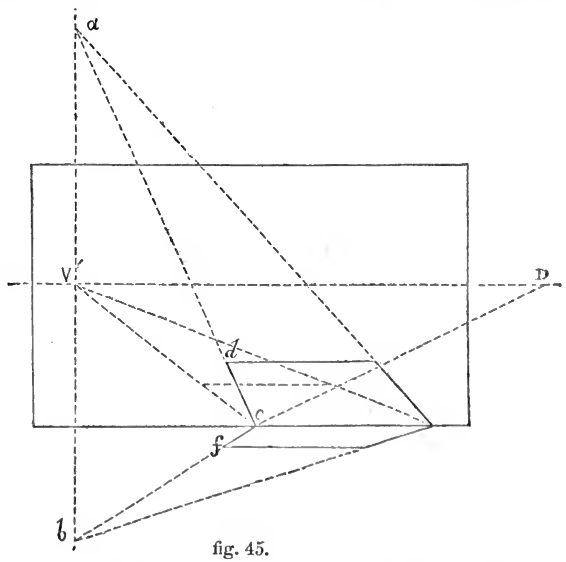


fig. 45.

short side to V^2. The centre of the roof may be found by diagonals, as already described in preceding figures.

But the statement just made respecting vanishing-points, that they will generally be found somewhere on the horizontal line, is only true as respects those of objects whose lines are parallel with the ground-plane. Many objects, and frequently the ground itself, are not parallel with the true ground-plane, but have various degrees and kinds of inclination. Thus, in the case

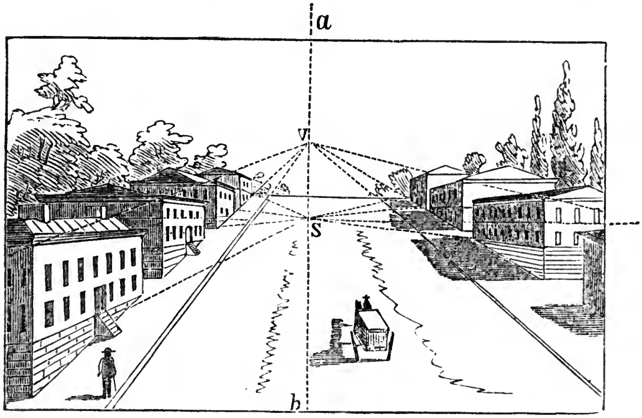


fig. 46.

of an *up-hill* view (fig. 46), in which the plane of the surface rises upwards from the spectator; or of a *down-hill* (fig. 47) view, in which the surface inclines downward from him; or of sloping objects, such as the roofs of

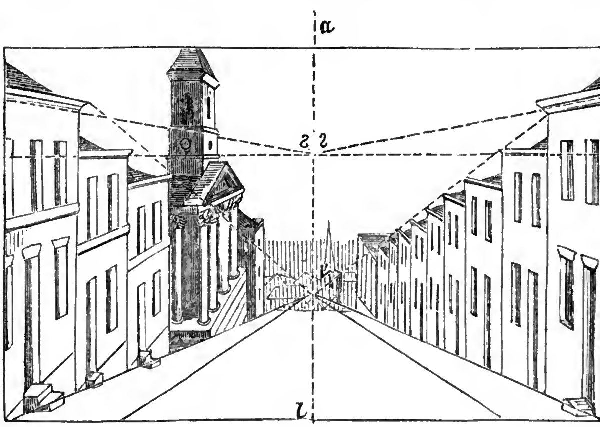


fig. 47.

many houses, which incline *side-ways* from him, the vanishing-points will obviously be either above or below the horizon, and the degree of their deviation from it will depend on the degree of the inclination. This brings us to the consideration of *inclined planes*, the vanishing-points of which are always *perpendicularly above or below those points on the horizontal line which would be their vanishing points if the plane had no inclination.* This will be better understood by consulting fig. 45, which gives three different views of the same plane at different degrees of inclination; by which it will be seen, that to find the vanishing-point of any inclined plane, we have only to find the point V[1] on the horizontal line which would be its vanishing-point were it not inclined, to draw through that point a line *a b* perpendicular to the horizontal line, and produce one side *c d* or *c f* of the inclined plane. Its intersection with the perpendicular *a b* will be the vanishing-point of all inclined lines parallel with *c d* or *c f*, and *a* or *b* will be either above or below the horizontal line, according as the inclination of the plane *from* the spectator is upwards or downwards.

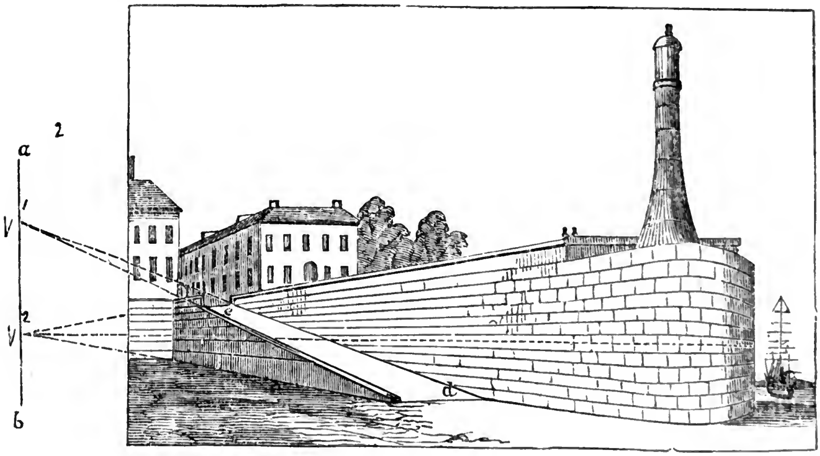


fig. 48.

The annexed figure (48), representing the jetty at Birkenhead as seen from the river, with the inclined ascent up to it, demonstrates the mode of

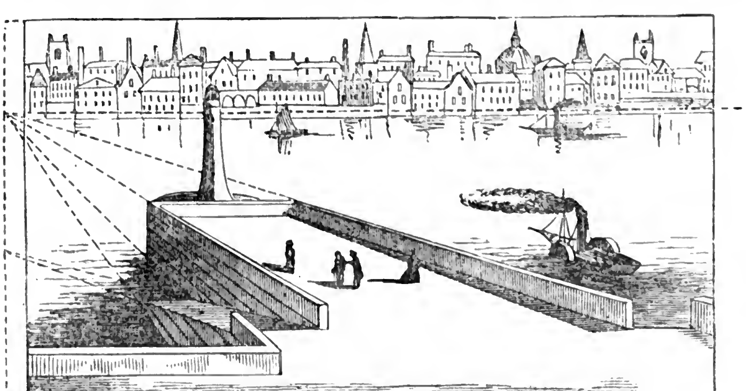


fig. 49.

finding the vanishing-point of the inclined plane, the points *d* and *e* being first obtained by the perspective lines of the jetty. Produce *d e*, intersecting $a\,b$ at V^1, which will be the vanishing-point of the incline; while V^2 on the horizontal line, intersecting the same line, will be the vanishing-point of the horizontal lines of the jetty. This is an up-hill view, at an angle with the spectator.

In the next figure (49) the spectator is supposed to be on the land, looking towards the water; in this case the inclined plane becomes a down-hill view, at an angle with the spectator. Its vanishing-point V^2 is still found on the line $a\,b$, but in this case below instead of above V^1, this vanishing-point, on the horizontal line, of the level part of the jetty.

Up-hill and down-hill views opposite to the spectator are regulated on the same principle; the point of sight being in these cases the vanishing-point of horizontal lines, while the inclined lines vanish at a point respectively above or below the point of sight, but on the same vertical line. A remarkable example of each of these cases may be seen by looking along St. Vincent Street, Glasgow, alternately from the upper and lower ends.

A slight consideration of these rules will suffice to show that planes of

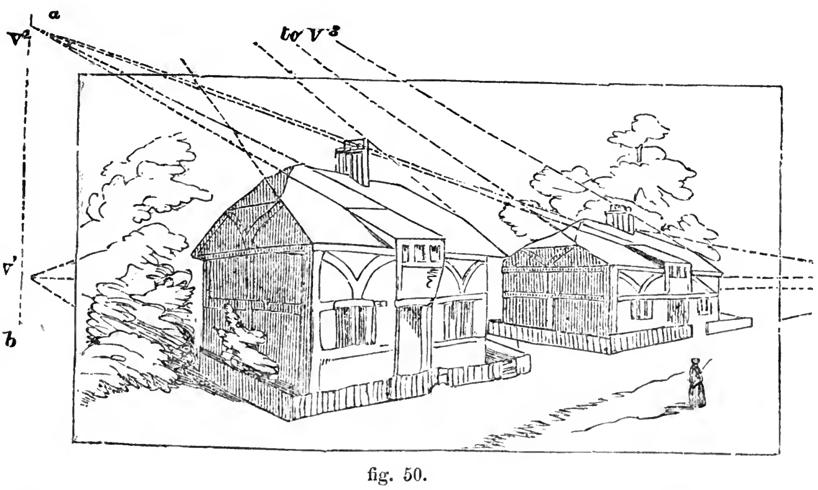


fig. 50.

various inclinations will have various vanishing-points, but that all these points will be found on a line perpendicular to the horizontal line, and passing through the vanishing-point of planes that are horizontal or parallel with the ground-plane. Thus in fig. 50, which is a view of two cottages near Welshpool, in Montgomeryshire, the portions of the roofs over the upper windows are inclined planes, at a different degree of inclination from that of the other parts of the roofs, and therefore have a different vanishing-point V^2 on the line $a\,b$ (which passes through V^1, the vanishing-point of the ends of the cottages on the ground-plane), V^3 being the vanishing-point of the roofs, on the same line $a\,b$.

Inclined planes, however, which when drawn in elevation are parallel with each other in all their sides, have in the perspective view the same vanishing-point, whatever be their position in the picture; if some only of the sides or lines be parallel, those sides or lines only will vanish at the same point; and if none of them be parallel, then each will have a separate vanishing-point of its own. An instance of this is seen in fig. 51, which is a view of the picturesque little church of Llandysilis in Wales. In this view, to produce it in correct perspective no less than five separate vanishing-points, 1, 2, 3, 4, 5, were necessary; which results from the planes of

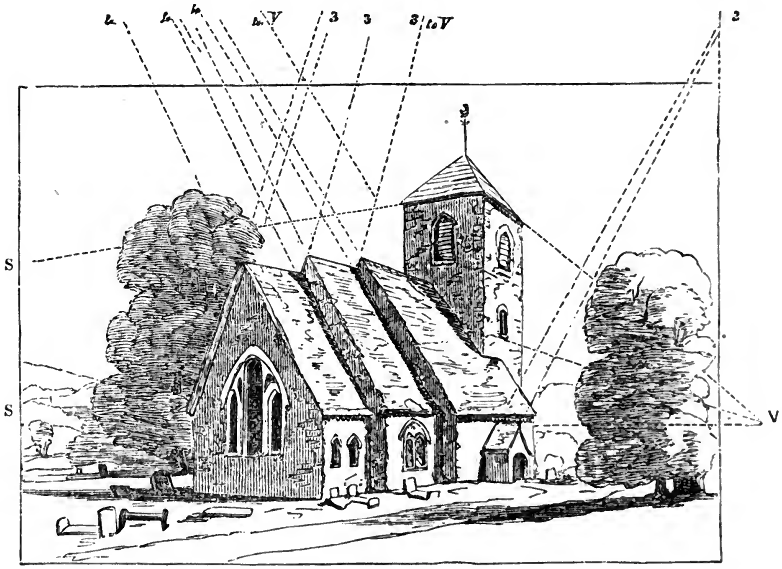


fig. 51.

the side, end, porch, and roofs tending in five different directions. The rule given at fig. 39 for finding the apex of a pyramid or cone will also be found useful for determining the point of the roof of the tower and the position of the weather-vane.

In fig. 33 an example was given demonstrative of the perspective of parallel *horizontal* planes at different elevations. That of parallel *inclined* planes has just been spoken of, and illustrated in figs. 50 and 51. That of parallel *vertical* planes is the same in principle, and must be dealt with in practice in the same manner. Their parallel sides will incline towards the same point, as in the street-view, fig. 2, where the fronts of the houses which form the two sides of the street may be regarded as two parallel vertical planes whose lines all tend towards the same point.

Having now described the general features and modes of proceeding in the delineation of lines, planes, and solids, including various regular and irregular figures, we have yet to consider the subject of solids with reference to their height. In parallel perspective, a large proportion of the lines of a picture are, in plan, at right angles with the plane of delineation, as was just now stated; and therefore the point of sight is the principal vanishing-point in such representations. In such cases, the proper way to obtain the perspective height of any object is, after having laid down the length of its elevation on the base-line of the picture, and connected the ends of that length by visual rays with the point of sight, to erect a perpendicular to the base-line at one end of that length; set off thereon the exact height, and from the point so obtained draw another visual ray to the point of sight; the space included between this visual ray and the one previously drawn from the bottom of the perpendicular will be the perspective height at any part of the picture. This has been already in part done in figs. 34 and 35, and is in all cases the mode of obtaining heights of objects in parallel perspective.

But in oblique perspective, very few, and frequently none of the lines in plan, lie at right angles with the plane of delineation. The point of sight and visual rays become therefore of less importance; but the vanishing-points become the more useful auxiliaries for determining the heights of objects seen at any angle. Keeping this strongly in view, the student should well consider the manner of proceeding adopted in fig. 44, by which the outline of the house was obtained, as it shows in a simple manner the whole principle of oblique perspective as applied to solids by means of ground-plan and vanishing-points. But there is one point in which he will soon find that this figure is incomplete, inasmuch as it *assumes* the height of the house. In true perspective nothing should be assumed; every part should be in its just and exact proportion; and the height of the house in the drawing must bear that proportion to its other dimensions which it does in the object itself. The only way in which these proportions can be correctly maintained is by drawing a perpendicular of the proper height, according to the scale of the drawing, on the plane of delineation, and drawing lines from its angles to the respective vanishing-points. By this means a triangular vertical plane will be obtained, stretching from the horizon to the plane of delineation, representing the given height throughout its entire length.

When, therefore, the front angle of any rectangular object is obtained by a perpendicular *b* from the plan, as in fig. 44, which line is here transferred to fig. 52, and also the lower line *a b* of any of its sides, produce that line

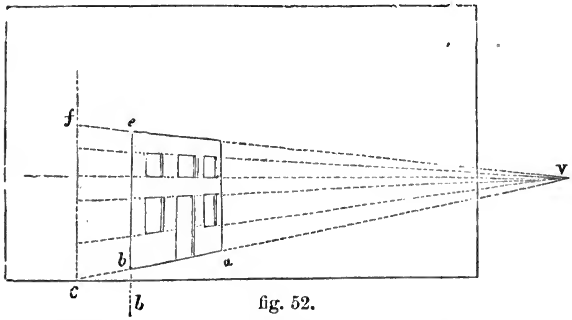


fig. 52.

to the base-line, as at *c*, and there erect a perpendicular, on which set off the proper height *c f* of the object to the same scale as the plan. In this figure the height of the front of the house is taken to be equal to the length *c b*, fig. 44. From this height draw to the vanishing-point a line *f* V, which will represent the upper line of the object; and from the point *e*, at which it intersects the perpendicular *b*, the space on that perpendicular down to *b* will be the true perspective height of the front angle of the object. The heights of the upper and lower lines of the windows and door are to be found in the same way by setting them off on the line cf.

When the perspective height of any one object in the picture has been found, that of any other object of the same height, in whatever part of the picture its position may be, may be easily found in parallel perspective by

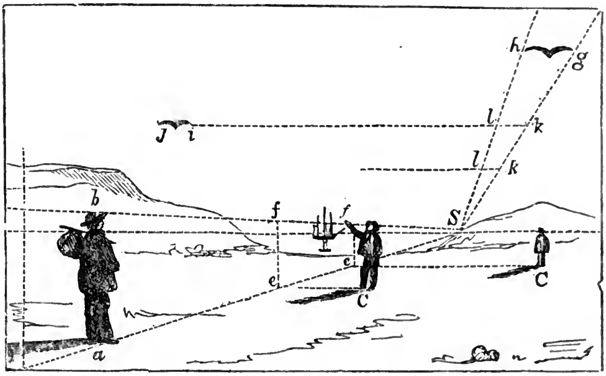


fig. 53.

means of visual rays to the point of sight. Thus, in fig. 53, having by the last rule found the height $a\,b$ of a figure standing at the position a, required the representation of another figure of equal height at the position c. Draw the visual lines S a, S b. From the position C draw C e parallel to the base-line, intersecting S a at e. From e draw $e\,f$ perpendicular to C e, intersecting S b at f. The height $e\,f$ thus obtained, transferred to a perpendicular on the position C, will be the perspective height of the figure at C. By this rule, the point of sight and perspective height in any one position being given, the perspective height for any other position may be readily found. Perspective widths may be found in a similar manner. In the same figure, 53, given the width of any object $g\,h$ (say a flying bird), required the respective widths of a similar object in the position i. Connect the ex-

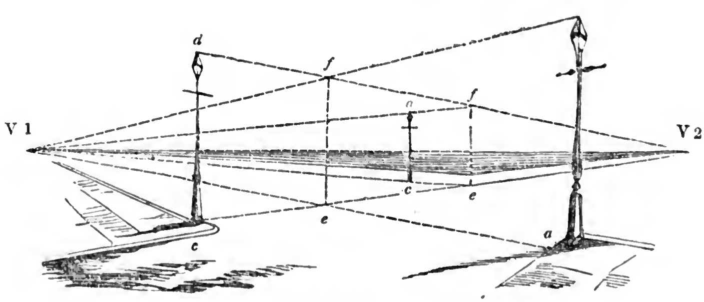


fig. 54.

tremities of the given width with the point of sight by visual lines Sg, Sh; draw a line from the position i parallel with the base-line, intersecting the visual rays at *k* and *l*; the width *k l*, transferred to the given position, will be the width *i j* of the object at that position.

But in oblique perspective the point of sight needs not in all cases to be found for the other purposes of the picture; and where it is wanting, the same problem may be solved in a somewhat similar manner, using the vanishing-points instead of the point of sight, and vanishing-lines instead of the horizontal lines *c e*. Thus, in fig. 54, given the position and height of a lamp-post *a b*, required the respective heights of similar lamp-posts at *c c*. Draw vanishing-lines from V^1 to *a* and *b*. From the position *c* a line to the other vanishing-point V^2 will intersect V^1 *a* at *e*. From the point *e* erect *e f* perpendicular to the base-line, intersecting V^1 *b* at *f*. Draw V^2*f* and the perpendicular *c d* intersecting it at *d*; *c d* will be the perpendicular height of the object at the position *c*. By this rule, the vanishing-points and perspective height at any one position being given, the proper height for any other position may be found.

In parallel perspective, the distances of objects or points on a visual line are found, as in fig. 35, by setting off their true distances on the base-line, and finding their corresponding distances on the visual line by diagonals to the distance-point. The same process is used in oblique perspective as in fig. 44, using the vanishing-point in the same way as the points of sight and of distance. But as the distance-points are often at a considerable distance outside the limits of the picture, and sometimes even of the paper, this mode of obtaining the intersections is in such cases inconvenient, the following method, by which a distance-point for the details of any object is obtained *within the picture*, may be substituted when practicable. To draw in oblique perspective the church A B G H, fig. 55,—which is a representation of St. Anne's, Manchester, before it was lately divested of its ornament,—required the perspective positions of the windows of the side A B. From the point A, parallel with the horizontal line, draw a line A 7, equal in length to the geometric length of A B in the plan or elevation. From the point 7 draw a diagonal through B, which will intersect the horizontal line at a point D within the picture, which is the distance-point required. Transfer from the plan or elevation to the line A 7 the distances of the sides of the windows A 1, A 2, &c.; and from the points 1, 2, 3, &c. thus obtained draw diagonals to the point D, which will intersect A B at corresponding points, &c.; from which intersections vertical lines will represent the corresponding sides of the windows. In this method, the line A 7 may, if more convenient, be drawn from the upper corner E of the side whose details are to be laid in, and as shown also at G, over the tower, and it may be made of any convenient length, provided it be made longer than A B; but in general it will be most convenient to make it the exact length of the given line on the plan of elevation. The upper and lower points of the windows may now be marked on the line A^1 E, whence lines drawn to the vanishing-point of that side of the church will give the perspective positions of corresponding points in the vertical lines denoting the sides of the windows. As the window-heads are arched, draw the elevation of the arch to the left of the line A E, and proceed, as directed in figs. 37 and 38, to draw the perspective arch over each window.

In order to render the student more familiar with the principles of oblique perspective and its practice by the aid of vanishing-points, two examples will now be given, and the manner of treating them explained; the one being an interior view of a room, with its doors partially open, at various degrees of obliquity; the other an exterior view of a house with a projecting cornice. Let the lower part of fig 56 be the plan of that part of the room which comes within the range of vision, that is, which is comprehended within an angle of not more than 60° from the station-point;

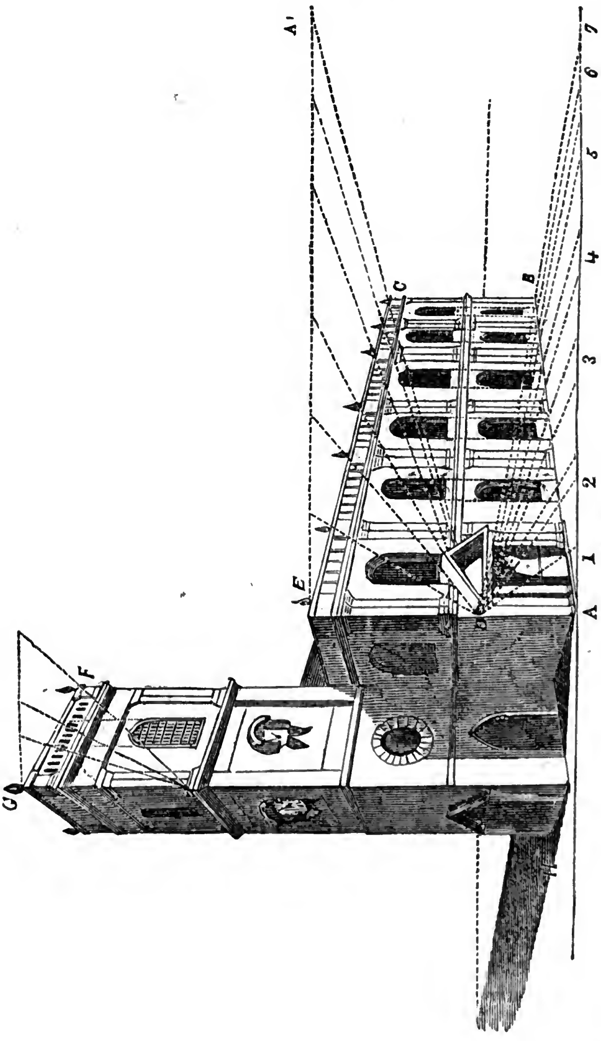


fig. 55.

and let the upper part A B C E be the boundary of the proposed view. Draw the base-line A B of the picture in plan, with its ends produced, intersecting the plan at such a distance that the extremities A B of the part beyond it, which is all that is to be included in the proposed drawing, shall form with the station-point V an angle not exceeding 60°. Parallel to the sides of the rooms and doors draw V V^1, V V^2, V V^3, intersecting the base-line at V^1, V^2, V^3. From the points and angles of the plan draw visual lines to the station, and from every intersection 1, 2, 3, &c. on the plan, draw perpendiculars *a* 1, *b* 2, &c. to the picture, intersecting the base of the plane of delineation at *a*, *b*, *c*, &c. The plan is now prepared for

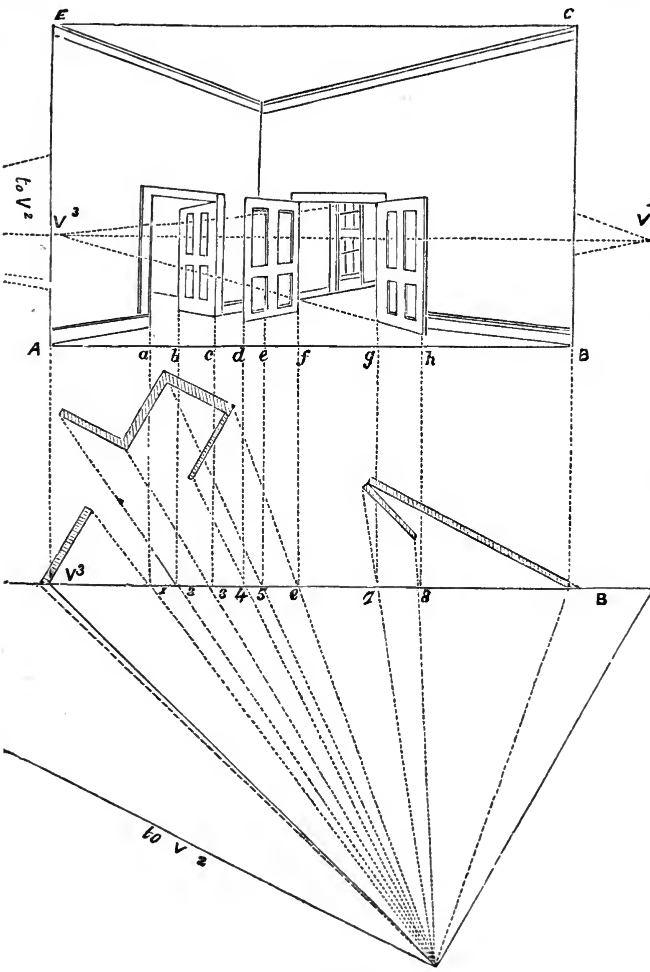


fig. 56.

transfer to the picture A B C E; across which draw the horizontal line at the proper height, and by perpendiculars transfer to it the vanishing-points V^1, V^2, V^3. Transfer the points *a*, *b*, *c*, &c. in a similar manner to the base-line A B of the picture; perpendiculars through these points will give the respective sides of the doors and openings, and the corner of the room. On the sides of the picture mark the proper heights of the door-openings; from which, lines to the opposite vanishing-points will denote the tops of the door-ways. In the same manner, lines from the respective varnishing-points of the doors, drawn through the upper and lower corners as far as the perpendiculars denoting their outer edges, will give the perspective lines of the upper and lower edge of each door. The heights of the skirtings and cornices must now be marked off on each side of the picture, and lines drawn from such marks to the vanishing-point of that side of the room will complete them. The panels of the doors may be found by lines to the vanishing-point of each door, denoting the upper and lower line of each panel, and the sides of the panels may be determined by the rule given at fig. 55.

Fig. 57 shows the manner by which the various lines of an oblique per-

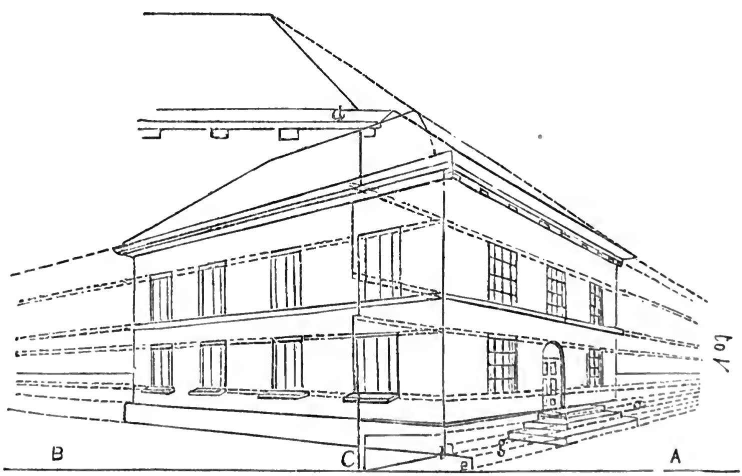


fig. 57.

spective view of a house are obtained. Let A B be the base-line, and let it be supposed that the perspective plan of the house has been obtained in the manner described at figs. 44 or 56, V 1 and V 2 being the vanishing-points of the two sides of the house: required to find the true perspective heights of the house and its various parts, namely, the roof, cornice, upper and lower window, string-course, heads and sills of windows, and plinth, including also the three steps at the front door. Produce the lower line *ab* of one side of the house till it meets the base-line, and at the intersection C erect a perpendicular *c d*, as in fig. 52, on which set off, according to the scale, the proper heights of the various points and objects desired; set off also from the same line, and in proper proportion, all projections from it, such as the steps, window-sills, and cornice; and on the other side of it all depressions, such as the window-recesses. This will give the outline of the house in elevation; and the true dimensions of these parts, according to the scale, being thus obtained at the plane of delineation, must now be transferred to their perspective positions in the picture. From the various points and angles of the different parts on this line, draw lines to the vanishing-point V 1, which lines will denote the perspective heights of those points and angles at any distance in the picture. Obtain from the base of the plane of delineation on the ground-plan, in the manner shown in fig. 44 or 56, the vertical lines denoting the three corners of the house; as also those showing the front corners of the cornice, plinth, and steps. From the intersections of these front corner-lines with the vanishing-lines to V 1 draw similar vanishing-lines to V 2, which will give the perspective heights of the corresponding windows, sills, &c., on the other side of the house. The sides of the windows, sills, and door may now be determined by vertical lines obtained either as shown in fig. 55 or 56, and the sides of the steps by lines from their points in the elevation to their respective vanishing-points V 1 and V 2.

The student will perceive that by this process not only perspective heights, but also breadths or widths are determined; for the points of the projections and recesses, as of the cornice, sills, and steps, are obtained in their horizontal as well as vertical distance from each other. Thus the breadth *e* C of the lower step is shown in true perspective width at *g*; and the same of the widths of the sills, projection of cornice, and depth of window-recesses. All these are determined by the intersections of perpendiculars from the base-line (transferred from intersections of visual lines with the base-line on the plan) with vanishing-lines from the elevation at the plane of delineation.

By the aid of the examples which have been given, it is hoped the student will have acquired a general idea of the principles and rules by which perspective drawings are regulated. He will find it advantageous to work out each example for himself, by the aid of the descriptions given, to a larger scale than has been admissible from the size of these pages: such a course will give him a much more intimate knowledge of the art than simply reading them over. As the vanishing-points and point of distance will be found frequently to have their situations far beyond the limits of his drawing, which would necessitate a much larger sheet of drawing-paper than the drawing itself actually requires, he is advised to stretch a sheet of common cartridge-paper on a board of large dimensions; and having cut his drawing-paper somewhat larger, but not very much so, than the size of the proposed drawing, to fasten it down on the centre of the board over the cartridge-paper by small brass-headed pins at each corner, taking care, by the aid of the T-square, that the sides of the drawing-paper are parallel with those of the drawing-board. By following this plan, those lines and points which are beyond the limits of the drawing will be continued on the cartridge-paper, and when the drawing is finished it may be taken off by loosening the pins; and if the lines on the cartridge-paper be then obliterated with india-rubber, and another piece of drawing-paper pinned down, the same cartridge-paper will serve for several successive drawings. Of course care must be taken that when a drawing has been pinned down and once commenced, it be proceeded with till finished; otherwise there is a chance that it may not he refixed in precisely the same position, which would alter the relative positions of all the points and lines with respect to the drawing.

The student being thus familiarised with parallel and oblique perspective—which two terms comprise the representation of the forms of all objects at any distance, and from any given point of view—will find no difficulty in applying their principles and modes of proceeding to more complicated objects than have been here illustrated, keeping always the leading principle in view. In most of the examples, the existence of a ground-plan of the object has been pre-supposed; and this will generally be found the most convenient way of working (sometimes further aided in elaborate objects by an elevation). It will generally be found in large drawings convenient to have the plan and elevation on separate paper, drawing a line across the plan to represent the situation of the imaginary transparent plane of delineation, marking the station in its assumed situation on the plan, and drawing thence visual lines to the points of the object. The intersections of these with the line of that plane may be transferred thence to the base-line of the actual drawing by compass or by an edge of paper, in the manner described at fig. 43, p. 79.

When objects are to be drawn in perspective to a scale of feet or inches, which is necessary in architectural and some other subjects, the scale must in all cases be set off *at the plane of delineation*, that is, either at the upper, lower, or side lines of the drawings; and must never be set off on the objects themselves, unless they are supposed to be close to that plane. Thus, in fig. 52, the front edge of the house being supposed to be at some distance *b c* beyond that plane, had the true height in feet been set off on the line *c b* it would have made the house taller than its true perspective height. In all such cases the lines must be continued from their vanishing-points to one of the four lines denoting the boundary of the said plane. In the figure just referred to, the line *a b* is continued on to the base-line, and the height *c f*, according to scale, is laid down on the perpendicular there erected. The line V *f*, by its intersection with *e b*, gives the true perspective height *e b*. The same rule is manifest in fig. 38, where the height of the arch and its various points, transferred by horizontals to the side of the picture from the elevation (which is supposed to have been drawn to a scale), gives the perspective heights of the corresponding points in the other arches of the series.

In most of the preceding illustrations the perspective view has been drawn with four lines, representing the boundary of the imaginary transparent plane through which the objects are seen; but in figs. 57 and 55 these lines are omitted, as they are in no way essential to the drawing, though often useful as a boundary, representing an opening or glazed frame, through which the picture is supposed to be seen. Drawings in which this boundary does not exist are called *vignettes;* and are in all cases supposed to be seen through such imaginary plane, though its outline be not represented by lines.

The elements of *linear* perspective being now explained, let us pass on to that which refers to the force and distinctness with which objects should be drawn in proportion to their supposed distance from the spectator, and which is called *aerial* perspective. As objects apparently diminish in size according to their distance, it follows that at a certain distance small objects, and at a greater distance those of somewhat larger size, will be so diminished as to be imperceptible. Lines, therefore, near the eye, of great thickness (speaking artistically, not with strict geometrical truth), lose a portion of their apparent thickness as they recede from it, till they are altogether lost in the distance, and if prolonged, would fade long before they reached the horizon. For this reason, objects at a certain distance lose a portion of their distinctness, and become more or less confused with each other. There is also another reason: the further an object is removed from the spectator, the greater is the quantity of air between it and him through which it has to be viewed; and though the atmosphere is a highly rare medium, it still possesses a certain degree of density which tends still further to diminish the distinctness of distant objects, in proportion to the quantity of air through which the visual rays have to pass. In certain states of weather, such as a damp or cloudy day, this density is increased, and distant objects become consequently less distinct. These circumstances being duly kept in view by the artist, and having their proper influence on the strength of his lines and depth of his tints, materially enhance the perspective effect of his drawing. The lines of distant objects should be very lightly traced with a fine-pointed pencil, while the strength and breadth of those representing objects nearer the plane of delineation should be increased in proportion as they approach it. The same rule must apply to the depth of tints and shadows; those of objects supposed to be at a great distance should be faint and light, those in the foreground must be dark and forcible, and those of the middle picture must have an intermediate strength. In short, in proportion as objects approach the plane of delineation from the horizontal line which forms the limit of the distance that can be taken in by the eye, so must the thickness of their lines and depth of their tints and shadows increase in the same proportion.

PERSPECTIVE DRAWING.

Part III.

SHADOWS—DEFINITION OF PRINCIPLES AND TERMS—LUMINARIES, NATURAL, ARTIFICIAL, AND SECONDARY—REFLECTION OF LIGHT—POSITION OF LUMINARY—SHADOW-PLANES, HORIZONTAL, VERTICAL, OBLIQUE, AND IRREGULAR.

Light and shade are important aids to perspective effect, and, since all objects partake of them more or less, are necessary constituents of true representation. It is therefore intended here to superadd to the preceding explanation of the rules which regulate the correct delineation of objects, a statement of those further rules which must be observed to obtain a correct imitation of their shadows. This is the more necessary, since it sometimes happens in drawing, that the presence and shape of an object, hid perhaps by others intervening, can only be intimated by its shadow being so situated as to be visible. There is a remarkable instance of a similar use of the shadow in Collins's picture of "Rustic Civility," where the presence of a man supposed to be advancing on horseback towards the picture by a road in front of the plane of delineation, is solely denoted by the shadows of a man and horse partly thrown into view on the foreground. Before entering on the subject some definition of terms is necessary.

Shadows are those portions of surfaces which are debarred from the rays of light which would fall upon them but for the intervention of some opaque body. That side or part of such opaque body which is turned *from* the source of light is said to be *in shade;* that which is *towards* the light is said to be *illuminated.* The source of light in a picture is called a *luminary.* Luminaries are of three kinds,—natural, artificial, and secondary. A *natural* luminary is one which exists in nature, as the sun, moon, stars, or an illuminated piece of sky. An *artificial* luminary is the result of art, as a fire, lamp, lantern, or candle. A *secondary* luminary is an opening through which light enters from any natural or artificial one, as a window, door, or opening in a wall. The *place* of a luminary is its perspective situation on the plane of delineation, or, if beyond the limits of the picture—as is mostly the case—on any imaginary extension of it. The surface on which the shadow is cast is called the *shadow-plane.* In landscapes, the ground-plane is the principal shadow-plane. The *foot* of a luminary is a point on the shadow-plane produced, at which a line at right angles with that plane from the luminary would intersect it. But in the case of a secondary luminary, as of a window, which usually occupies considerable width in the picture, the foot of the luminary is not a point, but a line comprised between the intersections of two lines with the shadow-plane at right angles with it, one of those lines being drawn from each extremity of the luminary. Thus, in an interior view, fig. 58, the window is a secondary luminary, whose *foot* is the line comprised between the lines drawn from the extremities of the window, which are at right angles with the floor.

Since it is the intervention of an opaque body between the luminary and the shadow-plane which causes a shadow, it follows that the shadow will be always projected in a direction *from* the luminary; and since rays of light proceed from a luminary in straight lines, it follows that a straight line passing from a natural or artificial luminary through any opaque point to any plane, will intersect the surface of that plane at a point which will be the situation of the shadow of the opaque point on that plane. It is important to bear this in mind, because by finding the shadows of points in any object we can often determine the form of its entire shadow.

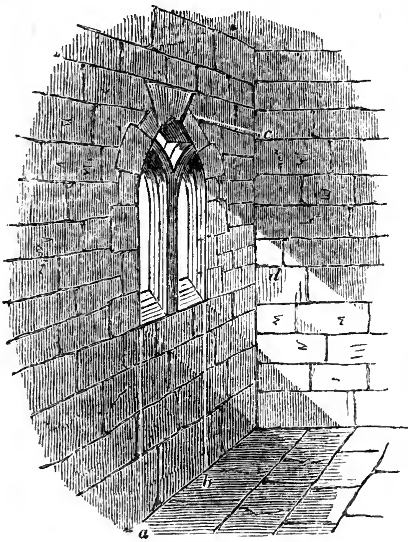


fig. 58.

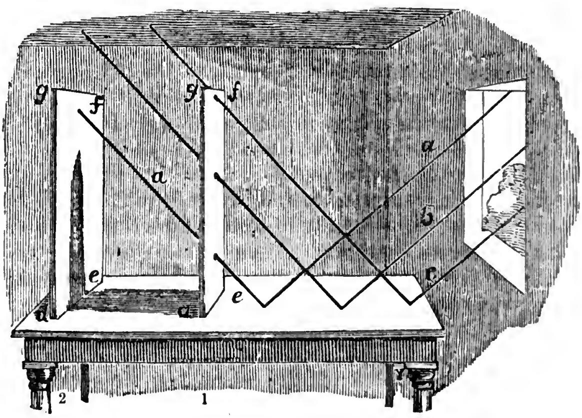
Rays of light, however, do not proceed from all luminaries in the same way. Those *natural* luminaries, the sun and moon (speaking of the latter when she is at the full), present to the earth's surface a luminous disc of much larger extent in reality, though rendered apparently less by their great distance, than any part of that surface which can be comprised within the limits of a picture. In such case the luminary is larger than the object illuminated; and since every point of the disc of those luminaries emits rays of light in straight lines, it follows that the rays will proceed in parallel lines from the luminary to the object. But parallel lines in perspective converge towards a point; and the converging point of such rays will therefore be that point on the plane of delineation which represents the centre of the luminary; in other words, the *place* of the sun or moon in the picture.

Artificial luminaries throw off their rays of light in a different manner. Being small, and the luminary generally within the picture, its rays proceed in all directions from it as a central point. Though this causes a material difference in the form of the shadow from that which would be projected by a natural luminary, the rule is the same, viz. that the rays converge towards the place of the luminary.

Secondary luminaries usually occupy a larger extent of the picture; and since the light they admit is a borrowed light, and diffused over the entire surface of the luminary, they generally admit a fainter light, and cast a feebler shadow. They must be dealt with by different rules from those which are natural and artificial; their greater service forbids their being considered as points. Each point in that surface must be dealt with as a luminous point; and the form of the shadow must be determined by rays from each of the outer extremities of the luminary.

These definitions will become better understood as the student proceeds; in the meantime it may be observed, that natural luminaries are generally adopted in landscape and architectural exterior subjects; artificial ones in parlour-scenes, robbers' caves, and all that class of subjects in which Rembrandt delighted, many of his finest drawings of "The Nativity" being stable-scenes, with a candle or lantern for the luminary; and secondary ones in interior daylight-scenes, such as occur in churches and dwellings.

Light is reflected from all opaque surfaces to others, less or more, according as they are rough or smooth, distant from or near to each other; and the same law obtains with respect to reflected light as applied to solid bodies falling on any surface—*the angle of reflection is equal to the angle of incidence.* For this reason less light is reflected to a distant than to a near object, as shown by fig. 59, in which three rays *a*, *b*, *c*, of light are



ɥg. 59.

supposed to pass through an opening in a wall, falling upon a table, and thence reflected to the plane *d e f g*, set up on it at the position 1, in which position all the three rays are reflected upon it. But if we suppose it moved backwards to the position 2, it can only receive one (*a*) of the reflected rays, the others passing away over it.

Another effect of reflection is, that the shadow of any object is always darker than the object itself, even than that side of it which is in shade, for there is no light reflected upon the shadow itself; while those parts of the shadow-plane which are illuminated do reflect a portion of their light upon the shaded side of the object, which will make it less dark than its own shadow.

Rays of light falling on any plane in a direction perpendicular to it, illuminate it to a higher degree than if they fell in an oblique direction; the degree of illumination decreasing in proportion to the obliquity. In fig. 60, let *a*, *b*, *c*, *d*, be four rays of light falling perpendicularly upon a plane *e f*. If the plane be moved to an oblique position *g f*, three only of the rays fall upon it; if to a more oblique position *h f*, two only can take effect upon it, and so on.

In architectural and other subjects, where a ground-plan and elevation are prepared for the purposes of the perspective drawing, the easiest way of drawing the shadows on the latter sometimes is to draw them first on the plan and elevation, and then put the points and lines of the shadows into perspective, by the rules given in Part II., in the same manner as though they were points and lines of the objects themselves. For this purpose no further rules are necessary, except that the place of the luminary as regards the plan, and its height as regards the elevation, must be given or assumed; this will determine the direction of the rays, and thence the geometrical forms of the shadows in plan and elevation, by which means their perspective forms will be easily obtained on the picture.

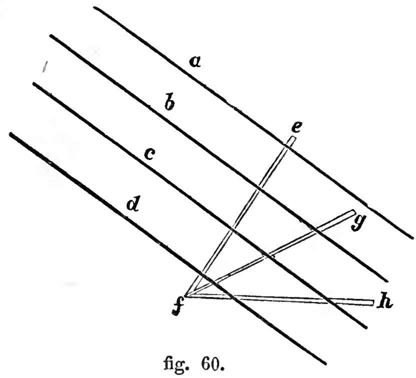


fig. 60.

But in many drawings no plan nor elevation has been necessary; for which reason rules are required by which perspective shadows may be found without them: as a safe guide to the true understanding of these, the learner must keep clearly in mind that the rays of light, on the direction of which the forms of shadows largely depend, are subject to all the perspective laws of parallelism, convergence, &c. which appertain to straight lines in general, and therefore that the shadows themselves are governed by the same laws. The principal circumstances influencing the form of a shadow are the form of the original object, the position of the luminary with respect to it, the nature of the luminary, and the direction of the shadow-plane. The following rules will be found to be of general application to these varying premises:—

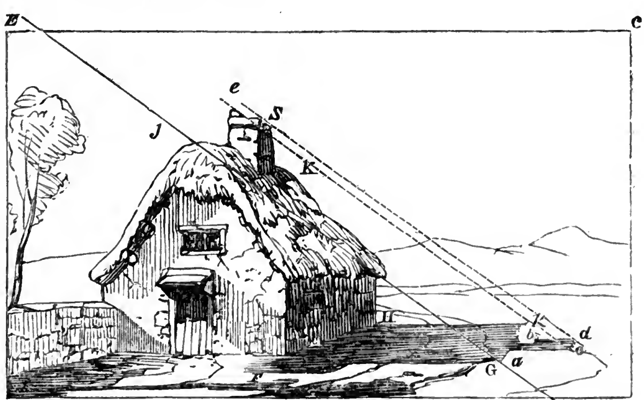


fig. 61.

Let it be required to project on the plane of delineation A B C E, fig. 61, the perspective shadow of the cottage drawn thereon; the direction of the sun's rays being supposed to be parallel with that plane, and the sun's height denoted by the line E D, making the angle of inclination of his rays equal to E D A. From both ends of the base of the cottage on the side in shade, or furthest from the luminary, draw lines S *c*, H *k* on the ground or shadow-plane in the direction of the sun's rays, that is, parallel with A B by the supposition. Through the upper corners J and K of the cottage, draw lines J *c*, K *k* parallel with E D, intersecting the two first lines respectively at the points *c* and *k*. These points are the shadows of the points J and K, and by connecting them together by a line, a figure *d e* H F is completed, which is the perspective shadow of the house. From the base of the chimney draw two similar inclined lines intersecting *e k a*, and from these intersections draw *e a*, *d b'* parallel to A B. Draw *e c*, S *d* through the points *e* S of the chimney parallel to E D, and join *c* to *d*, which completes the shadow of the chimney. The shadows of the wall, tree, &c. are found in the same manner.

In this illustration the luminary was supposed to be in such a position that the rays of light were parallel with the picture. In the following one, fig. 62, they are supposed to proceed from *behind* the picture, throwing

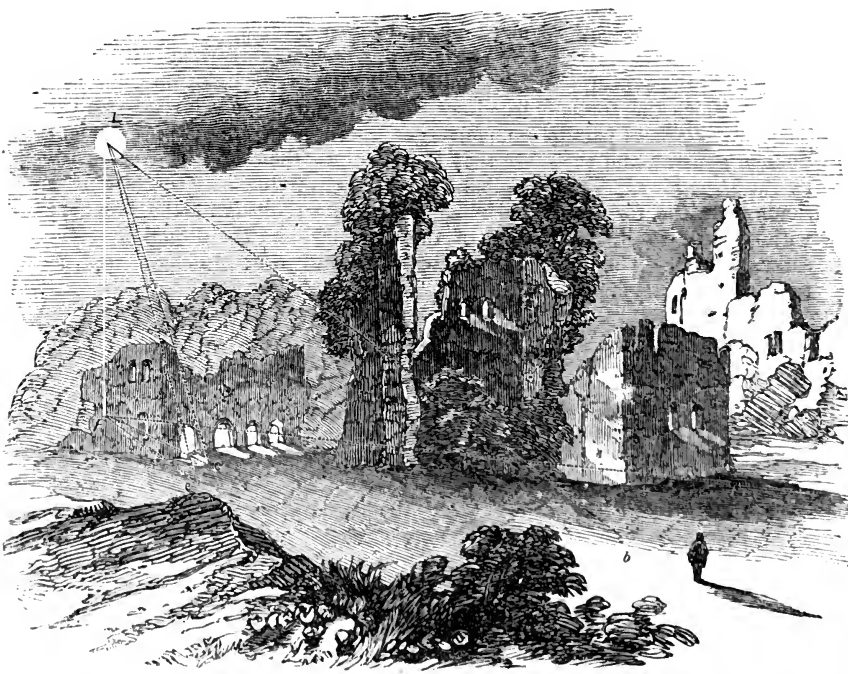


fig. 62.

the shadows rather towards the spectator; the moon is substituted for the sun as a luminary, and its place L, in this case within the picture, is given. Required the shadows of the arches and ruins. First find the foot of the luminary, by drawing L F through it perpendicular to the shadow-plane, intersecting it at F. Next, from F draw lines on the shadow-plane through the lower corners of the objects where they meet that plane. Then, from the luminary draw rays through their upper points or corners, the intersections of which with the lines on the shadow-plane will denote the shadows of those corners and points. Join these, and the figure of the shadow is completed.

Suppose now that the luminary, instead of being behind, is somewhat *in front* of the picture, which will cause the shadows to be thrown *from* the spectator; its place (in this example not within the picture) being given. In such case its position must be inverted, that is, placed as far below the horizontal line as its true position is above that line, and equidistant on the other side of the object (L, fig. 63). Draw F *a*, F *b*, &c.

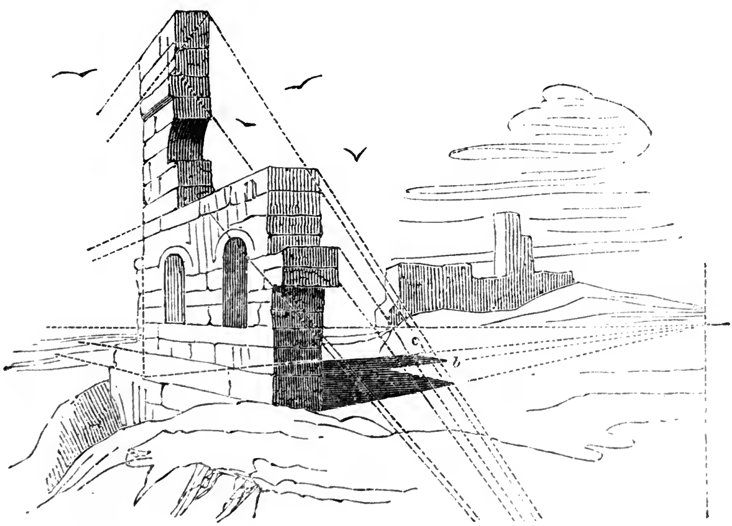


fig. 63.

from the foot of the luminary, as in the last example, and draw the rays from the inverted position through the upper corners of the object. Their intersections at *a*, *b*, *c*, &c. with the lines on the shadow-plane will give the shadows of those corners, by joining which the shadow is completed.

In fig. 61 the position of the luminary was such that the rays were *parallel* with the picture; but in figs. 62 and 63 their direction with respect to the picture-place was *oblique*; which is the reason why, in the former case, the lines on the ground-plane are drawn parallel with each other, while in the two latter they converge towards the foot of the luminary,—the one being a case of parallel, the other two of oblique perspective. From these three examples, the student will also perceive that the shadow of any point is found by drawing a triangular perspective plane, whose *perpendicular* is a line from the luminary to its foot, whose *base* is a line on the shadow-plane passing perpendicularly beneath the given point from the foot of the luminary, and whose *hypothenuse* is a line from the luminary through the given point intersecting the base-line at the shadow of that point. A clear conception of this will give an insight into the whole principle of shadow-drawing; for by obtaining perspective views of this imaginary triangular plane, as applied to the various prominent points of objects, we easily obtain, at the places where its hypothenuse meets its base, the perspective shadows of those points which denote the outline of the entire shadow.

Having found the shadow thrown by any one plane on another, it is easy to find those of others parallel with it thrown upon the same plane. It was stated (fig. 59) that rays of light, and therefore the lines of shadows,

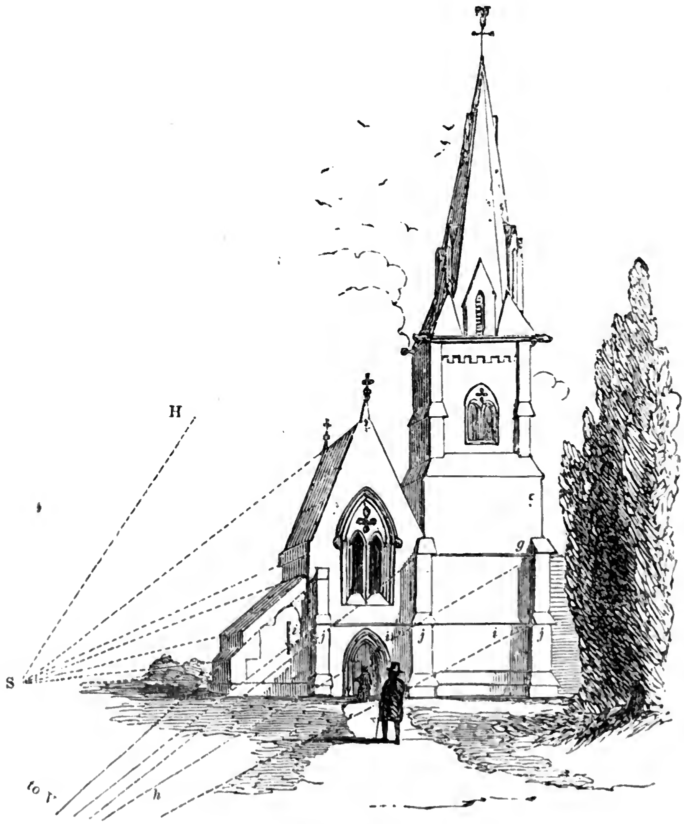


fig. 64.

are subject to perspective laws: hence parallel shadow-lines have a common vanishing-point in oblique perspective, and often in parallel perspective. In the adjoining view of Birch Church, near Manchester (fig. 64), given the shadow of one of the buttresses, to find those of the outer buttresses on the parallel shadow-planes of the end of the church. Let S be the point of sight on the horizontal line, and S H the inclination of the upper line of the given shadow, passing through S. Draw *g h*, intersecting S H at V, which will be the vanishing-point of all lines parallel with *g h*, and which will determine the situations *i* of the shadows of the various points *j* of the buttresses.

Shadows on vertical planes are determined by the same rules as when the shadow-plane is horizontal; care being taken that the line from the luminary denoting its foot, where it cuts the shadow-plane, be at right angles with that plane. Thus, in fig. 65, to find the shadow of the window-

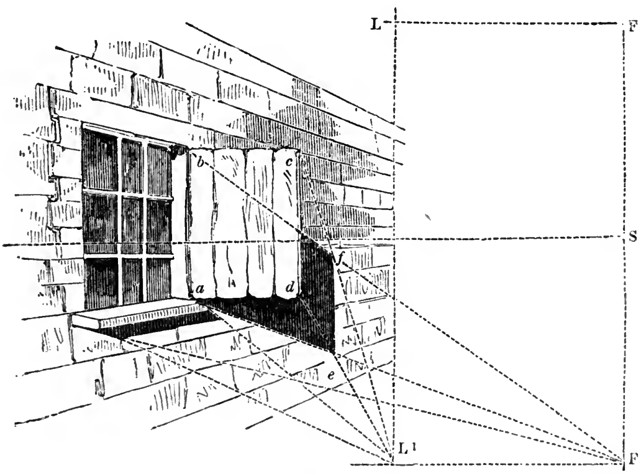


fig. 65.

shutter, as thrown on the wall from the sun's place L, in front of the picture, draw L F perpendicular to the shadow-plane, cutting it at F, which is the foot of the luminary. The shadow being in this case thrown *from* the spectator, invert the luminary, as in fig. 63. Draw F^1a, F^1b, and L^1c, L^1d, crossing each other respectively at *e* and *f*; join *e* and *f*, and *e f a b* is the outline of the shadow, part of which is hid by the shutter.

The same rule applies when the shadow is thrown towards the spectator from a luminary behind the picture, omitting the inversion of the luminary. In fig. 66, L being the sun's place, F the foot, and a sign-board the object whose shadow is required, produce the object to the shadow-plane; draw on the shadow-plane F *a*, F *b*, and the rays L *c*, L *d*, intersecting each other respectively at *e* and *f*; join *e* and *f*, and *a b e f* is the outline of the shadow.

When a shadow falls partly on a horizontal and partly on a vertical plane, the points at which the rays intersect the vertical plane, in conjunction with vertical continuations of the lines on the horizontal plane, determine the outline of the shadow. Let the shadow of the tombs (fig. 67) be intersected by a vertical plane; the sides of the shadow continued vertically upwards will intersect the rays at points, by joining which the outline of the shadow is completed.

When a shadow falls on an inclined plane, the rays must be drawn, as before, parallel with each other, if parallel with the picture-plane, but radiating from the place of the luminary if oblique with respect to that plane. In fig. 68, which is another view of Birch Church, Manchester, required

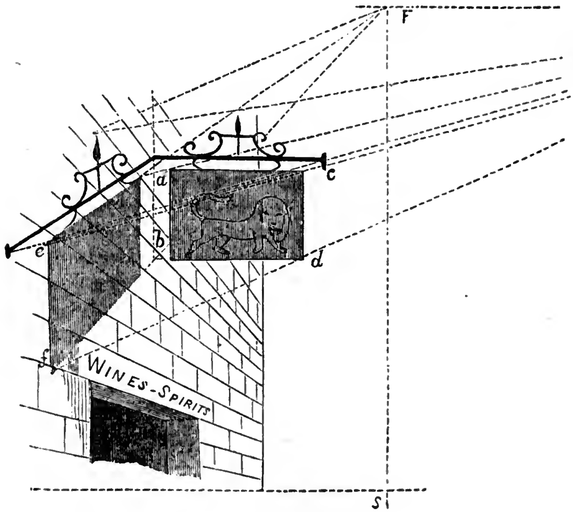


fig. 66.

the shadow of the tower on the slopes of the roof, L being the luminary's place, F its foot, and the shadow being thrown rather towards the spectator,

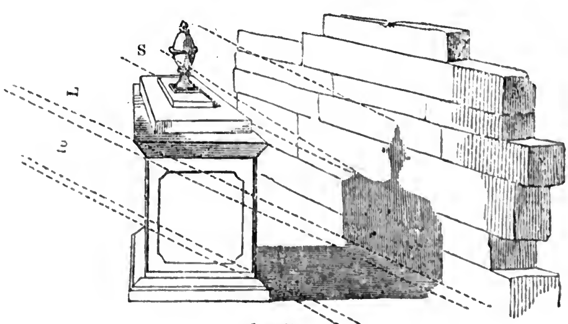


fig. 67.

the rays being at a small angle with the picture. From F draw *a b* across the ground-plane, from the front corner of the base of the tower, through the side of the church; on which carry up *b c* parallel with the angle of the tower to the roof of the side-aisle at *c*. From the point *d* on the ground-plane, where *a b* intersects the base-line of the clerestory wall, carry up *d* parallel with *b c*, intersecting the top line of the lower roof at *f*. Join *c* and *f*, which gives the shadow's outline on the inclined plane of the lower roof; next find the perspective centre-line of the plan of the church, perpendicularly under the ridge; and where *a b* intersects it, erect a perpendicular to K, intersecting the ridge-line at K. Join K and *e*, which continues the shadow's outline over the second inclined plane of the upper

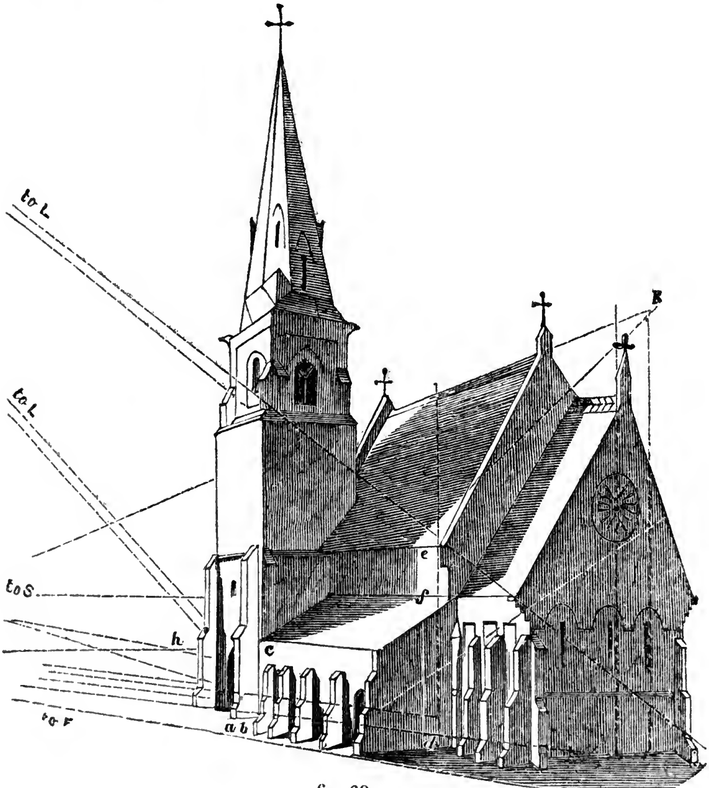


fig. 68.

roof; find the perspective position of the furthest angle of the tower, and by the same process of finding its shadow-line on the ground-plane, and erecting a perpendicular where it crosses the centre-line under the ridge, the intersection of the shadow with the ridge and the boundary-line of its other side are found. The shadows of the buttresses are found by the simple process shown on a larger scale at fig. 69, and those of the church itself are obtained by preceding rules.

It will be observed, that the principle which has been acted on in this case to find the shadow of the tower on the irregular shadow-plane formed by the body of the church, has been to find the base and extremity of the triangular perspective plane previously alluded to, in the position it would have assumed had the body of the church not intervened, and then by perpendiculars at proper points on that base to find the points at which that plane would intersect the building, by which means the irregular line into which the hypotenuse is thrown by the irregularities of the shadow-plane is found thereon.

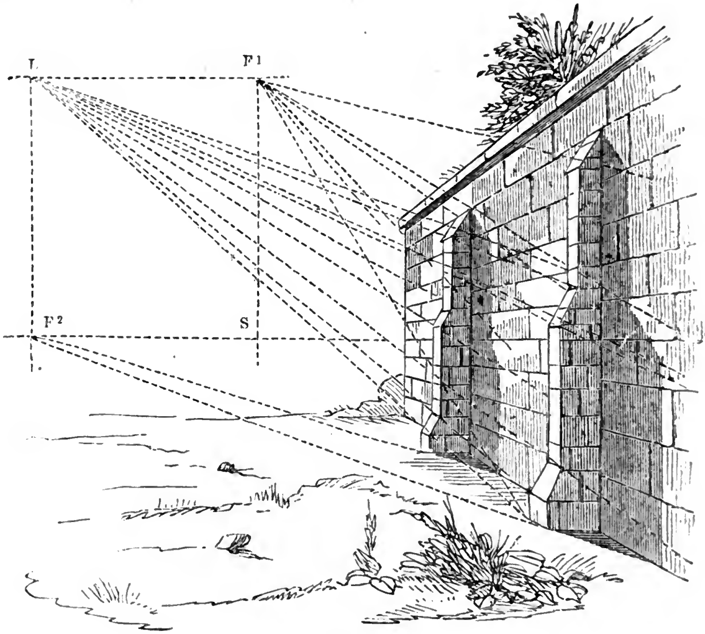


fig. 69.

In fig. 69, it must be noted that there are two feet of the luminary; F[2] being the foot as regards the horizontal shadow-plane of the ground, and F[1] that for shadows on the vertical plane of the wall. The shadow of each

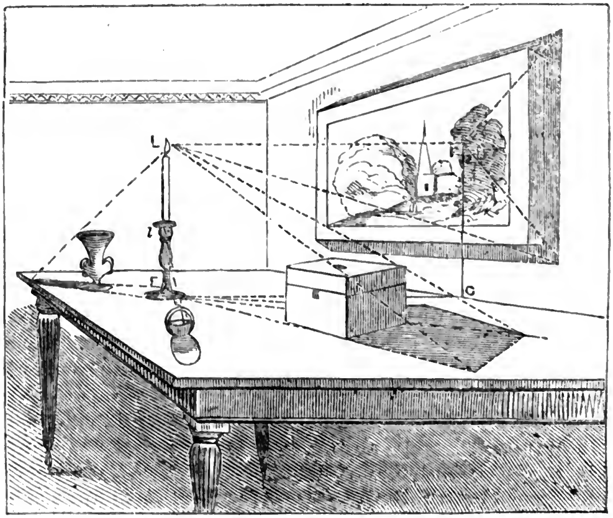


fig. 70.

point of the buttress is found by drawing through the foot of that point on the shadow-plane a line from the respective foot of the luminary, and intersecting it by a ray from the luminary through the point whose shadow is required. F^2 is on the horizontal line, and F^1 on a line perpendicular to it passing through the point of sight.

Artificial luminaries are less often introduced into drawings than either natural or secondary. A few examples will therefore suffice, especially as the rules are the same, though, from the fact of such luminaries radiating light in all directions, rather differently applied. In fig. 70, the shadow of the work-box is found on the shadow-plane, in this case a table, by means of intersections of the rays with the foot-lines, precisely as in the previous examples of natural luminaries, with their shadows towards the spectator; while that of the vase, being on the other side of the candle, is thrown

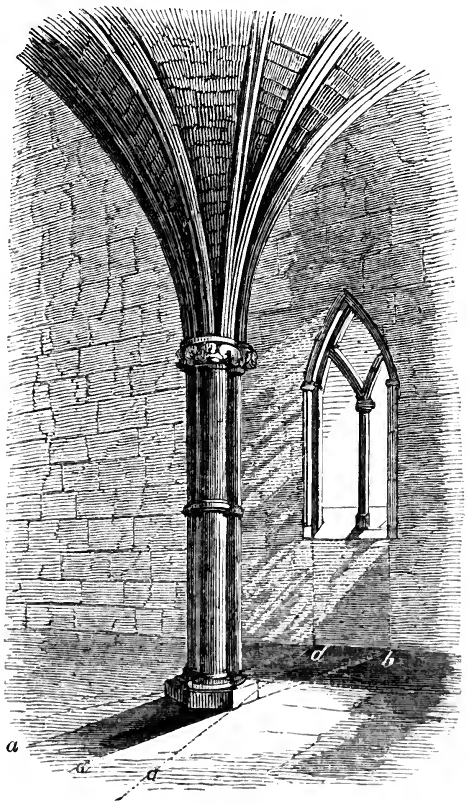


fig. 71.

from him. The shadow of the picture-frame on the wall being thrown on a vertical shadow-plane, the foot F^2 of the luminary on that plane is to be found by drawing F G to the wall, and there making G F^2 perpendicular to it; the intersection of this last with L F^2 is the foot for that plane, which must be dealt with as previously directed. Foot-lines from it through the corners of the frame, intersecting rays from the candle, will give the extreme points of the frame's shadow.

Secondary luminaries not being points, but frequently large surfaces giving out rays from every point within them, require rather different treatment. The foot of such a luminary was shown at fig. 58 to be not a point, but a line as long as the width of the luminary where its plane meets the shadow-plane. From each end of this line it may pass the object on either side, but there will always be a space behind the object in full shadow, and a space on each side in half-shadow. The rule for finding these spaces is shown in fig. 71; a line *a b* drawn from each end of the foot of the secondary luminary past the *opposite* side of the object denotes the entire space occupied by the half-shadow; and another line *a d* from each end of the foot, past the *same* side of the object, denotes the part of that space in full shadow.

An object whose side that is in shade has less breadth than that of a secondary luminary, throws a shadow tapering to a point; whereas if the shaded side be broader than a luminary, the shadow continually increases in width. This is exemplified in fig. 72 by the tapering shadow *a b c* of the

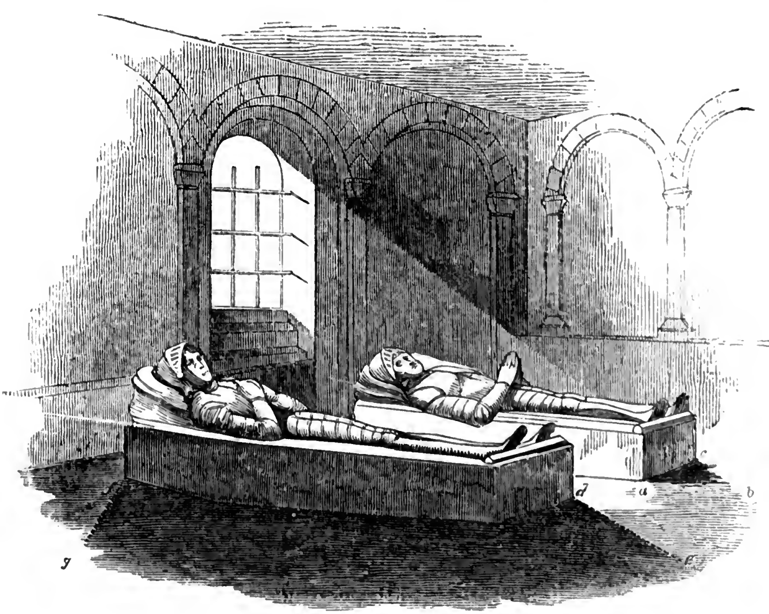


fig. 72.

second tomb, whose *end* is turned from the window, and by the widening shadow *d e g* of the first tomb, the *side* of which is turned from the light.

The foot of a secondary luminary, like that of the other kinds, is found by lines at right angles with the shadow-plane in fig. 73. There are three shadow-planes; the floor being a horizontal one, and each side-wall a vertical one. The lower end of the steps is the luminary's foot as regards the shadow on the floor, and the sides of the doorway are its feet as regards those on the walls.

A most striking instance of the successful treatment of perspective effect produced by a secondary luminary is observable in a picture in the Duke of Devonshire's collection at Chatsworth, entitled "Monks at Devotion," painted by Granet, a French artist, in 1817. The "dim religious light" is introduced into this picture through a small window at its further end, and the long dark shadows of the devotees, projected towards the spectator, greatly enhance the artistic effect of this remarkable work. An engraving from it in mezzotint, and another of its sister picture, "Nuns at Devotion," has been published with excellent effect, and may be studied with great advantage.

In interior views with many windows, as of churches, each window is a secondary luminary producing its own effect, yet affected in some degree by the others. In general, those on the sunny side of the building admit the stronger light and cast the deeper shadow; so much so, sometimes, as almost to neutralise the effect of the other. On this point precise rules can scarcely be laid down; the artist's attention being called to this effect, its imitation must be left to his judgment and observation.

The examples that have been given, if duly worked out by the student, will convey to his mind a tolerably clear conception of the mode of finding shadows under every variety of circumstances, as regards form of object, kind and position of luminary, and nature of the shadow-plane. They have been arranged with the view of fixing in his mind the principles on which he ought to proceed; an accurate knowledge of which is the surest guide to correct practice.

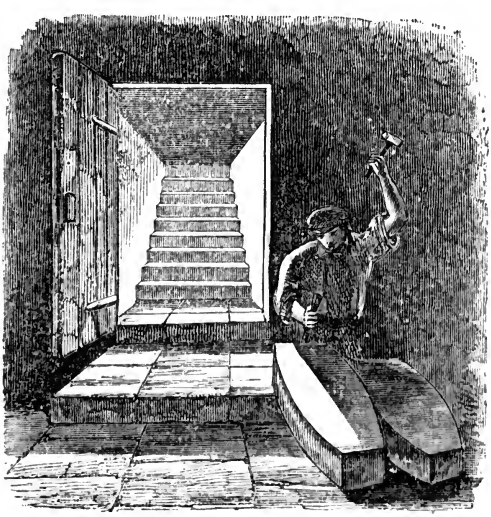


fig. 73.

PERSPECTIVE DRAWING.

Part IV.

APPLICATION OF PERSPECTIVE TO SKETCHING AND LANDSCAPE-DRAWING—CHIARO-SCURO.

The rules which have been thus far given will enable the student, in most ordinary cases that occur, to give correct representations of objects and their shadows. They are, however, most applicable to those classes of subjects which depend for their effect on the exact fidelity with which their straight lines and plane surfaces are portrayed, which must therefore be drawn by strict rule. Of this kind are exterior and interior views of buildings, street-scenes, and the like. Architectural drawings are in most cases intended to be faithful representations of new buildings; their lines and angles must therefore be shown with great exactness. But this is inadmissible in landscape-drawing, as it would communicate to natural scenery a stiffness and sharpness of outline which does not exist in the scene itself. In many drawings, even of buildings, truth to nature requires the artist to present them more or less worn and dilapidated by the effect of time, which destroys the sharpness of their angles, breaks up the straightness of their lines, and gives them that irregularity and rusticity which are essential properties of that quality called the *picturesque*. But even with scenes and objects such as these, perspective rules must not be violated; the general outlines must be consistent with those rules, into whatever deviations from strict right lines they may be thrown.

It is not expected, therefore, that the learner, when copying nature, will apply our rules in making his sketch. Having worked out the previous examples, he will have such a general idea of the direction his lines ought to take as will enable him, with care, to copy nature with tolerable fidelity; especially if he has well practised the examples in object-drawing in Sections I. and II., which must have given him a facility with his pencil and a command of hand. This copy being taken home, and pinned down on a drawing-board, as before recommended, he may prove his sketch and correct errors by applying exact perspective rules.

The first essential in sketching is the selection of a proper station. Its distance from the scene or object should not be less than the width of the latter; in many cases it may be greater; but when the distance equals the width of the scene, the angle of vision will be not much less than 60°, which was stated in Part I. to be the greatest that the eye can take in at one view. Having determined on, and taken his position at, the station, and settled what objects are to constitute the front of his picture, the paper having previously been cut nearly to the size of the drawing, let him hold it up with his left hand before the scene, with its lower edge corresponding with the front line of these objects, and at such distance from his eye that its width may exactly comprise the scene to be drawn. With the paper in this position, let him first mark on both its sides the exact position of the horizon, which connect by a line across it, having a mark on it opposite to his eye denoting the point of sight; then on the sides and upper and lower edges let him mark the places, the heights, and the widths of the principal lines and objects. With the assistance of these marks and the point of sight, and frequent careful reference to the scene, he will be enabled to draw the objects in their proper places, and in tolerably good perspective; which he may afterwards verify and correct by rule at home.

The thickness and force of the various marks and lines must, as explained in Part II., be tinted to the distance of the objects they respectively represent. In sketching, this is a great aid to perspective effect; and by beginning first with the distance with a finely-pointed pencil, the marks as they approach the foreground will of themselves acquire increased thickness by the wearing down of the point. Care must be taken to avoid too many marks and lines, which will produce a confused effect, and is a common error with beginners, who should study to attain the smallest number of marks that will correctly denote the character of the object. Increased boldness in the outlines of the foreground may be attained by using a softer and blacker pencil, of the kind marked B B; this will often assist the perspective effect by increasing the idea of their nearness to the spectator.

These are the main points to be attended to in a sketch from nature, so far as perspective is concerned. They will be found to be embodied in the sketch, fig. 74, which the student is recommended to copy; producing

fig. 74.

the strong and dark lines of the foreground, not by a succession of marks laid one over another, which will produce a misty and indistinct effect, but by laying each of them on at one stroke boldly and with decision.

The character of the marks representing the various kinds of foliage appertaining to the different trees, as the ash, the oak, the elm, &c., should vary according to the distance of the tree, and will thus in some degree assist the perspective idea of distance. Thus, in the case of an oak in the foreground, the branches and separate small collections of the foliage may be each denoted,—the foliage by a number of small, decided, and angular markings, which convey the impression of that tree to the mind. But the same tree at a distance must be represented by marks of a less decided and different character; inasmuch as at that distance the outlines or separate small portions of foliage cannot be given, but only the general outline of the whole mass. At a greater distance these markings must lose their distinctive character; and a distant wood consisting of trees of various kinds may be denoted by marks all of the same character. A due attention to this effect of distance increases the perspective effect of a landscape.

It is not intended here to give precise directions as to the kind of marks to be used to denote trees of different species, as it does not come within the province of perspective. In this part of the art of drawing, nature will be found the best teacher; by observation of the objects themselves and frequent practice, the young artist will soon learn how to communicate to his trees their distinctive character. Almost every artist has a way or *touch* of his own, by which he conveys the idea that his tree is an oak, an elm, &c.; and by the study of the real foliage, which nature displays in profusion before him, better than by any lessons, will he acquire a facility for representing it.* After carefully considering and comparing the works of nature, however, he may with advantage refer to those of the best masters, should his opportunities permit. Among those works from which he may derive most valuable hints as to the treatment of foliage may be mentioned the paintings of Cuyp, Both, and Ruysdael, of the Flemish school; of Salvator Rosa in the Italian; and of Wilson in the English school, who attained great success in representing it under different effects of sunshine and of storm; and of our Gainsborough, whose quiet rural scenes owe much of their beauty to the leafy masses therein depicted.

The proper management of *light and shade*, and their judicious arrangement into breadths and masses, called by painters *chiaro-scuro*, are also valuable aids to the perspective effect of a landscape. It is a common mistake with beginners to appropriate to each individual tree, figure, house, or other object, its own light and shade, irrespective of the general effect (fig. 75). The consequence is, that the picture is cut up, so to speak, into a great number of lights and shadows of nearly equal size and intensity, alternating over the entire surface of the picture; by which means the eye is distracted, and cannot rest with satisfaction on any portion of it, since all the objects depicted are thus made to present nearly equal claims to attention. The avoidance of too many small lights, the placing of the principal object in one larger and more intensely illuminated space, the keeping of other lights subordinate to it, and the proper regulation of the contrasts between light and shadow according to distance, all tend to direct atten-

* In Section II. the pupil will find examples of different kinds of foliage.

tion to the principal object, and to preserve the proper *keeping* of the picture. The same may be said of the shadows. There should be one principal shadow, to which the others should be subordinate; they should not be too much subdivided into numerous small shadows, but a proper degree of breadth of shade should be maintained undisturbed by intervening lights, which will much contribute to the repose of the picture.

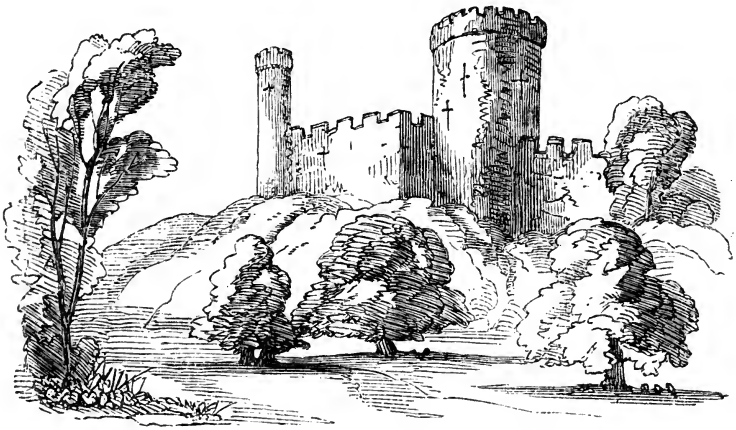


fig. 75.

The same scene is depicted in fig. 76 as in the previous figure, with more attention to the repose resulting from the observance of these few hints. On this subject a few general observations may be of service.

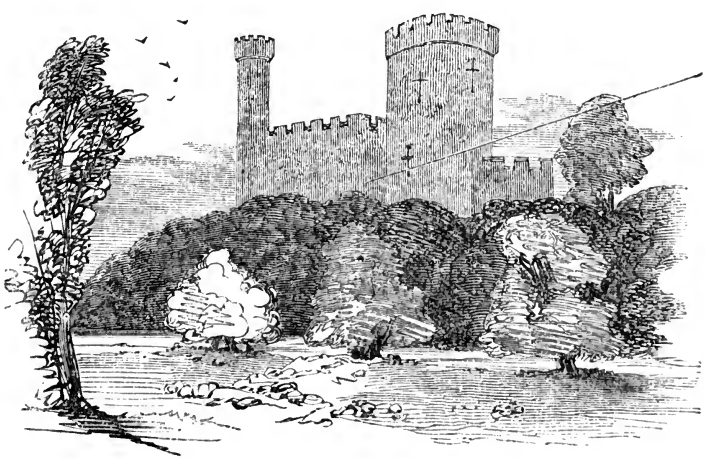


fig. 76.

Every landscape may be divided with greater or less precision into three parts, the distance, the middle-picture, and the foreground. As the effect of distance is to subdue both lights and shadows, the first of these

fig. 77.

seldom plays a conspicuous part in the general arrangement of the chiaroscuro; although the deep blue of a distant mountain in full shadow is

fig. 78.

sometimes effectively introduced. The largest breadth of shade is generally spread over the middle-picture, while the deepest shadows, as well as the strongest lights, naturally, from its proximity, occupy the foreground.

Sometimes, however, the foreground is in full shadow throughout, and the principal light falls on the middle-picture. In this case, a few strong and scattered touches of light falling on objects in the foreground, contrast very effectively with its dark tints. In daylight scenes, in nature, the principal light is generally in the sky; but in a showery or stormy sky, when the sun is supposed to be shining, but not from within the limits of the picture, the entire sky may often be in half-shadow, and the principal light on the foreground or middle-picture. Fig. 77 represents a cloudy sky, with the principal light on the foreground, and the whole middle-picture in shadow. In fig. 78, the principal shadow, on the contrary, is on the foreground, the lights being on the sky and middle-picture.

Should a mass of shade be required for the sake of repose in a position where there is nothing naturally to produce it, a tree, a house, or other object may occasionally be introduced for that purpose. This is, however, an artistic liberty which should be used sparingly, and with the utmost caution; and the painter will better display his judgment by selecting a station from which the objects and their shadows naturally produce a pleasing view, and may be represented to the best perspective and pictorial advantage, than by introducing others for the sake of effect. If no position can be found answering this condition, the object or scene may generally be abandoned as not admitting of picturesque representation, and some other chosen; although the ever-varying effects of light and shade caused by passing clouds, which may be introduced at pleasure, will often, under judicious management, produce a breadth and repose which will confer an interest on scenes otherwise wanting in pictorial effect.

PERSPECTIVE DRAWING.

Part V.

ISOMETRICAL PERSPECTIVE.

In the Work on Architectural, Engineering, and Mechanical Drawing, we give the methods of drawing plans, elevations, and sections of various architectural and mechanical subjects. One decided advantage possessed by geometrical drawings is, that measurements from one scale will serve for all the views of an object, whether these be in plan, elevation, or section. While, however, presenting this desideratum, they are deficient in another; by their aid the relative position of vertical to horizontal lines, or *vice versâ*, cannot be delineated on the same paper or plane. Thus, if one view is in plan, it is confined to plan alone, no lines delineating elevation being admissible in the same drawing; hence the variety of drawings required to give the measurements and positions of an object or design having many points of view. The rules of perspective, which we have just considered, are applicable to the delineation of objects by which two or more sides can be seen. Thus, in the case of a box which is longer than it is broad, but having the bottom of the same dimensions as the top, to give drawings *geometrically constructed*, from which a workman might take measurements, three separate views would be essential, namely, one of the side, one of the end, these being in elevation, and one of the top, this being in plan; the bottom being of the same dimensions as the top, no plan of this would be requisite. Now, by the rules of perspective, the box might be drawn in such a way that the side, end, and top would all be visible. The sketch of the box given in figure 23, Section I., is an exemplification of this. But as the reader will know, if he has studied the matter given in the section on perspective, the lines converge or recede from one another, in order that the idea of distance may be given, and as the lines to produce this effect are—even in comparatively simple subjects—numerous, the intricacy of the drawings renders it a matter of extreme difficulty to take measurements from the various parts with that ease and facility which ought to be an essential feature in mechanical operations. A method of drawing objects, then, by which two or more views could be shown in one drawing, and *yet all measured from the same scale*, is of considerable importance. By isometrical perspective or projection, this desideratum is attained with great facility. The term projection, in its widest sense, means a plan or delineation of any object, but is also used by some writers and practitioners to distinguish the method of drawing in which the principle is involved of delineating the objects as if viewed at an infinite distance; this resulting in all the parts being drawn without the converging or diminution of parts visible in common perspective, from their being viewed from the same distance. The methods by which objects are *projected* are very numerous, but it is foreign to the scope of our work to enter into a detail of their peculiarities; we shall confine ourselves to the elucidation of the simple rules of isometrical projection, which is the only mode by which the various parts of an object so delineated can be measured from the same scale. Professor Farish, of Cambridge, was the first publicly to elucidate the principles of this method of drawing, and he gave the name isometrical as indicative of its chief feature, from two Greek words signifying EQUAL MEASUREMENTS. Isometrical projection gives the representation of the three sides of the cube, all of which are equal, and the boundary-lines of which are also equal. In the examples which we present to the reader will be found sufficient illustration of the ease with which objects can be represented by this mode of drawing, and the applicability of its principles to many of the details of architectural, engineering, or geometrical subjects. After the first principles are mastered, the method of adapting them is so obvious, that in many cases a mere inspection of the diagrams will be sufficient, but, whenever opportunity offers, we shall further elucidate them by explanatory and suggestive remarks. We have deemed it better to give numerous illustrations, rather than enter into long theoretical investigations, preferring to run the risk of being thought over-minute in illustrative details to incurring the charge of obscurity, which, if these were less numerous, might otherwise result.

The quickest method of forming a cube is by describing a circle, fig. 79, *i*, *d*, *g*, *h*, *e*, and *f*, of any diameter, and dividing its circumference into six equal parts, first drawing the diameter, *d e*, at right angles to the bottom edge of the paper or board on which the circle is drawn; thereafter from either

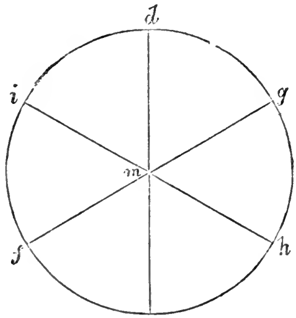


fig. 79.

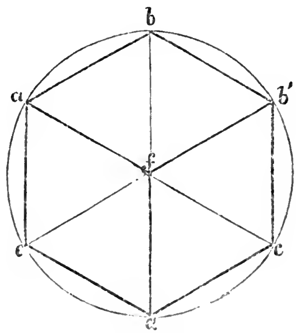


fig. 80.

end as *d*, measuring three times to *e*, and this on both sides; join these points by lines *f g* and *i h*. Now to make the cube, join the lines as in the figure 80, as *a b*, *b b′*, *b′c*, *c d*, *d e*, *e a*; the cube is complete. The square *a b b′ f* is the *top*, the square *f b′ c d* the *right hand*, and the square *d f a e* the *left-hand* side of the cube. In isometrical drawings, all lines which are horizontal in the geometrical drawing are parallel to any of the lines *d e*, *d c*, *f b′*, *f a*, while those which are vertical are at right angles to these, or parallel to *a e*, *f d*, and *b′c*. Thus, to give the representation of a block of stone, as in figure 81, a circle, as in figure 82, may first be drawn, and a cube formed by the rules given in figure 80; then to draw the representation of the right-hand face, measure off from *d* to *a*, and parallel to *x* in fig. 81 draw the lines *a b*, *d e*, and from *a* and *b* draw lines parallel to *h e*; *a b e d* is the right-hand side of the block: next put in the left-

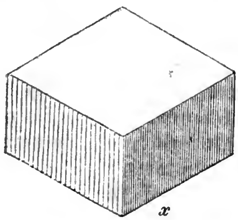


fig. 81.

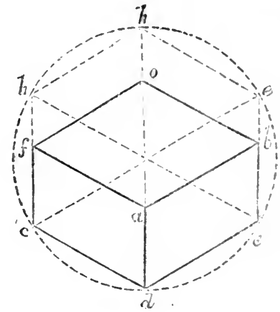


fig. 82.

hand side *a f c d* as before; then from *f* and *b* draw lines *f o*, *b o* parallel to *h h*, *h e*, meeting in *o*; *a f o b* is the upper side of the block. Thus it will be seen that all the lines which are horizontal in the drawings are parallel to the top and bottom lines of the right and left hand sides of the cube; while those that are vertical are at right angles to these. In the formation of a cube in a circle, a hexagon is first made by joining the extremities of the diameters, as in fig. 80; *a b b′ c d e* is a true hexagon, the cube being ultimately formed by the lines as in the diagram. But simple as this method of forming a cube is, it would be a tedious waste of time to draw each cube required in this way. Make a triangle, the base of which will be from two and a half to three inches long, the hypotenuse being at an angle of 30° to the base, the third side being at an angle of 90° to the base. Suppose it is desired to make a cube in the circle in figure 80: draw *d b*, place the T-square so that its edge lies at right angles to *d b*, and coinciding with the point *d*; lay the base of the triangle on the edge of the square, and along its hypotenuse draw the line *d e*, touching the circle at *e*; parallel to *a f* draw *e b′*, touching the circle at *b′*; move the square up towards *b′*; lay the triangle so that its point shall be towards *b′*, and draw along its hypotenuse the line *b′ b*, meeting *d b* in *b*; reverse the triangle, so that its point is towards *a*; draw *a b*, and so on, the last line drawn being *e d*. By this means a circle and its diameter, as *b d*, being given, a cube can be speedily drawn by means of the triangle.

Having thus explained the simplest modes of making isometrical cubes and squares, we shall proceed to exemplify the system of these as applicable to the delineation of various objects and forms, first showing how these are contained within circles and cubes without reference to any particular scale. Believing that the pupil will more speedily obtain a knowledge of the practice of the art by inspection and study of examples than by close attention to theoretical rules, which at the best are dry and uninteresting to the *general* reader,—as before intimated, we shall be unsparing in our illustrations, these conveying very rapidly to the mind the nature of the principles.

To give the representation as in fig. 83. First draw the circle of any diameter, and put in the cube *a*, *d*, *c*, *b*, *f*, and *e*, fig. 84; put in the lines *b f*, *b c*, and measure from *b* to *g*. From *g* draw a line parallel to *b c* to *n*, and from *c* a line to *n*; next, parallel to *f b*, draw *g h* to *h*; and from *h*

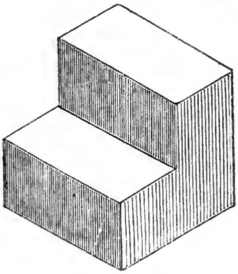


fig. 83.

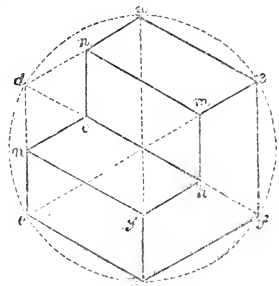


fig. 84.

draw *h m*; draw *f e*, and from *e* and *m* draw lines *a* and *n′* parallel to *g n* or *b c*; from *n n′* draw lines meeting in the point *o*, and put in the line *h o*: the drawing is complete. From an inspection of the figs. 85 and 86, the

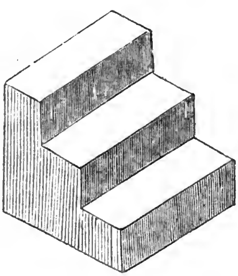


fig. 85.

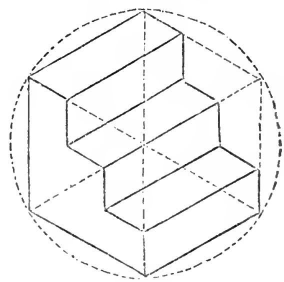


fig. 86.

pupil will be able to draw the representation as given. Fig. 87 gives the isometrical representation of two blocks of stone. In fig. 88 *a* represents a block laid across two blocks placed in the position as in fig. 87. To copy this, draw the circle and cube as before, and put in the

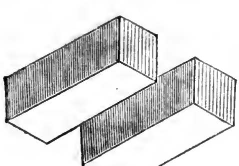


fig. 87.

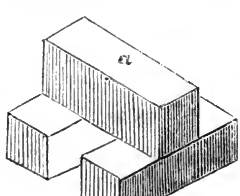


fig. 88.

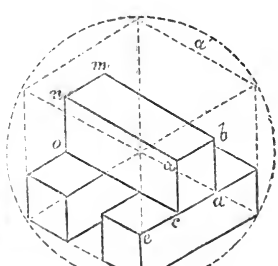


fig. 89.

two blocks as in fig. 87; then from *e* measure to *c* fig. 89, and from *c* to *d*; measure and put in the height of the block from *c d* to *a* and *b*; parallel to the side *a′*, draw from *a* and *b* to *n* and *m*, and from *c* to *o*; join *a b*, *n m*, and *n o*: the figure is complete. The two blocks on edge, represented isometrically in fig. 90, will be copied very speedily by proceeding as follows: draw the circle and cube as formerly; and from *a* measure to *b*, and from *b* to *c* and *a* (fig. 91),—these give the thickness of the edge of the blocks, as in the copy; next measure from *a* to *e*,—this gives the length; and from *a e* to *g* and *h*,—this gives the height of the block.

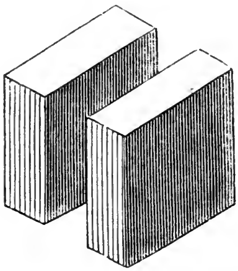


fig. 90.

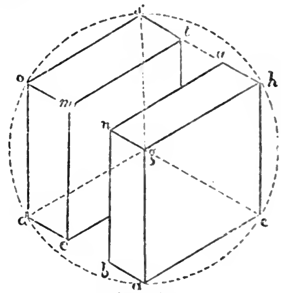


fig. 91.

From *c* and *d* and *b* draw the lines *b n*, *c m*, and *d o*, meeting the diagonal *o e;* from *h* draw *t*, *v*, *s*, parallel to *o g;* and from *g*, *n*, *m*, *o*, draw to *h*, *v*, *t*, and *s:* the representation is complete.

In fig. 92 is given the representation of an oblong block standing perpendicularly on a flat stone. The method of drawing it is shown in fig. 93. From *a* draw to *d* and *c*,—these give the length of the sides of the under block; from *a* measure to *b*,—this gives the thickness; from this point parallel to *a c*, *a d*, draw lines meeting perpendiculars from *d* and *c:* the right and left hand faces of the under block are finished. From *a* measure to *e*, and from *e* to *h* and *g*, these lines being parallel to *a c* and *a d*,

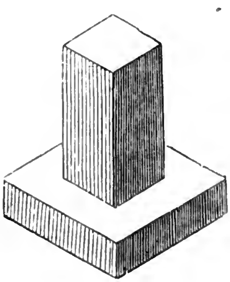


fig. 92.

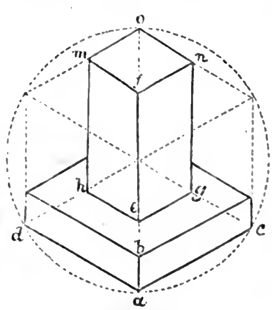


fig. 93.

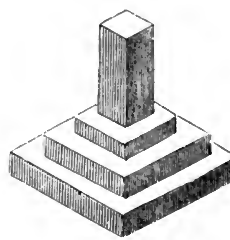


fig. 94.

and giving the breadth of the faces of the oblong block; from *e* measure to *f*, and put in the square *o m*, *f n;* join all the points, and the figure is complete, the distance *e f* being the height of the block.

In fig. 94 the same subject is represented, but a succession of under blocks is given, gradually reduced in size. The method of putting this in will be deduced from a consideration of the mode of drawing the last problem in fig. 93. The representation of the cross given in fig. 95 is an exemplification of the foregoing lessons; the cross being, in a measure, formed of blocks properly disposed. The method of drawing it will be seen by an inspection of fig. 96. In fig. 97 is given a representation of a block of stone *a*, supported by an oblong block, resting on one of the

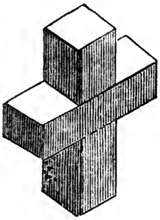


fig. 95.

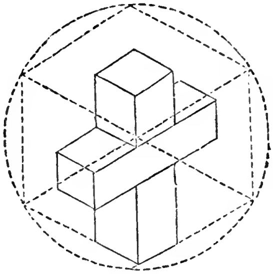


fig. 96.

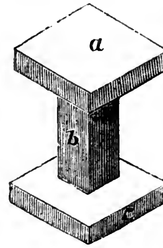


fig. 97.

same dimensions as *a*; the pupil should have no difficulty in drawing this, if he has attended to the foregoing lessons. A block of wood or stone with a square part, *a*, cut out of it in its upper face, *b c*, is represented in fig. 98. The pupil should draw it either enlarged or the same size. The representation of a similar block, but with the edges downwards, is given in fig. 99. The manner in which it is drawn is given in fig. 100. The

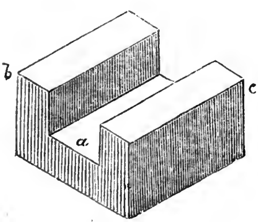


fig. 98.

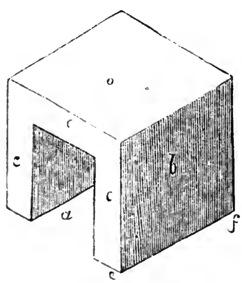


fig. 99.

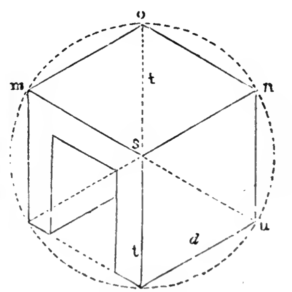


fig. 100.

faces *o* and *b*, fig. 99, are formed by the upper and right-hand sides of the cube *m o n s* and *s t v n*, fig. 100, the parts *c c c* being drawn by lines parallel to *m s* and *s t*, the line *d* being the line corresponding to *e f*. The

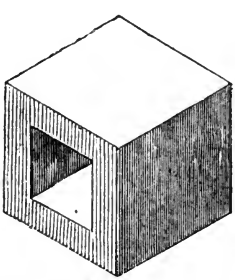


fig. 101.

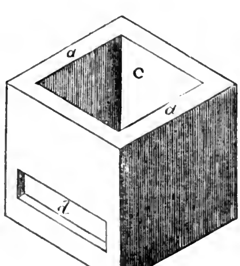


fig. 102.

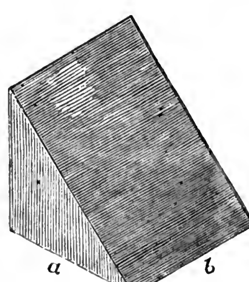


fig. 103.

representation given in fig. 101 is a modification of the previous lesson; it shows the easy method of delineating the representation of apertures in walls, boxes, &c. Thus in fig. 102 a representation of a box is given, *a a* being the thickness of the wood, *c* the size of the interior, and *d* the aperture for the drawer. In the foregoing lessons the examples have been confined to the illustration of objects having only straight lines in their outlines. We shall now show the method of drawing angular surfaces, circles and cubes in all cases being previously described. Thus the representation in fig. 103 is drawn in the manner shown in fig. 104. For the side *a* of the angular block draw the line *a b*, and for *b*, *b c;* measure the height of fig. 103, and set it from *a* to *d;* from *d* draw *d m*, equal and parallel to *b c;* join *d b*, *m c:* the figure is complete. Again, the representation given in fig. 105 is drawn as in fig. 106: draw *c b*, *b d* for the ends of the angular

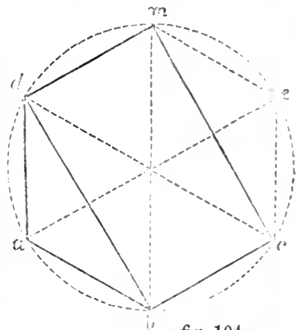


fig. 104.

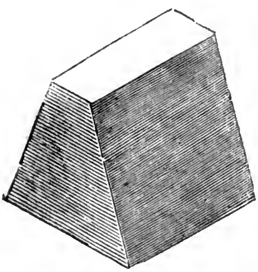


fig. 105.

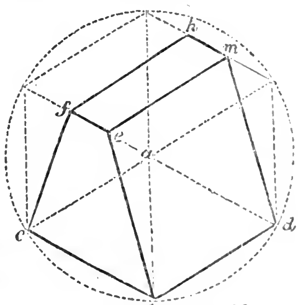


fig. 106.

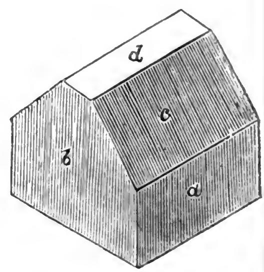


fig. 107.

block; from *a*, the centre of the circle, measure to *e* and *f;* from *e* and *f* measure to *h* and *m;* join *fe*, *h m*, *e b*, and *m d:* the figure is complete. The representation in fig. 107 exemplies the system of putting in roofs of houses; fig.

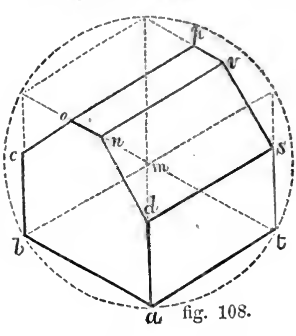


fig. 108.

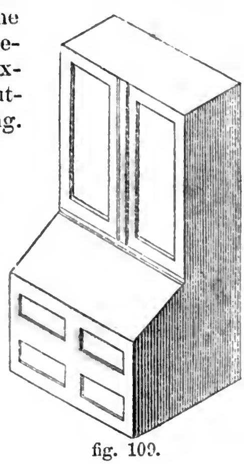


fig. 109.

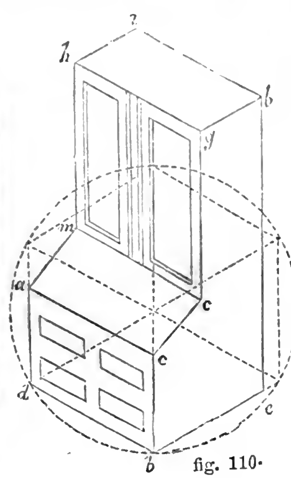


fig. 110.

108 shows the method in which it may be drawn. First draw the side *a*, fig. 107, as *a d s t*, fig. 108; then the side *b*, by measuring from *a* to *b*, and from *a*, *b* to *c*, *d*; from *m*, the centre of the circle, measure to *n* and *o*; from *n*, *o* draw parallel to *d s*, the lines *n v*, and *o p*; join *c o*, *o n*, *n d*, *p v*, and *v s*: the figure is complete. The representation of the plain cabinet given in fig. 109 affords an exemplification of the use of the isometrical lines of the cube in drawing objects. Fig. 110 explains the mode in which the drawing is executed. The part *a d c b* should first be drawn, then *b g c o b e*, next the top *g b h l*, measuring from *g* and *h* to *o* and *m*; and joining the parts *h m*, *g o*, *m o*, *a m*, and *c o*, the front is put in. After proceeding thus far, the details should next be drawn as in the diagram. The example here given will illustrate the extreme ease and rapidity with which such objects can be drawn isometrically; to draw the figure as given by the line of true perspective, would have involved an amount of operations truly puzzling to any one not thoroughly conversant with the principles and practice of the art. But simple as these illustrations seem, and easy as they are to be copied, the operations necessary are much simplified by the use of the isometrical rules previously explained (p. 116). Thus in all the foregoing lessons, circles and cubes have been drawn, and this was necessary in order to obtain the proper direction of the lines. Now by the use of the isometrical rulers, the trouble and time expended in drawing an isometrical cube for every object to be represented is entirely obviated.*

In drawing isometrically, the pupil is recommended in all cases to use the drawing-board and T-square, described in the work on Practical Geometry; it will much facilitate his operations. Place the edge of the isometrical "ruler" on the edge of the T-square, so that the lines drawn from *f* 4, fig. 111 will be at right angles to those drawn from 1 7; let the point of the ruler be towards the left hand, and along the edge draw right, hand isometrical lines 1, 2, 3, and 4, as may be required, and at the distances from each other deemed desirable; reverse the position of the ruler (the T-square remaining unaltered), so that the point shall be towards the

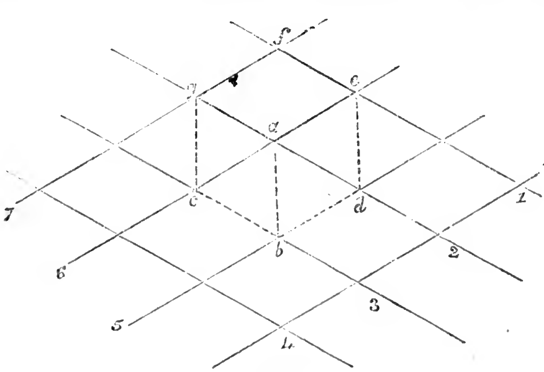


fig. 111.

right hand; then along the edge draw left-hand isometrical lines 5, 6, 7, &c.; the intersections of these, if all are drawn at the same distances

* Mr. Sopwith, author of an excellent work on "Isometrical Drawing" has published a series of useful isometrical rulers.

from each other, form isometrical squares, and by joining the points cubes may be formed. Thus, by joining the points *g c*, *a b*, and *e d*, a complete isometrical cube is formed; *a e f g* being the upper side, *a b c g* the left hand, and *a b d e* the right (fig. 111). Simple as this method is, of obtaining the direction of the isometrical lines, when compared with the mode previously given of drawing circles for every example, it may be rendered more so by merely applying the hypotenuse of the ruler in such a way that the right and left hand lines may be drawn at once. Thus, in fig. 112, which represents the combination of timbers in a "single floor," *a a* being the rafters and *b b* the flooring-boards, the lines are at once obtainable by using the ruler, without forming cubes or isometrical squares. Thus, by placing the ruler so that the point may be towards the left hand, the right-hand isometrical lines, representing the direction of the lines *c d*, *e f*, and all those parallel thereto, are at once drawn, the lengths being measured off in the usual way. Again, by reversing the position of the ruler, so that the point shall be towards the right hand, the left-hand isometrical lines, representing the direction of the lines *f g* of the rafters, or line of direction of the flooring-boards *b b*, are in the same way easily drawn: the perpendicular lines are put in by the usual methods.

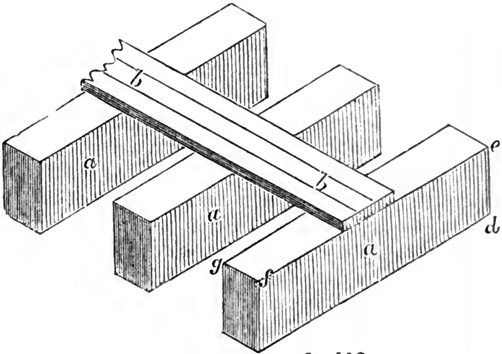


fig. 112.

In fig. 113 two beams are represented, *a* being fastened to *b* by a notch. Now, instead of forming a cube or isometrical square, the whole of the lines may be put in by the ruler: all the lines marked 1, and those parallel thereto, are right-hand isometrical lines, and are drawn along the edge of the ruler, when the point is towards the left hand; the lines 2, and those parallel thereto, are left-hand isometrical lines, and are drawn on the edge, the point being towards the right hand. Base-lines, as *c a*, *a e*, should first be drawn, from which to take measurements.

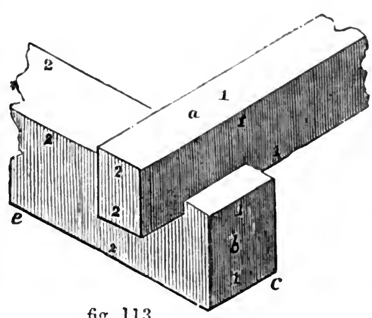


fig. 113.

The representation given in fig. 114 is a combination of timbers called a "double flooring;" *a a* being the "binding joists," *b b* the "bridging joists," and *c c* the "ceiling joists." The lines 1 1, and those parallel thereto, are left-hand isometrical lines, while 2 2 are right-hand ones. In fig. 115 the representation of part of an iron girder is given; and in fig. 116 an elevation of a chimney-stack having three chimney-vents. In both, the lines 1 1 are left-hand, and 2 2 right-hand isometrical lines, and are all put in by means of the ruler.

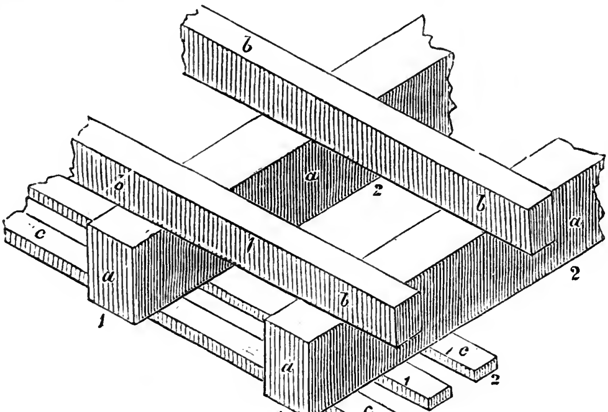


fig. 114.

We have hitherto described the construction of isometrical drawings without reference to the use of scales for taking measurements from. If an object be drawn geometrically to a scale, the isometrical projection is not expressible in the same way; thus, the isometrical projection of a square one inch in the side would not measure one inch, but considerably less: the proportion an isometrical line bearing to one of which it is the projection being as 9 to 11. Thus, if the geometrical plan is drawn to a scale of say one inch and three-eighths to a foot, or eleven-eighths, the isometrical projection of the plan will be nine-eighths, or one inch and one-eighth. In fig. 117 a common scale and an isometrical one are given; the way in which the latter is constructed geometrically is as follows: draw the line *a b*, and divide it into any number of equal parts, as fifteen; each of these denoting any equal measurement, as eighths of an inch; divide this line again into

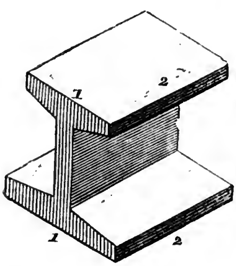


fig. 115.

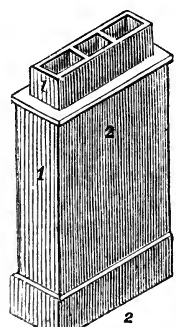


fig. 116.

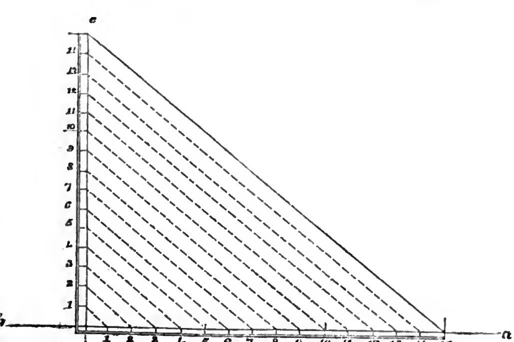


fig. 117.

eleven parts, and with nine of these make the line *d c* perpendicular to *a b;* the line *d c* is in isometrical proportion to the line *a b*, that is as 9 to

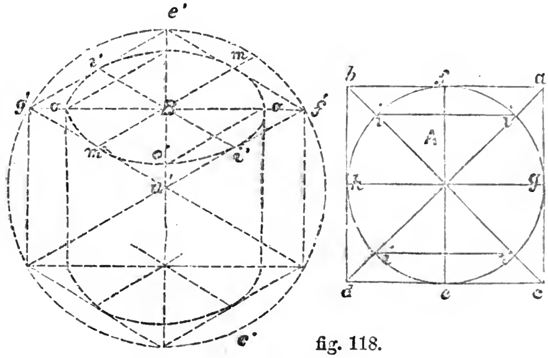


fig. 118.

11. The line *d c* is next to be divided into the same number of equal parts as *a b*, as 15. Hence it follows that any measurement taken from the scale of equal parts *a b* can be taken from the isometrical scale *d c*, and all measurements thus taken would be in strict isometrical proportion. Thus in figure 118, the line *a' m g'* of the square B is the isometrical projection of the line *a g c* of the square A; by measuring these, the line *a' m g'* will be found to be shorter than *a g c*. To put the circle A in isometrical projection, describe a square *a b d c* about it, and draw the diagonals *a d, c b*, and the diameters *e f, g h;* at the points *i i i i*, where the circle cuts the diagonals, draw another square, of which the lines *i i, i i* are two sides. Now as the circle A is to be inscribed in a square which is the face of a cube, drawn in isometrical proportion to *a b c d*, make the radius of the circle *f' c' g'* and *e'* equal to the diameter of the circle A; this being 8, take 8 from the scale *c d*, fig. 117, and from *a'* describe the circle; by the usual method describe the hexagon; and form the cube. The upper face *a' g' e' f* is the isometrical projection of the square *a c d b*. Through the centre of this draw the diagonals *f' o o g', a' o' e'*,—these are the isometrical projections of the diagonals *a d, b c* of the square A; parallel to *a' g', g' e'*, draw the diameters *i' i', m m*,—these are the isometrical projections of the diameters *e f, g h* of A. The radius of the circle A, taken from the scale *a b*, is equal to 4 parts, from the centre B of the diagonals of the upper face of the cube, lay off on the diagonal *f' g'* to *o' o*, the distance of 4 parts from the scale *c d*, fig. 117; from these points, with the ruler, draw the lines *o o,' o i* parallel to *e' g', f' a'*, cutting the diagonal *a' e* in *o' o'*. Now, by the hand, trace through the points *o' i' o, m, o', i', o m*, as shown by the dotted lines; the curve, which is an ellipse, is the isometrical projection of the circle A. A cylinder is formed as in the diagram, making the ellipse at the bottom part of the cube, as partly shown by the dotted lines. The circles in all isometrical figures are ellipses, the curves of which are found as in the diagram. Where the circles are large, and designed to be traced by the hand, more points may be found in the same way as above described; but where the hand cannot trace the outline sufficiently clear, the ellipse may be geometrically constructed by any of the methods we have given in the work on Geometry, the major and minor axis being found by the above

method. In fig. 119 is given the representation of a cylinder, the method of drawing which will be learned from the construction of the preceding figure. In fig. 120, a hollow cylinder B is represented, of which A is the geometrical plan. And in fig. 121, a cylinder B, represented with a square hole D, running in the direction of its length, and supported on a square plinth *c c;* this figure is an exemplification of the mode in which pillars can be drawn isometrically.

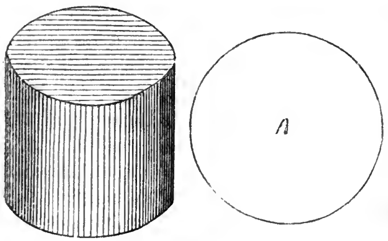


fig. 119.

The method of using the isometrical scale, for the purpose of giving

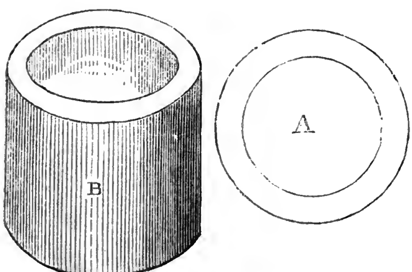


fig. 120.

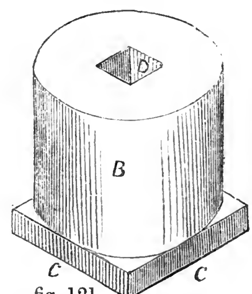


fig. 121.

isometrical proportions to geometrical plans, will be clearly evident from the preceding remarks. If, however, isometrical scales were used in every case, and which would be requisite if isometrical projections were wished to be accurately constructed, the labour of making them would be very considerable, as each geometrical plan would require an isometrical scale to be made for it; that is, if the scale happened in each to be different. This difficulty is easily obviated, and a simple method of drawing isometrically at once available. As we have already noticed, an isometrical line is smaller than a geometrical one, and consequently a series of lines isometrically projected appear, and are, less than those of which they are the projections; but suppose two isometrical lines to be enlarged so that they are equal to the geometrical one of which they are the correct isometrical delineations, although they are longer than formerly, they still bear the *same relative proportion to one another;* hence it follows, that if all the lines could be made equal to the geometrical ones, although larger, they would all be in strict proportion to one another, and be capable of being measured from the same scale as used in the plans of which they were an isometrical copy. It also follows that an isometrical copy of any plan might be made in any proportion to the original copy—as one-half, one-third—by reducing or enlarging the original scale, and measuring the isometrical lines therefrom. All that is necessary is, that the lines be drawn in isometrical directions. To draw these with facility, we have already given ample instructions. Our remarks on the subject have been confined almost exclusively to the explanation of simple methods of delineating objects in this attractive and useful style of drawing, refraining purposely from entering into theoretical disquisitions regarding either the principles or the practice of "true projection." We trust that we have given instructions which will be easily available. To those who prefer to study the subject mathematically, we cordially recommend the works on "Isometrical Drawing," by Mr. Sopwith, of Newcastle, to be had of Mr. Weale, Holborn; and of "Isometrical Perspective," by Mr. Jopling, to be had of Taylor, Wellington Street, Strand. By even a moderate share of attention to the instructions we have given, the reader will be able to understand very speedily the principles of this style of drawing. In all cases we would advise him to persevere in the use of the instruments, and in copying all the illustrations; we can assure him that before he has proceeded far, the labour which at first may be looked upon as a task, will speedily be deemed a pleasure. We have been unsparing in our illustrations, believing that the pupil will find the principles carried quicker to the mind when the eye is assisted by illustrative delineations.

In figs. 122 and 123 are given further exemplifications of the mode of

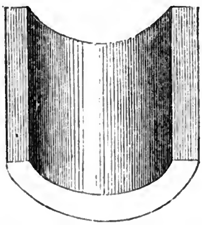


fig. 122.

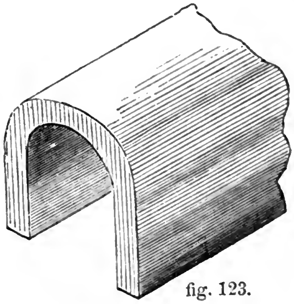


fig. 123.

delineating circular objects. Thus fig. 122 is the representation of half a hollow cylinder; this form is applicable to the delineation of parts of machinery, as brasses, sections of pump-barrels, &c. &c.; while fig. 123 shows the method of drawing arches, &c.

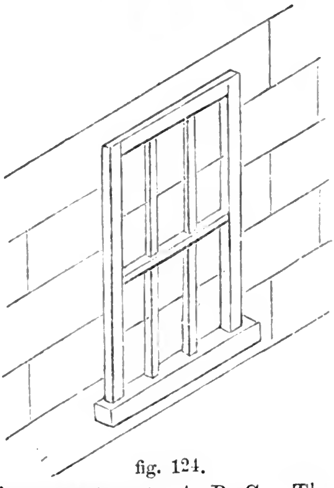


fig. 124.

Isometrical drawing is peculiarly useful in the delineation of architectural subjects, as elevations of houses, plans, and sections, as well as for the parts or details of the various arrangements: in the preliminary lessons we have given several exemplifications of the use of this mode of drawing for the latter purpose, as floors, &c. &c.; we now give in figure 124 an additional example, being the representation of a window. In figure 125 we give an isometrical plan of a house with three apartments, A, B, C. The isometrical plan gives the thickness of the walls, partitions, &c. &c. in a clear and distinct style; the height at which the walls stand being 12 or 14 inches. But the whole height of a wall may be shown by this mode of drawing as well as its thickness; thus, in a future example the reader will find the isometrical drawing of a house with the height of the walls delineated up to the second floor. This, in one view, serves the purpose of a plan and elevation; as the height of the rooms, doors, and windows are plainly delineated, as well as the thickness of walls, position of partitions, fire-places, flues, &c. In fig. 126 we give the drawing of the plan

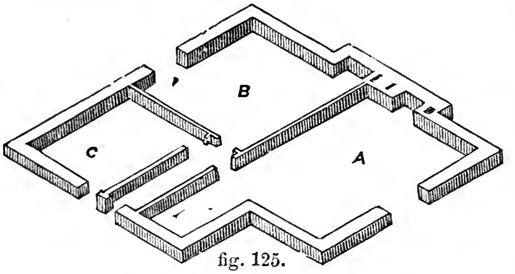


fig. 125.

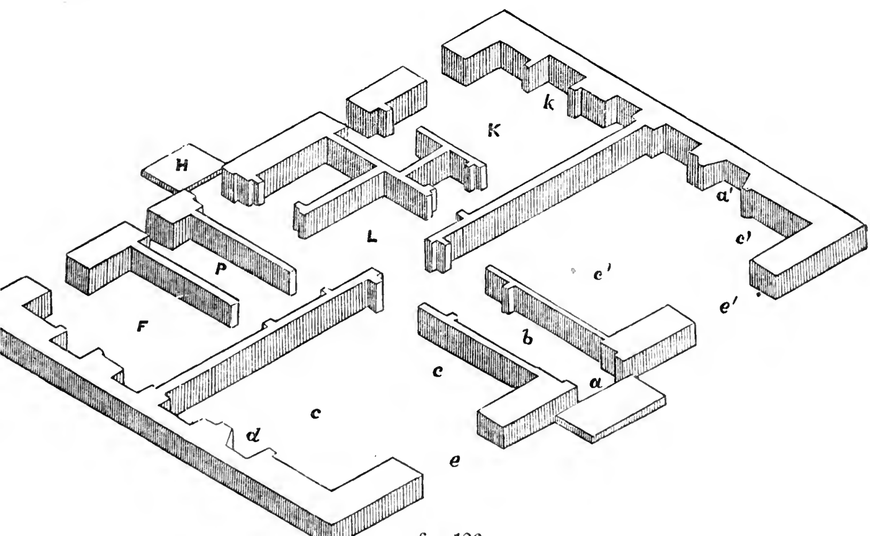


fig. 126.

of a house the height of the walls being somewhere about one-fourth or the actual height. The whole measurements are taken from a scale of equal parts, feet, and inches. Thus *a* is the main entrance door, with the flag before it; *b* is the entrance-hall, *c c* the drawing-room, *d* the fire-place, *e* the window; *e′ e′* is the dining-room, *a′* the fire-place, and *e′* the window. F is a study or small sitting-room, P a closet, H the back entrance, L the staircase-lobby, K the kitchen, *k* the fireplace. Fig. 127 shows the method of representing agricultural enclosures, or walls of gardens, &c; a smaller enclosure is delineated in the centre. This diagram exemplifies the way in which the enclosures of a field or fields may be delineated, thus giving data by which not only the extent of the fields may be measured, but also for the measurement of the enclosing erections.

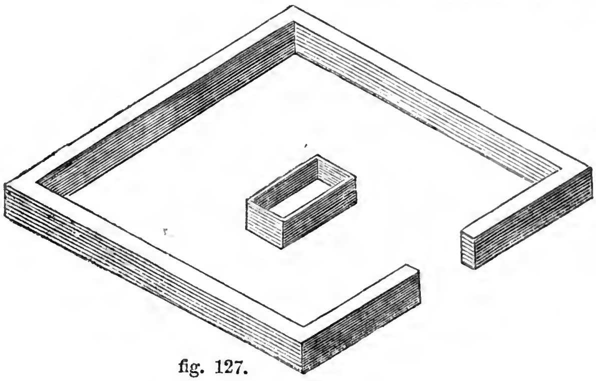


fig. 127.

Where the scale is sufficiently large to admit of the details being delineated, the gates and other objects may be drawn in the plan.

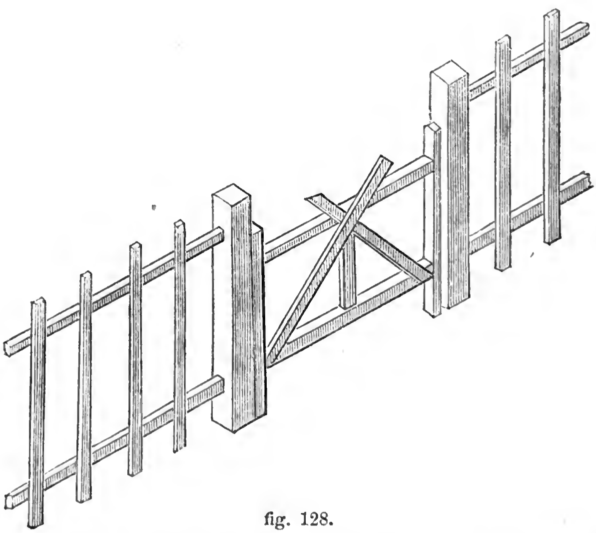


fig. 128.

In fig. 128 we have given the representation of a gate and part of the adjoining and connected fence. In fig. 129 the drawing of a house is given isometrically; the length and breadth of the house is shown, as well as the height, position, and size of windows, chimney-flues, &c. The parts may all be measured from a common scale. The method of applying this style of drawing to the delineation of horticultural edifices is displayed in fig. 130. The length, breadth, and height are all shown in one view; the scantling and position of rafters, glass-door, also clearly delineated; drawn to a common scale by means of the isometrical ruler, the measurements of the various parts can easily be taken.

In fig. 131 the reader will find the geometrical plan, and in fig. 132 the isometrical drawing of the house previously referred to, the height of the

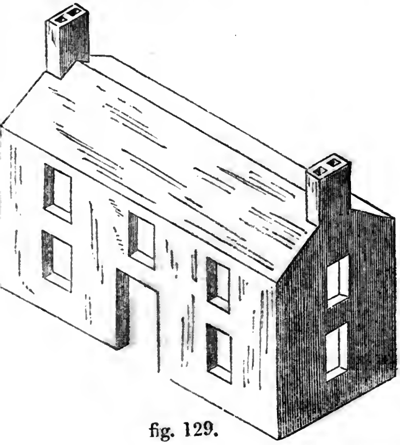


fig. 129.

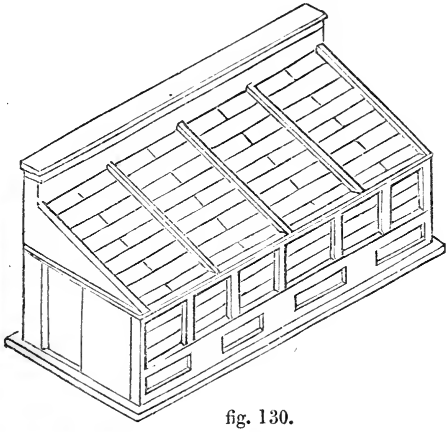


fig. 130.

walls being shown up to the second floor; had not it tended to make the drawing appear confused, the size and position of the timbers of the flooring might have been shown. All the lines in fig. 132 have been taken from

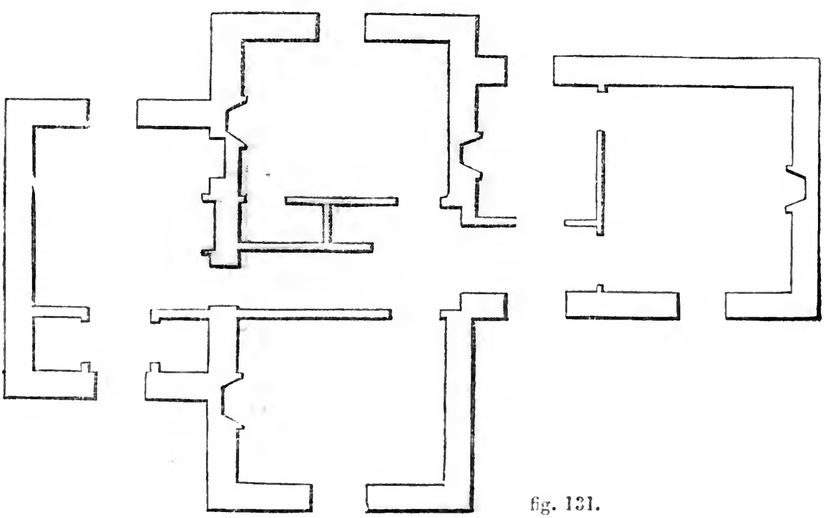


fig. 131.

the same scale used for the plan in fig. 131. The pupil should try to draw the geometrical plan from the isometrical sketch, and *vice versâ;* if he can do this with facility and correctness, he will be able to proceed to the isometrical delineation of any geometrical plans which may be presented to him. In concluding this part of our present volume, we would earnestly advise the reader wishful of having an acquaintance with this attractive style of drawing to use the instruments at every lesson,—to try and draw them as given, not merely to content himself with understanding the accompanying explanations: an hour's practice in drawing the lessons will be worth a day's reading on the subject.

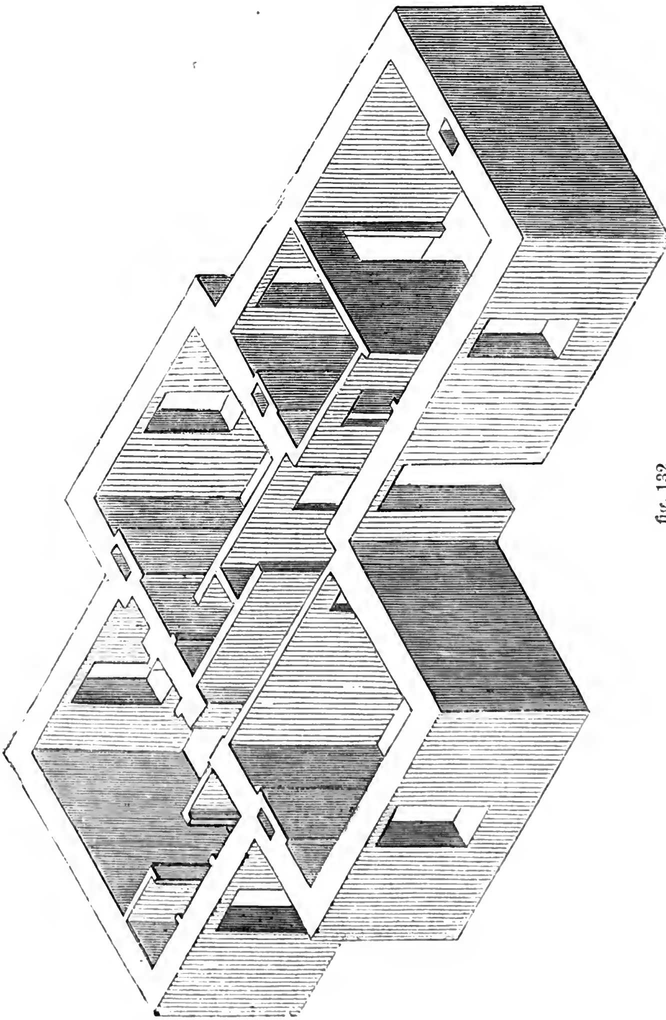


fig. 132.

SECTION IV.

ENGRAVING.

In the foregoing sections we have amply explained and illustrated the principles and practice of drawing in all its branches; it now remains for us to describe the methods by which the emanations of the mind in conceiving, the eye in arranging, and the hand in copying, may, from one original source, be multiplied to any desired extent.

In view of the important place which the art of multiplying drawings holds in the social system, we need not offer an apology for briefly explaining the details of the practice of the more important branches in the pages of a work professedly devoted to drawing. Before engravings can be executed with taste and precision, the manipulator must himself be a draughtsman; at all events, a merely mechanical engraver can never render accurately the works of an artist, so as to present them with that freedom of touch so essential in a good production. This section, however, is not designed for professional engravers; it is chiefly for the use of those who have followed us through the various departments of our work, who have acquired a considerable facility in designing and drawing, and who are anxious to have a slight knowledge of the methods by which their labours may be multiplied,—a knowledge not deep enough to serve them in all the routine of extended or professional practice, yet so well arranged and practical that the desire above alluded to may be gratified with a moderate degree of success.

It would be extremely interesting to trace the history of the rise and progress of the art of engraving; but this the limits as well as the nature of our work preclude: we shall therefore at once proceed to the consideration of the various styles of engraving practised at the present time, confining ourselves chiefly to the art of etching on copper; this being the most attractive style, a knowledge of which is soonest obtained, and the principal requisite for which is the capability on the part of the operator to draw freely and accurately.

It will be our endeavour to describe the process in such a clear manner as to enable any one who has a knowledge of drawing to make a successful plate.

Etching enables us to produce lines on a metal plate capable of throwing off an impression. To effect this, it is necessary to cover the plate with a preparation which will resist acid. If on such a preparation acid is applied, it will not act on the copper; but if a scratch is made through the preparation, and the acid thereafter applied, it will eat into a line, deeper or shallower according to the length of time the acid is allowed to remain. The metal generally used for etching is copper, the plates of which should be carefully prepared.

Etching is not meant, as some suppose, to be an easy method of imitating line-engraving; in fact, the grand distinction between the two styles is this, that in line-engraving the lines, however beautiful in effect, are produced by means more or less mechanical, while in etching the lines and effect are put in with a facility of drawing and freedom of touch which is displayed in free pencil-sketching on paper. In etching, the needle and the aquafortis are the only assistants; the graver is seldom required, and the oftener it is used, the stiffer the drawing becomes, and more removed from that exquisite freedom and ease which is the characteristic of a true etching, representing, as it does, or ought to do, the ease with which the original design or subject is transferred to the paper or the canvass.

First, as to the "ETCHING GROUND." This is a preparation of wax, asphaltum, gum mastic, &c. As much depends on the quality of the ground, the expense not being great, we would recommend our readers to purchase it ready-made. It is sold by Fenn, in Newgate Street, and by most of the dealers in engravers' tools, &c. In order to prevent any grit coming to the plate, it is better to inclose the ground in silk for the purpose of filtering any imperfection.

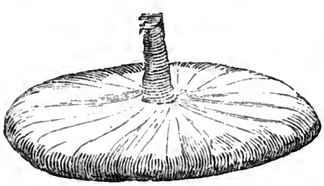


fig. *a*.

The following tools and implements are necessary. The "dabber," which is composed of silk of a fine texture, and evenly stuffed with wool until it assumes the form required (fig. *a*). It is necessary to place a circular piece of card at the top of the dabber, immediately below the handle. The "etching-point," the "graver," the "scraper,"

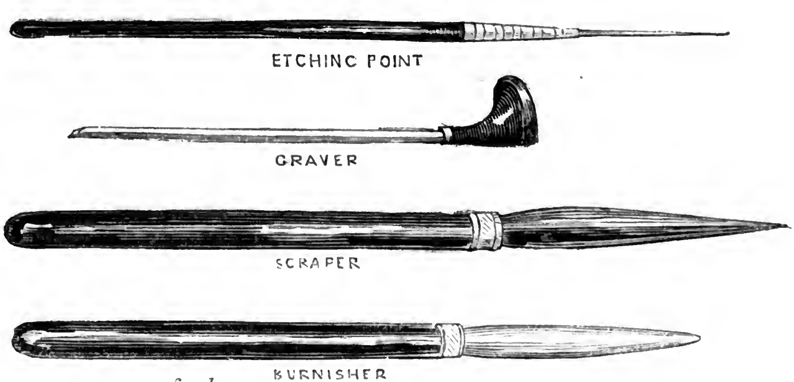


fig. *b*.

the "burnisher," and the "hand-vice." These are all delineated in the annexed diagrams (fig. *b*). An etching-table must also be provided, with the following accessories:—

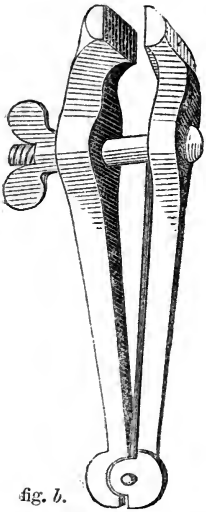


fig. *b*.

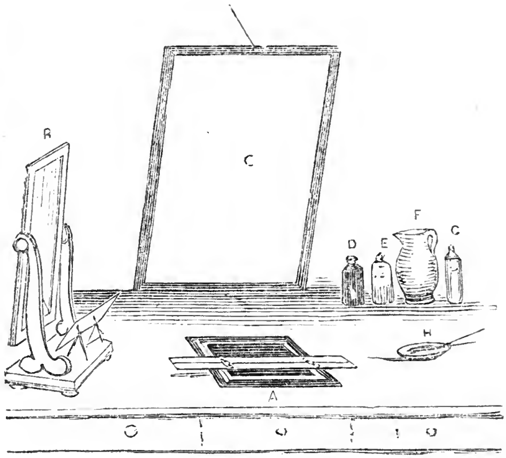


fig. *c*.

A, the plate on which the subject is to be etched, with support and ruler.

B, Looking-glass for the purpose of reversing drawing.

C, Tissue-paper strained on a thin frame to prevent the light from glistening too much on the plate.

D, Black varnish for stopping out scratches and such tints as are "bit" sufficiently dark.

E, Nitrous acid.

F, Water.

G, Spirit of turpentine.

H, Plate and pencils for mixing the varnish (fig. *c*).

The first preparatory process is laying the etching-ground.

The plate having been polished from tarnish, in order to remove all grease from the surface wash it well with spirit of turpentine, and after the plate is dry rub it carefully with whiting and wash-leather; then fix the hand-vice, and proceed to heat the plate either on the top of a stove, or by any other process by which a steady and not too great a heat may be obtained; in the absence of a stove, a piece of flat metal, heated and placed on bricks, is a good substitute. It may be known when the plate is sufficiently hot by placing the etching-ground on the plate with a gentle pressure, and, after allowing it to remain a few seconds, pass it slowly from one end of the plate to the other; if a thin layer is equally left along the surface, the heat is proper. Continue to pass thin layers of etching-ground from end to end of the plate, at tolerably equal distances, and then, in the same manner,

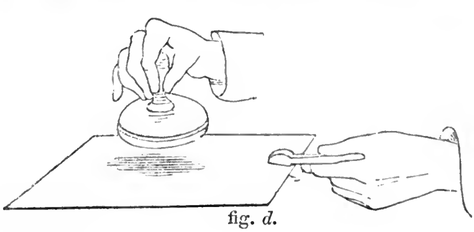


fig. *d*.

from side to side; the object of this is to place an equal quantity of etching-ground, in order that the dabber may spread it more readily over the surface; then take the dabber (fig. *d*), now in requisition, and use it by constantly dabbing over the plate for the purpose of entirely covering the portion of the plate required. On an even and complete layer having been obtained, take a wax-taper (fig. *e*), and next proceed immediately to smoke the ground; the taper must be kept in motion, in order that the whole of the ground may be evenly blacked: if the flame of the taper is allowed to remain too long in the same position, the ground will be burnt, and not offer sufficient resistance to the acid; and if the plate, during the process of smoking, is too cold, the smoke will not incorporate itself with the ground, but remain on the surface. The essentials of a good ground are—first, that the surface be *completely covered;* second, the covering to be as equal as possible, and not so thick as to prevent the free use of the etching-point; and third, that it shall present, when cold, a polished black surface. If when the plate is cold the surface appears in parts dull, it is caused either by the ground being burnt by using too much heat while spreading the ground, or that, when smoking, the plate has been too cold. It is easy, when the plate is cold, to discover from which of these causes the dulness of the surface proceeds, by rubbing the part slightly with a soft handkerchief: if the black is removed to the handkerchief, the plate has been too cold when the taper was applied; but if the dull black remains on the plate, the imperfection has been caused by heat. If the dulness arises from the smoke lying on the surface, it may be readily altered by slightly heating the plate; if from burning, the ground must be removed by heat and spirit of turpentine, and the plate again thoroughly cleansed.

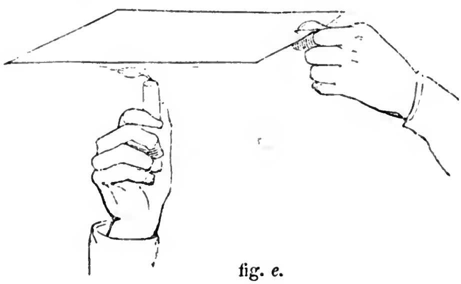


fig. *e*.

The best method of getting the subject transferred to the plate is to send a careful outline, either in pencil or red chalk, to a copperplate-printer, who will slightly damp and pass it through the press. If this is not convenient, a piece of tissue-paper may be rubbed with powdered vermillion, and fixed with the coloured side towards the plate. The tracing must then be put in its proper place, and fastened with wax at the corners to prevent it shifting. The outline must be then gone over with a blunt etching-point. This process will leave a clear outline in red, on a black ground. When thus transferring, the pressure should not be so strong as to damage the etching-ground.

The student will observe that, in order that the plate may throw off a correct impression, the subject must be reversed. This difficulty may be remedied by placing the drawing so that it may be seen in a looking-glass, which will have the effect of giving it the same appearance that it would have on the plate.

The plate is now prepared for the etching process.

When etching, care must be taken to prevent any grease from coming into contact with the etching-ground; and it is proper to fix pieces of thin wood or folded paper round the edge of the plate, in order, with the help of a ruler, to form a sort of bridge on which to rest the hand. This erecaution is necessary in order to protect the ground from scratches. These supports may be fastened with bordering wax. The etching-point is used in a similar manner to a blacklead-pencil; and it is very important to bring it into good working condition by rubbing it on a hone or leather strop. The point ought to be of such a degree of sharpness as to move freely on the plate; at the same time it is necessary that each line should go completely through the ground, otherwise the etching, after biting, will present a very rotten appearance.

Wax is now used for the purpose of forming a wall round the plate of about an inch high to confine the acid; it is composed of beeswax and Burgundy pitch, in the proportion of one pound of beeswax and a quarter of a pound of Burgundy pitch. The ingredients must be chopped into small pieces, and allowed to boil slowly in an earthen pipkin. As soon as the whole is dissolved, it is necessary to pour it into a basin partly full of warm water; it must then be worked by the hands until it becomes a pliable substance similar to shoemaker's wax. When using the bordering wax, it may be placed in hot water for the purpose of rendering it more workable, and it is necessary to be very careful to press it closely to the plate in order to prevent the acid from escaping (fig. *f*). It is also better to varnish round the inside of the wax with great care, lest the ground underneath the wax may have been removed. If not thus protected, the margin will be filled with holes, which are troublesome to remove.

fig. *f*.

It is difficult to give any precise directions for biting, as much depends on the strength of the acid, the hardness of the copper, and the degree of pressure which has been laid on the point when etching.

The following figures illustrate the appearance of the plate at different stages of the biting-in process. Fig. *g* represents the etching as it would

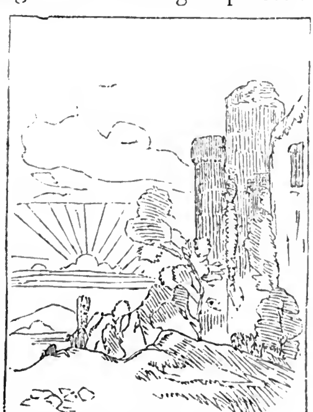


fig. *g*.

fig. *h*.

appear after the acid had been applied five minutes; fig. *h*, the etching with the lightest tints stopped up with varnish. Fig. *i* represents the etching as it would appear after the acid has been applied ten minutes; and fig. *k* after it has been applied fifteen minutes.

fig. *i*.

fig *k*.

Generally the nitrous acid sold by druggists may be diluted with a little more than twice the quantity of water; but until the student has by experience acquired a knowledge of the action of the acid, it will be advisable to make frequent examinations of the etching, lest the tints are bit too dark. In order to effect this, the acid must be poured off, and then the plate carefully washed with water, and dried either by blowing with a pair of bellows or by dabbing with a very soft handkerchief; a portion of the etching-ground can then be removed by the scraper (see page 132). If the line is not dark enough the plate can be stopped up with varnish, and when dry the acid can be again applied. It is, perhaps, well to mention that the common *Brunswick black*, used for blacking chimney-ornaments, is a very good varnish for stopping-out. This varnish may be had at any oilshop; but a very superior description is prepared by Crease and Son, Cowcross-street, Smithfield. A plate, if covered with this varnish and permitted to dry, will as effectually resist the action of acid as if covered by the etching-ground; but it is not so proper for the purpose of etching, as it cannot be so neatly removed by the point. Care must be taken in all cases not to put the acid on the plate until the varnish is dry. If this is not attended to, the varnish, instead of protecting the plate, will rise to the surface of the acid, and the plate will bite into holes in such portions as the varnish has been removed from. It may be easily known when the varnish is sufficiently dry, by breathing on it: if the breath remains for some time on the surface, the acid may be applied with safety; but if it rapidly passes off, then it is not safe. It is a consideration in biting to produce a clear deep line. This desirable quality is more likely to be produced by pouring a depth of at least half an inch of acid on the plate, and by carefully removing, with a very soft feather, the small globules which will be seen to congregate on the surface of the plate.

The biting is the most uncertain portion of the process of etching, and the most experienced are liable to fail. For general purposes, however, a very little practice will ensure success. When it is considered that the etching has been bit to a sufficient colour, it is necessary to remove the bordering wax by heating the plate, and then clearing it with spirit of turpentine, and afterwards rubbing with oil and a soft rag; it will then be necessary to send to the copperplate printer for a proof.

The process of copperplate-printing is exactly the reverse of printing from woodcuts and type. In the latter the ink is passed from the surface of the block, &c., to the paper by means of pressure; in the former the impression is delivered from an incised line. In copperplate-printing the whole of the surface of the plate, and also the lines, are covered and filled with ink; the printer then (with the assistance of heat and whiting), by passing his hands gently and repeatedly over the surface of the plate, removes the ink from the entire surface, but leaves it in the lines or scratches. Damp paper is then passed through the rollers of the press, between the upper roller and the plate are several layers of cloth, and the ink from the lines is thus placed on the paper. If it is found, on examining the proof, that some portions of the etching are not sufficiently dark, the fault may be remedied by "rebiting."

The lines on the plate *must be most carefully* cleaned from all remains of printing ink, or any substance that would interfere with the proper application of the etching ground or acid. It is best to wash the plate well with spirit of turpentine and a perfectly clean rag; then rub the lines and surface of the plate with spirit of turpentine and bread, and afterwards with spirit of turpentine and whiting; after that with whiting and bread. If any portions of whiting remain in the lines, it can be removed by wash-leather and soft bread: the object of all this care is to free the lines from any impediment to the action of the acid, and to enable the student to cover the *surface of the plate* with etching-ground, so that, the surface being protected from the action of the acid, but the *lines left unfilled*, the parts which are already sufficiently dark can be stopped up with varnish and acid applied in the regular manner, and an increase of depth be got on any part of the plate that may be required. The principal things to be attended to in laying a rebiting-ground are, that the lines shall be left free from etching-ground, and the surface completely covered; if this is not attended to, the acid will fill the parts of the plate that are not covered with varnish or ground with numerous small holes, which will certainly produce impure tints: this appearance is known among engravers by the name of foul biting. The dabber used to lay the etching-ground may be used for the rebiting-ground; but it is perhaps well not to apply so much heat, as the ground, if too thin, is liable to run into parts of the lines; this produces, perhaps, as ill an effect as foul biting; for if the acid is placed on such a ground, it will cause an unsteady or rotten appearance, by biting the lines which are clear to a greater thickness than others.

Considerable finish may also be got by using the "dry-point," which is nothing more than an etching-point made sharper than it is required for the purpose of etching; indeed it is used for scratching such lines into the copper as will throw off an impression. On examining a line made with the dry-point, it will be found that the metal is not removed as if cut with a sharp graver, but merely pushed to one side; if this, which is called the burr, is allowed to remain, it will, by its roughness, collect the ink and form a blot on the impression. To remove this burr it is necessary to use the scraper in such a manner as not to drive the burr back into the line, but rather to cut it from the sides in order that each line may be thoroughly clean.

The graver is used to increase the darkness of small portions, and is used in the hand as follows:

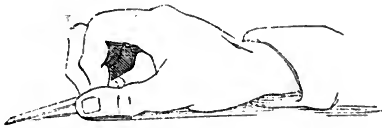
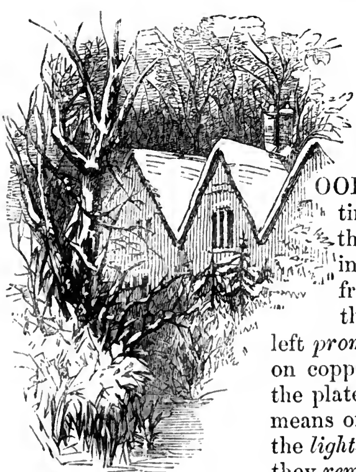


fig. *l.*

WOOD-ENGRAVER AT WORK.



SECTION V.

WOOD-ENGRAVING.

OOD-ENGRAVING is the art of cutting figures on wood, for the purpose of their being printed upon paper. It differs in principle, and in its mode of operation, from engraving on copper and steel: the lines which form the impression being left *prominent* in the wood; while in engraving on copper or steel, the lines are either *cut into* the plate by means of a graver, or *bit into* it by means of a corrosive liquid. In wood-engraving the *lights* are *removed;* in copperplate engraving they *remain.*

From this difference between wood and copper-plate engraving arises the different manner of printing from a wood-block and from a copper-plate. Wood-blocks are printed in the same manner as the type for a book: their *prominent* lines are *covered* with ink, and an impression is formed by the paper being pressed *on to* them; while in steel or copper-plates the *hollow lines* are *filled* with ink, and an impression is obtained by pressing the paper *into* the inked lines.

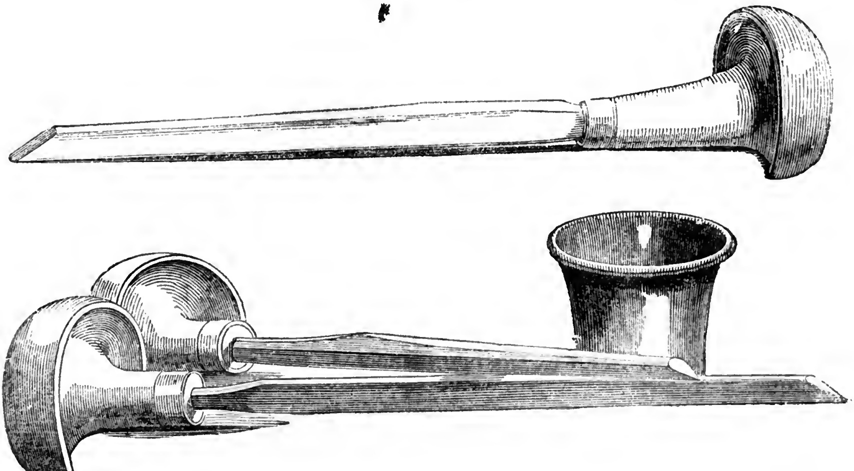
Box is the wood mostly used by modern wood-engravers; pear-tree, and other wood of a similar grain and fibre, being now only used in executing large cuts for posting-bills. Box, for the purposes of engraving, is sawn into rounds about an inch thick,—the height of type,—and the cross way of the wood. As the usual diameter of even the largest logs of box does not exceed five or six inches, it becomes necessary when a large block is wanted to join several pieces together; and to do this properly, so that the joinings may not be perceptible in the impression, requires very great dexterity on the part of the person who prepares the block; indeed, the joining together of several pieces of box, so as to form one large compact block of uniformly smooth and level surface, requires as much skill as the most delicate piece of cabinet-work. Perhaps the largest block of this kind ever made or engraved was the large view of the interior of the Great Exhibition of 1851, presented by the proprietors of the *Illustrated London News* to their subscribers.

The best box is that which is of a yellow colour, like gold, throughout the whole surface, displaying neither specks of white nor reddish-coloured rings. Such box being of a close grain, and uniformly dense and tenacious, not only allows of the lines being cut with the greatest clearness and precision, but is also the least liable to display unevenness at the surface, which is usually occasioned by inequality in the density of the several layers of the wood. Wood of a red colour usually wants tenacity, and cuts soft and short; and if it displays many distinct rings, it is extremely liable to shrink irregularly, and thus to render it difficult to obtain a perfect impression. Wood containing whitish specks or streaks is apt to break away under the graver in such places. All kinds of box are subject to warp, especially such as have not been well seasoned. When a block has warped in the progress of engraving, it will generally return to a level on being kept for a day or two with its face downwards on a table or shelf. Sometimes, however, it can only be remedied by means of overlays in printing, to bring up the hollow parts of the surface. Box is not only the best wood for engraving on, but is also the best for the purposes of printing, as no other kind so well resists the action of the press. In the latter respect it is even superior to type-metal; for a greater number of good impressions can be obtained from an engraving on box than from a cast taken in type-metal. In the former, the lines, though liable to have small pieces broken out of them when thin and comparatively wide apart, retain for a longer time their distinctness and precision; while in the latter, they are more liable to become thickened from pressure.

Some artists, before they commence drawing on wood, whiten the smooth surface of the block with a slight wash of flake-white and gum-water; others rub the surface with a little finely-powdered Bath-brick, mixed with water, rubbing it off when dry, to prepare the slippery surface of the block for drawing on with a black-lead pencil. All the lines which appear in a woodcut are generally drawn on the block by the designer or draughtsman in pencil, with the exception of what are technically called "tints," indicative of the atmosphere and the sky, such tints being merely washed in with Indian ink. The most faithful wood-engraving of an artist's design is that in which the engraver has, without adding or diminishing, *worked out* a perfect fac-simile; this, however, is rarely effected, there being always some alteration or omission made by the engraver.

As all the lines in an engraved wood-block are in relief, their extremities, both at the edges and in the middle of the subject, are extremely liable to come off too heavy in printing, in consequence of the paper in such places being pressed not only upon, but, to a certain extent, down over them. In order to remedy this, when it is particularly desirable that certain parts should be lightly printed, and show the lines gradually declining in strength, the block is lowered in such places before the drawing is made on it; by which means the pressure of the platten or the cylinder on such places is reduced, and the desired lightness obtained. In vignette subjects, where the edges are required to be light, the lowering of the block in such places is extremely simple: lowering in the middle of the block, however, is not so easy an operation; and before it can be properly done, it is necessary to have the parts intended to be light sketched in, as a guide to the operator. For lowering a block in this manner, a tool something like the burnisher of a copper-plate engraver is used. Sometimes, also, the lines in such places are lowered by means of a fine file, after the cut has been engraved on a perfectly flat surface.

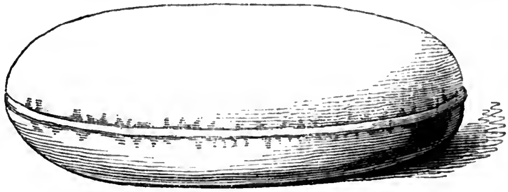
The tools which a wood-engraver employs consist of gravers, to cut the lines defining the forms, and suggesting the idea of the varied tint and texture of his subject; and of chisels and gouges, to cut or scoop out the larger masses of wood where the subject has to appear white. The gravers are of two kinds: gravers, simply so called, and "tint-tools." The gravers proper are used to cut the various lines, straight, crooked, curved, or crossing, which define the forms of the different objects, and indicate their character and texture; tint-tools, which are thinner in the blade, and more acutely angular at the point than gravers proper, are used to cut the parallel lines which constitute what is technically termed a tint. In the use of those tools, in clearly cutting the more delicate portions of his subject, is displayed the engraver's skill; if in the adaptation of lines of all kinds to significantly convey as complete an idea of his subject as



GRAVERS AND EYE GLASS.

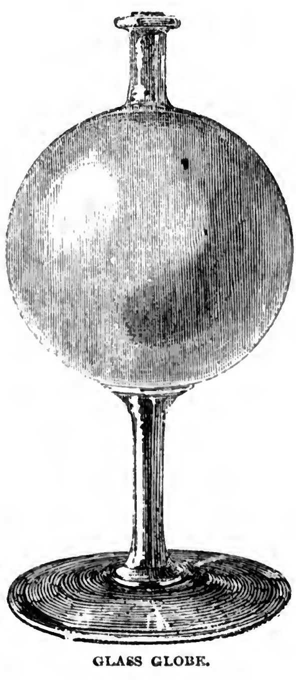
his art will allow, he displays both a knowledge of pictorial effect and a power of representing it by the means of wood-engraving, he is justly entitled to the name of an artist.

Most wood-engravers, when at work, are accustomed to place the block on a leather sand-bag, which at once affords a firm rest, and allows of the



SAND-BAG.

block being turned with facility in any direction by the left hand, while the right is employed in cutting a line. Some, however, place the block on a kind of frame, on which it is movable by means of a pivot. On the comparative merits of these two modes of resting the block it is not easy to decide, seeing that each is adopted by some of the best wood-engravers of the day. Those who have been accustomed to the one mode rarely abandon it for the other: to us, however, the sand-bag appears preferable, as being the simplest and affording the greatest facility of turning the block, and suiting it, by the motion of the left hand, to the action of the graver.



GLASS GLOBE.

As the wood-engraver requires a strong and clear light, he generally, when working at night, employs either a glass globe filled with water, or a large lens, to concentrate the light of his lamp, and to cast it upon the block which he is engaged in engraving. The advantage which the globe has over the lens consists in the greater clearness and coolness of the light which it transmits.

In taking a proof the wood-engraver employs a small ball to ink it, and a blunt-edged burnisher to rub off the impression, which is usually taken on India paper, a piece of card being placed above, to equalise the friction, and to prevent the lines being broken. The wood-engraver who bestows great labour in the execution of a cut which cannot be properly printed, not only mis-spends his time, but also deceives the person who employs him. The best mode of cleaning a block after a proof has been taken, or a certain number printed off, is to rub it with turpentine and a soft brush, and carefully wipe dry.

HOUSE OF BEWICK, THE CELEBRATED WOOD-ENGRAVER.

LONDON:

PRINTED BY PETTER AND GALPIN, PLAYHOUSE YARD,

ADJOINING THE "TIMES" OFFICE.