THE STEAM ENGINE

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STEAM-ENGINE.

THE

STEAM-ENGINE;

BEING A POPULAR DESCRIPTION OF THE

CONSTRUCTION AND ACTION OF THAT ENGINE;

WITH

A SKETCH OF ITS HISTORY, AND OF THE LAWS OF HEAT AND PNEUMATICS.

ILLUSTRATED BY A NUMBER OF WOOD ENGRAVINGS.

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SECOND EDITION, REVISED AND ENLARGED.

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PREFACE.

The Steam-engine is so interesting a subject—from the extent and variety of its applications, the great power with which it has armed mankind, the varied forms in which it meets us at every turn, the singular ingenuity of its construction, the beautiful mechanical contrivances which it presents, and the many great laws of nature which it illustrates—that there are few who do not desire some knowledge of its structure and mode of action.

The present work is designed to furnish to the general reader such an account of this great machine as may be easily understood by those who are previously unacquainted with the subject. The general laws of Heat and Pneumatics, on which the action of the engine depends, are fully detailed; its construction and mode of action are minutely explained, so that, with the aid of the figures, it may be readily understood, even by those who have never seen an engine; and the different forms into which the engine is thrown, to fit it for its various applications, are separately described. A sketch of its origin and progress is given, as every one must be desirous to know something of the history of an invention, second only to that of Printing in the magnitude of the results which have flowed from it, and far surpassing that operation in the genius displayed in its conception, and the points of interest it offers to the intelligent observer.

It is hoped that this little work may furnish the general reader with all that he requires on the subject of the Steam-Engine, and enable him, when he meets one, to observe its motions with that interest and enjoyment which a knowledge of its structure is calculated to impart. The author trusts, also, that it may be useful, as an introduction or guide, to smooth the path for those who intend to prosecute the study more fully. In page 224 will be found a list of books on the Steam-Engine, which may be studied or consulted by those who wish to go farther than this work can carry them.

The full scope of Steam, in its varied applications, is yet but dimly seen. Even now, it may be deemed an eighth wonder of the world, from the changes it has wrought in the Arts and Manufactures. But its powers of increasing the swiftness, multiplying the means, and reducing the expense of locomotion, are only beginning to be developed. The wonders it is to work in this respect cannot be properly estimated until the time, which is fast approaching, when the great wilderness of the ocean shall present a stirring scene like what meets us near some crowded port. The ocean will be alive with steam. The paddle wheel will be heard, and the dark wreath will be seen where nought but the howl of the tempest or foam of the breaker has before disturbed the solitude of the deep. The shipwrecked mariner, tossed in his open boat, or drifted in his shattered bark, with scarcely a hope to cheer him, will not then wait long for a rescue. Stirring, hurried, exciting, as the world is at present, it is calmness and lethargy to what a century will bring forth. What a busy, bustling, buzzing world it will be, when the people of the most remote climes will be whisking past each other on the waters, in every direction; when India, North and South America, the myriads of fruitful and sunny isles in the Indian and Pacific oceans, and the continent of Australia, will be connected by regular and frequent steam-communication; when the resources of these hitherto desert countries will be developed, capital introduced, the arts and comforts of civilised life established, a busy, active and intelligent population created,—when every little nook over the wide surface of the earth shall have its ships and railroads—its ports and marts, its spot where "merchants most do congregate;" and every port shall be crowded with these active messengers, arriving in rapid succession, with news, and travellers, and treasure, from all quarters of the globe.— Then will the power of steam be felt; and those joint sovereigns, the Printing Press and Steam-Engine, will receive the homage of all the nations of the earth, and be acknowledged as the master-spirits who have created a new world.

Since the remarks in the body of the work on the invention of the Steam-Engine were printed,* I have perused the life of Watt by Arago, in which there are some observations on that subject. Where there are so many, who have each contributed a little to an invention, it is not possible to fix on one as *the* inventor; and M. Arago properly remarks, "By seeking to discover a single inventor where it was necessary to recognise many, we have been in 'endless mazes lost.'" This remark is particularly just when applied to the invention of the Steam-Engine. As elsewhere remarked (par. 185,) no one, except Watt, can be singled out pre-eminently. But, on reading M. Arago's remarks, it does not appear that he has adhered to the rule he has himself laid down. Two Frenchmen, De Caus, and Papin, are particularly held forth, as the grand originators of ideas, which others have only extended; and peculiar honour is awarded to them, to the disparagement of Porta, Savery, and Newcomen; all of whom, according to my own view, and the two latter acording to the generally received opinions, have claims fully equal, if not superior, to those of M. Arago's favourites.

In one point, I certainly concur heartily with the distinguished author of the Eloge on Watt; namely, with respect to the claims of the Marquess of Worcester. I cannot consider that there are any sufficient grounds for assigning to that nobleman, a place among the inventors of the Steam-Engine. See par. 183.

With regard to De Caus, M. Arago observes, "I cannot allow that that individual accomplished nothing which was useful, who, pondering upon the enormous power of steam, raised to a high temperature, was the first to perceive that it might serve to elevate great

* These are not altered from the first edition of this work.

masses of water to all imaginable heights. I cannot admit that no gratitude is due to that engineer who was the first also to describe a machine which was capable of realising such effects."

There is a mixture of truth and exaggeration in the above quotation, which would be very apt to mislead one who is not precisely aware of what De Caus had effected, and what had been done previously by others.

It is true that De Caus was the first to propose the application of steam to raise water on the large scale.

It is true that De Caus described a thing which he called a machine, by which *water put into the machine might be raised above it.*

But De Caus did not perceive this useful application of steam by "pondering," as if he was the original discoverer of this power of steam;—for, 10 years previously, in a work with which there is good reason to believe that De Caus was acquainted, Baptista Porta had shewn that imprisoned steam would raise water, and given a drawing of a small machine, far more effectual than that of De Caus; though he did not propose it as a machine for the purpose of raising large quantities of water for use.

And, the machine which De Caus described "capable of realising such effects" was no more capable of realising any useful end than Porta's. It was only fit for a toy, or for an experimental illustration of a philosophical truth. We are not to consider it as a useful machine because De Caus loosely described it as such. In truth, Porta's drawing was a far better hint for a useful machine, than that of De Caus.*

* Porta formed the steam in a vessel separate from that containing the water to be raised. Mr. Robert Stuart, in his very instructive and entertaining work "Historical and Descriptive anecdotes of Steam-Engines," remarks of Porta, "The author, it is admitted, made no application of his apparatus as a mode of raising water, directly by the force of steam, from rivers

PORTA, then, pointed out the principle, *and method of applying it.* DE CAUS proclaimed—*this may be made useful.* We can place no value whatever on his drawing of a machine: it was useless. The *suggestion* of the application on the large scale is all we owe to DE CAUS, and that was certainly an important step. But PORTA ought not to be forgotten: DE CAUS is not entitled to be considered as the inventor of a machine, capable of giving effect to his suggestion, thereby exaggerating his merits, and detracting from those of SAVERY, who followed him, and worked out the idea into a practicable form.

PORTA, DE CAUS, and SAVERY, were on the same track, raising water by steam directly applied, and must be associated together. SAVERY was the first to construct a truly serviceable engine, to go beyond the bare idea; and he did so by combining ingeniously together a number of beautiful contrivances and adjustments, many of them entirely new. See par. 191.

"It is to PAPIN," says M. Arago, "that France owes the honourable rank she may claim in the history of the Steam-Engine."—PAPIN is certainly entitled to more credit than is generally allowed him, and I trust full justice has been done to him in this work: See par. 185, &c. But taking the highest estimate of the value of his invention, and of the genius it displayed, it is surely too much to associate

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and fountains; but his *diagram* and description are so complete, that its application to this purpose by another, could not be considered even as a variation of his idea."—M. Arago rejects PORTA altogether from the catalogue of contributors to the invention of the Steam-Engine, because he did not propose a machine for use on the large scale—"*did not speak, either directly or indirectly, of any machine.*"—Surely this is treating lightly the value of the *principle*, and of the clear hint how to apply it, which PORTA's apparatus gave, and which formed the *leading* and *distinguishing* features of the new power. DE CAUS could have been better spared than PORTA.

him with WATT in the following manner:—"When the immense services already rendered by the Steam-Engine shall be added to all the marvels it holds out to promise, a grateful population will then familiarly talk of the ages of Papin and Watt."

Why, in this enumeration of the landmarks of an era, is NEWCOMEN forgotten, who developed the capabilities of the scheme of PAPIN, on which his claims rest, but which he never was able to work out, and left in a perfectly useless condition. NEWCOMEN, by a great number of beautiful contrivances, brought this crude project into practice (par. 216, 235, and 236,) at the very time when it was abandoned by its parent, so completely abandoned, that, though he was still endeavouring to work out the application of steam, he proceeded on a totally different principle. See par. 208, 209.

Why is PAPIN placed on a level with WATT, who not only suggested a new and beautiful principle, (separate condensation), fully equal in novelty and ingenuity to PAPIN'S; but gave practical effect to that principle, and extended immensely its range of application, by a number of the most ingenious, beautiful, and novel mechanical contrivances; who shewed such fertility of resources, in meeting the difficulties which the extended applications and more complex structure of the engine offered to him; who brought his machine into such a state—not only inventing the principle, but extending and adding so much to it, that seventy years' experience has suggested few material improvements on it? WATT did far more for the Steam-Engine than PAPIN and NEWCOMEN combined. The separate condensation was but a small part of what WATT did. If, however, M. Arago's estimate of the other parts of WATT'S labours, as will be naturally drawn from the following passage, be correct, there are good grounds for placing WATT and PAPIN side by side, or even placing PAPIN above WATT; though it is usually considered that WATT's merits lay very much in those identical contrivances spoken so lightly of:—"It was to the production of an economical moving power, capable of effecting the unceasing and powerful strokes of the piston of a large cylinder, that PAPIN consecrated his life. The procuring afterwards from the strokes of the piston, the power requisite to turn the stones of a flour mill, the rolls of a flatting mill, the paddles of a steam-boat, the spindles of a cotton mill; or to uplift the massy hammer, which with oft-repeated stroke, thunders upon the enormous masses of redhot iron just taken from the blast-furnace; to cut with great shears thick metal bars, as easily as you divide a ribband with your scissors; these, I repeat, are problems of a very secondary order, and which would not embarrass the most ordinary engineer."—Surely there is some mistake. One would consider the above an extract from an Eloge on PAPIN, not on WATT. These problems, which "would not embarrass the most ordinary engineer," involve WATT's happiest efforts—the invention of the parallel motion, double acting engine, expansively acting engine, and the application and adjustment of the crank, governor, fly-wheel, &c. They were a stumbling-block to SMEATON, long after PAPIN's idea had received all the perfection of which it was capable.

Having, both in the former and present editions of this work, given a more favourable view of the share of the French (DE CAUS and PAPIN) in this great invention; and a less favourable estimate of the claims of Lord WORCESTER, than most British authors; I trust I will not be accused of a national leaning in the preceding remarks. *Suum cuique tribuito* has been my guide; how far I may have adhered to it, others must judge. I have given what appears to me, on data accessible to every one, the true state of the case. Let me add, in justice to the distinguished man on whose views I have ventured to remark, and to myself, that it is impossible to assign a positive numerical value to the services of each inventor, and that the estimate of the comparative value of each step will therefore vary with the intellectual constitution of the individual who judges of it. There must be a *positive* in this as in every thing else; but the degrees are too small, the distinctions too subtle, to enable us to detect and define it.

ERRATUM.

Page 209, 10th line from bottom, *for* 520 *read* 420.

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APPENDIX.

THE

STEAM-ENGINE.

INTRODUCTION.

1. THE STEAM-ENGINE is a machine, in which steam (the vapour of boiling water) is used, and of which the object is, the production of force, or moving power, by means of which continuous motion may be communicated to other bodies—as the wheels of a carriage; paddles or oars for propelling vessels on water; the rod of a pump for raising water; grindstones for reducing bodies to powder; machinery for spinning, weaving, turning, hammering, boring, communicating pressure, &c.

2. MOTION is the general object of all machines; and, in every sort of machinery, there are two parts which must be carefully distinguished:—*First,* The machinery which comes into immediate contact with the substance to effect some change upon which is the ultimate object of the operation; *second,* The engine, or machine, which sets that machinery in motion. The latter is called the *first mover*, *first moving power*, or *prime mover*.

3. In a common turning lathe, or in the case of the

hand-pump for raising water; in the windmill; or the water-wheel for moving a grindstone—the MAN who, by his muscular power, sets the turning lathe in motion, or works the handle of the pump; the VANES OF THE WINDMILL; and the WATER-WHEEL—are the first movers. It is in them that the motion commences—their object being simply *the production of moving power*, which has to be transmitted from them to the machinery which comes into immediate contact with the wood to be turned, the water to be raised, or the corn to be ground.

The steam-engine is a FIRST, or PRIME MOVER.

4. In every case of the production of motion by machinery, the first mover is simply an engine, or machine, so constructed as to take advantage of some *natural properties of bodies which are capable of giving rise to motion.* In describing the steam-engine, then, there are two things to be considered:—*First*, Those natural powers resident in bodies from which we procure a force, or moving power; *Second*, The machine, or engine, by which those powers are made effective for the general production of motion. We shall first direct our attention to the former—the source and mode of action of the natural forces, which, in the steam-engine, give rise to the motion.

5. Infinitely various as the different kinds of power may, at first sight appear, and however complex the machinery by which they are applied so as to produce motion, upon analyzing them, it will be found that there are only *three sources* from which we can obtain a force, or moving power—ANIMAL STRENGTH, ATTRACTION, and REPULSION.

6. Of these, the first and most obvious, and the only one within reach of man in an uncultivated condition, is the MUSCULAR POWER OF ANIMALS, or, as it is frequently called, ANIMAL STRENGTH. This source of

power resides in the muscles—long, fleshy bodies, of a fibrous structure, fixed at each extremity, and possessed of the property of contracting, (diminishing in length,) in obedience to the will of the animal. By this concractile power, the more movable of the points to which the extremities of the muscle are attached, is made to approach the other. These muscles are possessed of great strength, being capable, as has sometimes happened, of breaking the bone to which they are attached. The muscles of the thumb are believed to exert a force nearly equal to a weight of 4000 pounds. We have familiar examples of the application of this power, in the plough, carts, and carriages, canal-boats, horse and cattle mills, all set in motion, and continued in that state by the contractile power of the muscles of animals.

This power is not made use of in the steam-engine; but the power of an engine is generally estimated by the number of horses that would be required to do the same work—the first steam-engines having been used chiefly as substitutes for horse labour.

7. The other two sources of moving power are—*First*, THE ATTRACTION WHICH EXISTS BETWEEN BODIES, and tends to make them approach each other; and, *Second*, THE REPULSIVE POWER, which exists, more or less, in all bodies, and tends to drive their particles asunder. These influences are universally diffused through bodies, and are antagonists—*i. e.*, opposed to each other in their action. To the operation of these fundamental properties of matter, all the phenomena of inanimate nature can be traced; and animate beings, though endowed with the independent principle of *life*, are in no small degree subject to their control while living, and when dead, are solely obedient to the laws of these great powers.

They act with great energy, and both have been used as sources of power in the steam-engine. The first is applied in some kinds of engines only (now called atmospheric engines); the latter, either applied directly as a moving power, or used to prepare for the action of the attractive force, has been a leading element in the operation of every sort of steam-engine; and, as steam is the medium through which the repulsive power is introduced, all are called *steam-engines*, although the steam may not be the direct cause of the motion. At first they were termed *fire-engines*, the steam being formed by the action of fire upon water.

8. The attractive force was taken advantage of by man as a moving power—as in the water-wheel, the windmill, the common pump—long before the repulsive principle was applied, or even thought of, as a source of motion. Now, however, this great power, so long overlooked, has almost entirely superseded the other; acting in the form of steam, it is seen everywhere, and is the prime mover chiefly employed by civilized nations of modern times. For ages a hidden treasure, it has at last been brought to light; and has placed within the reach of mankind a force so enormous, that it is limited only by the strength of the materials which must be employed to give it effect; a power unremitting in its labours and universal in its applications; so versatile, that it may be transferred from place to place, worked at any time, and suspended or set in action again at a moment's warning;—and withal, so steady and regular, so manageable, so completely under our control, and possessed of a self-regulating property to such an extraordinary extent, that it almost realises the fable of Prometheus, and may fitly be compared to an intelligent being devoted to our service.

PART I.

OF THE PHENOMENA OF ATTRACTION AND REPULSION, AND THEIR APPLICATION AS MOVING POWERS.

9. Excluding the vital energy, then, which give rise to muscular motion and all the phenomena of life, there are two great powers which are (one or other, or both) concerned in producing all the motions and changes which we see going on around us. These are Attraction and Repulsion: they are universally diffused through bodies; and they are *antagonists—i. e.*, opposed to each other in their action.

10. As the latter, Repulsion, is called into action in an unusual degree in bodies which are heated, while its power seems to diminish in proportion as they are cooled, it has generally been regarded as identical with the influence which gives rise to the phenomena of heat.

SECTION I.

ATTRACTION.

11. The universal *influence*, Attraction, which operates in drawing bodies and the particles of bodies together, and retaining them in contact, is of several kinds,* of which two chiefly must be attended to in the consideration of force, or motion:—*First*, That which forms bodies into coherent masses, acting between their minute particles only when in contact, (at insensible distances,) called the *attraction of cohesion*, *attraction of aggregation*, or simply *cohesion;* illustrated by the firmness with which the particles of a piece of iron or marble adhere to each other: and, *second*, That which brings and retains bodies near to each other, acting at sensible or apparent (indeed at all possible) distances, called the *attraction of gravitation*, or simply *gravitation*, illustrated by a stone falling to the ground when left in the air unsupported.

12. Probably the phenomena of every kind which consist in a drawing together or holding together of

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* We here omit *chemical attraction* or *affinity*, *electric attraction*, and *magnetic attraction*. The first, acting between the particles of *different* bodies, unites them together, gives rise to new varieties of bodies, and to the phenomena of combination and decomposition; but is not a source of visible motion. The two latter give rise to distinct motion; but the moving power exerted has hitherto been considered unfit for use as a mechanical force, working through too short a distance, and not being easily procured. Attempts have lately been made, however, to render magnetism efficient for this purpose.

bodies, are the result of one fundamental power. But it is convenient to subdivide them, and to make distinctions between the different effects produced.

CHAPTER I.

ATTRACTION OF COHESION.

13. When we attempt to break a piece of wood, stone, glass, ice, or any other solid, we find that its particles are firmly bound to each other, and that the exertion of a considerable force is necessary before we can effect a separation. The force which binds the particles so firmly together, and which must be overcome by some superior force before we can break the solid, is spoken of as the ATTRACTION OF AGGREGATION, or ATTRACTION OF COHESION.

14. It is particularly to this form of attraction that the repulsive influence is opposed, as we see in water, which, when cooled, (see note to paragraph 114,) becomes ice, in which cohesion predominates, and the particles are firmly bound to each other, so as to form a solid; while the ice, when heated, again becomes water, in which the cohesive attraction is neutralized or overcome, and the particles are loosened, so as to be movable upon each other.

Application of Attraction of Cohesion as a Moving Power.

15. This force has never been used as a source of motion, except, perhaps, in the following remarkable instance, in which it was happily applied for that purpose:—The walls of a building in Paris had declined from the perpendicular, and were in danger of falling

outwards, from the pressure of a heavy roof. By the following plan, suggested by M. Molard, they were restored to the upright position. A number of iron bars were stretched across the upper part of the building, passing freely through the walls. The bars were heated, in consequence of which they increased in length (57), and parts of the bars, at first within the walls, were now exterior to them. In this state, the bars were *fixed* to the walls. They were then allowed to cool; when cooled, they returned to their former size, and, being firmly fixed to the walls, necessarily pulled them inwards, (towards each other;) the contraction of the bars taking place gradually, but with great force. By repeating this process several times, the walls were restored to the perpendicular. Here the repulsive influence, repelling the particles of the bar, made it longer. When the bar had cooled, some power drew the particles back to their former distances. This force is considered the same as that which binds the particles of a solid so firmly together —the attraction of cohesion.

16. The same means were used to save from destruction Armagh Cathedral, in Ireland, by restoring to the perpendicular the pillars, which were considerably inclined, and on the stability of which the whole structure depended. These are two very interesting and striking illustrations of the application of scientific knowledge to practical purposes, and of the truth of the fine saying—*knowledge is power.*

17. Though this force is not, in ordinary cases, made use of as a moving power—by giving materials rigidity, and strength, and firmness, so as to bear pulls, strains, thrusts, and pressure of every kind without yielding, it is an essential element in giving effect to other moving powers. Cast-iron pillars, chain piers, iron cables, steam-engines, suspension bridges, are striking

instances of the power of the cohesive attraction. See an interesting account, in *The Penny Magazine* for 1836, of the suspension bridge at Fribourg. The great force of the cohesive attraction is well illustrated by the following table, shewing the loads required to break (*i. e.* overcome the cohesion of) a prism, or cylinder, of one square inch transverse section, of the following bodies, if suspended from them.

	Pounds Avoirdupois.
Rope, or hempen fibres	6,400
Memel fir	9,540
Beech	12,225
Ash	14,130
Copper	19,072
Cast-iron	19,096
English malleable iron	55,872
Swedish do. do.	72,064
Cast-steel	134,256

The *cohesive attraction*, and *friction* (arising from the roughness of the surfaces of bodies), are the sources of that *resistance*, without which we could not have any control over motion, or power of regulating it.

CHAPTER II.

ATTRACTION OF GRAVITATION, OR GRAVITY.

18. The peculiar feature of those cases of attraction which are classed under "gravity," is, that the substances drawn towards each other are at distances apparent to our senses; or, if in contact, yet not so near as to be within the sphere of action of the cohesive attraction. A stone falling to the ground is an example of the attraction of gravitation. It is retained there with a certain force, and cannot be lifted without

applying force: the attraction between the earth and the stone, is the force which retains it there. But it does not stick to the ground in the same way in which its particles adhere to each other; therefore, although, to our sense of vision, apparently in close contact with the ground, it is not so near as to be within reach of the cohesive attraction; not so close as the particles of the stone are to each other.

19. When a heavy body is suspended by a wire, its GRAVITY pulls it towards the ground; causes it to hang perpendicularly, giving it that property of downward force which we call *weight*. The cohesive attraction, binding the particles of wire firmly to each other, enables it to support the weight.

20. This attractive force is found to operate between all bodies, at whatever distances; and it acts with a force directly proportional to the mass of matter, and in inverse proportion to the square of the distance. Thus, if the distance be 1, and the attractive force 1, (the mass remaining the same,) the following proportions will hold:—

Distance.	Force.
1	1
$\frac{1}{2}$	4
$\frac{1}{3}$	9
2	$\frac{1}{4}$
3	$\frac{1}{9}$
5	$\frac{1}{25}$

21. The earth being of a globular form, and so enormous a mass (7912 miles in diameter) compared with any of the bodies on its surface—*in regard to them*, the earth, though continually in motion, may be looked upon as a fixed body, drawing towards its centre, with a prodigious force, everything which rests on its surface.

22. Formerly, this was the great source of motion for all sorts of machinery; and it was procured from

the falling of water, which was made to strike upon a board, or fall into a bucket, fixed to one side of a wheel. Its weight and force in falling, pressed the board or bucket downwards; and, by having a series of these around the wheel, a continuous circular motion was procured. The motion in the vanes of a windmill is also an example of power from the force of gravity. These methods have now been almost entirely superseded by the steam-engine. When Watt's steam-engines first came into use, some of them, instead of being applied directly, as now, to work machinery, were used to raise water to turn a water-wheel, by which the machinery was impelled; and Papin's engine was proposed by him to be applied in a similar manner.

23. This source of power is not applied in the modern steam-engine; but, in the first forms the engine assumed—as in the engines of Newcomen, Savery, Leopold; and even in Watt's first engine (single acting)—it was a leading element. There were two ways in which it was taken advantage of:—*First*, In causing the descent of heavy bodies, as in Newcomen's, Leopold's, and Watt's first engine; *second*, In producing that constant force, acting on all bodies at the earth's surface, which we call atmospheric pressure.

A.—*Power from the Descent of Heavy Bodies.*

24. In Newcomen's, Leopold's, and Watt's first engine, this power performed the important, though secondary office, of restoring the parts to the proper situation for the exertion of the other or direct moving power. Indeed the descent of a heavy body can hardly be called a *source* of power (except in the case of a natural fall of water); for, as much force is

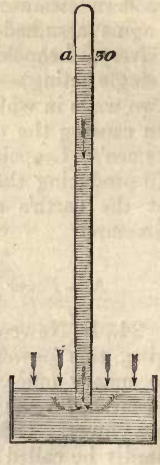
expended in raising the heavy body to the necessary height as is procured by its fall; so that there can be no gain of moving power.

B.—*The Pressure of the Atmosphere.*

25. That thin, light, attenuated, and invisible body, which surrounds the earth on every side, and which we call the air, or atmosphere, possesses the same property as other material bodies—that of gravity or weight. Hence it exerts a downward force or pressure on every substance at the surface of the earth; and though a light body, this force is considerable, as the air extends upwards to a height of about forty-five or fifty miles.

The amount of this force has been estimated with great precision. Take a stout glass tube, closed at one extremity, and about thirty-three or thirty-four inches long, and fill it with quicksilver; then, having the open extremity closed by the thumb, a cork, or any flat plate, so as to prevent the quicksilver escaping—invert it, and place the open end under the surface of the quicksilver in a vessel containing a quantity of this liquid. Now, withdraw the substance closing the lower end of the tube; immediately, the quicksilver will descend a little in the tube, leaving a vacant space at the top, and will soon become settled at a point (*a*) about *thirty inches* above the surface of the quicksilver in the lower vessel. The accompanying figure will illustrate this experiment.

Fig. 1.



26. Here, the quicksilver in the tube, contrary to the usual action of gravitation, which causes fluids communicating freely to come to the same level, remains considerably elevated above that in the lower vessel. There must be some force supporting it in that elevated situation. This power is the pressure of the air. The air is pressing with great force on the surface of the quicksilver in the lower vessel, and thereby tending to push the quicksilver up into the tube. There is nothing in the upper part of the tube pressing the quicksilver down; but the column of quicksilver, by its weight or force of gravity, is pressing downwards upon the quicksilver in the lower vessel, resisting the atmospheric pressure, and tending to descend in the tube, and come to a level with the quicksilver below. As these powers—the atmospheric pressure and gravity of the quicksilver—are the only forces acting, they must be equally balanced (in equilibrium) when the quicksilver has become stationary in the tube. This takes place when the column is about thirty inches high. In *Figure* 1, the arrows outside of the tube represent the force and direction of the atmospheric pressure, which, from the movability of liquid particles, communicates its pressure to the liquid at the mouth of the tube, as shewn by the curved arrows, evidently tending to push the liquid upwards into the tube, and resist its descent. The arrows within the tube represent the gravity of the quicksilver, acting in an opposite direction.

27. It may perhaps be remarked, that the pressure of the quicksilver in the tube is that of a narrow column only, while the air's pressure acts upon the whole of the exposed surface of the mercury below; and it may be asked, *how much of the air's pressure on the liquid in the lower vessel acts against the column in the tube?*—The weight of air which presses on the

surface of the liquid in the vessel is, evidently, that of a column of air equal in transverse section to the surface of the liquid, and reaching from it to the extreme limits of the atmosphere; and of this, the portion which acts against the column of quicksilver in the tube, is, *that of a column of air equal in transverse section to the orifice of the tube.* The two forces meet at that point, and may be said to be equal to columns of air and of quicksilver of the respective heights of each fluid, and equal in horizontal section, to that of the orifice of the tube.

28. We thus ascertain that a column of air, reaching from the surface of the earth to the extreme limits of the atmosphere, exerts the same downwards force as (is equal in weight to) a column of quicksilver thirty inches high. And if we suppose the horizontal section of the tube to be equal to a square inch, the column of quicksilver would weigh 14.7 avoirdupois pounds.* The pressure of the air which balances the quicksilver, must be the same in amount; and, as the pressure which is transmitted to the orifice of the tube is that of a column of air the same in section, a column of air a square inch in section must weigh 14.7 pounds; and the atmosphere must press with that force on every square inch of surface. Or, every square inch is as much pressed by the air as if, supposing there were no air, a weight of 14.7 pounds rested upon it.

29. The degree of pressure to which any surface is exposed from a gaseous body, is always spoken of by

* The specific gravity of mercury being reckoned 13.58. But the mean pressure of the air in this country is less than 30 inches of mercury—about 29.8 inches. If this estimate were taken, it would reduce the pressure on the square inch to 14.6 lbs. Few scientific works, however, have reduced it even to 14.7 lbs.; the rougher estimate of 15 lbs. to the square inch is more usually adopted.

stating the amount of pressure on the square inch. A force double that of the air is 29.4 pounds per square inch; half that of the air, 7.35 pounds per square inch. The term "atmosphere" is sometimes employed, to denote degrees of pressure—as, a pressure of "two atmospheres," meaning a pressure double that of the air—three atmospheres, ten atmospheres, an atmosphere and a half, and so on. To know the total amount of pressure exerted by a gas on any body, find the number of square inches in the surface on which the gas acts, and multiply this number by the pressure on each square inch. To find the number of square inches in a circular area, multiply the square of the inches in its diameter by .7854; or, multiply half the circumference by half the diameter. The area of a circle is a little more than three-fourths, and a little less than four-fifths of the square of the diameter.

30. The instrument which has just been described, (25,) is the common barometer, which is used to indicate variations in the pressure of the air; for, from some causes at present not well understood, its pressure varies. These variations, however, are within small limits, the mercury in this country seldom rising higher than 30.8 inches, or falling lower than 28.1 inches. Its mean height, at the level of the sea, is 29.82 inches. The barometer is a useful instrument for measuring the force of confined gases or vapours, as will be seen afterwards.

31. The space between the upper surface of the mercury (a) and the top of the tube, *Fig.* 1, is called a *vacuum* or void; meaning thereby an empty space, a space containing *nothing*, or, at least, none of the material bodies with which we are at present acquainted. A vacuum procured in this manner, is called the *Torricellian vacuum*—(36.) It is the only perfect vacuum; that of the air-pump and steam-engine not being quite free from elastic fluid.

32. As water is a much lighter fluid than quicksilver, it is supported in a tube much higher than the latter fluid. A column of water 33.87 feet high is required to counterbalance the pressure of the air. Accordingly, the surface of the globe is as much pressed by the air as if, in place of air, it were encircled with mercury to the height of 30 inches, or water to the height of 33.87 feet, above the level of the sea.

33. If, in the tubes described, filled with water to the height of 33.87 feet, or mercury for 30 inches, an opening be made at the top, so that the air is admitted to press on the upper surface of the liquid,—as the pressure of the air communicated from outside the tube, and which supported the liquid in that elevated position, *is now balanced* by the atmospheric pressure acting *directly* upon the liquid in the tube, and pressing it in an opposite direction,—the liquid will obey the law of gravitation, and descend till it come to the same level without and within the tube.

34. A good example of the action of atmospheric pressure is seen in the pneumatic trough of the chemist, in which, by taking advantage of this power, water is supported in jars far above the level of the water in the trough. The action of the sucker, or moistened leather with string, with which boys raise stones for amusement, depends on atmospheric pressure, which presses the leather to the stone with a force of 14.7 pounds on every square inch. When the nozzle and valve-hole of a pair of bellows are shut, it requires very great force to separate the sides, as the atmosphere presses them together with great force—(102.)

35. As air is composed of very fine particles, and exposed to great pressure at the surface of the earth, there is no situation in which it is not to be found, insinuating itself into all crevices, however minute, and rushing in on all sides, and filling up the vacant space when any body is moved. Or, if it be not itself

adjoining to the vacant space, it presses the adjacent bodies into it—hence the effects of *suction*, the syringe, the common pump for raising water, &c. There are few operations going on at the earth's surface which are not, more or less, influenced by atmospheric pressure.

36. The pressure of the atmosphere was discovered in 1643 by TORRICELLI, who also invented the barometer. The air-pump—a machine for withdrawing air from a vessel containing that substance—was invented by OTTO GUERICKE, a magistrate of Magdeburg, about the year 1650. It will be explained afterwards.

Application of the Atmospheric Pressure to produce Motion.

37. As every space above the surface of the earth is filled with air, or some substance which resists and balances its pressure, it cannot be taken advantage of as a moving power until we have procured a *vacuum*, or empty space—into this the air will press with great force.

38. If we introduce under quicksilver the extremity of a tube closed at both ends, containing no air* or other substance, and open the end under the quicksilver, the fluid will be pushed up in the tube to that height at which the gravity of the mercury will balance the pressure of the air—thirty inches; or water (had that liquid been used) to the height of thirty-three feet. If we place a thin plate of glass, or piece of bladder, air-tight, on the top of a glass cylinder open at both ends, and set the cylinder on the plate of an air-pump, with the closed end uppermost, the air, though pressing the glass plate downwards with a force of 14.7 pounds on every square inch of its surface, will nevertheless cause no motion or change, as the air

* The method of extracting the air from a vessel is described in par. 104.

in the interior resists and balances this pressure by its elasticity (102). But, if, by working the air-pump, the air be withdrawn from the interior of the cylinder, the exterior air will then crush the glass plate, and rush with great force into the interior of the cylinder. Or, had there been, in place of the flat piece of glass, a piston fitting air-tight to the sides of the cylinder, the atmospheric pressure would have forced it gradually down, as the air was withdrawn from the interior.

39. Here is a source of motion; but *how is the air to be removed from the interior of the tube or cylinder?* this being essential before the atmospheric pressure can be applied as a moving power. The process of extracting the air by the air-pump requires force, and there would therefore be no gain of power by removing the air in that way.

40. Take a glass flask with a long neck, and, having put a little spirit of wine in it, make the liquid boil, by holding it for a short time over a fire or spirit lamp. When the liquid is boiling briskly, having the hand protected by a thick glove, take the flask and invert it quickly, dipping the mouth under cold water. Immediately the water will be forced up with great violence into the flask; and it may even be forced out of the hand if the experiment be performed smartly, and the flask be not held very firm. In this experiment, the vapour arising from the boiling liquid gradually expelled the air from the flask, the vapour resisting the pressure of the air at the mouth of the flask. But when the flask was removed from the heat, and the vapour brought into contact with the cold water, it was rapidly condensed (returned to the liquid state). A sort of vacuum was thus formed in the flask, little resistance was offered to the entrance of any substance, and the atmospheric pressure forced the liquid up into the body of the flask.

41. Here is a *gain* of moving power from the atmospheric pressure; and this experiment is an exact representation of one part of Savery's steam-engine. Indeed, it is said that this experiment, performed by Savery with a little wine in a flask—accidentally suggested to him, from having thrown the flask on a fire, and seen the vapour issuing from its mouth—led him to the construction of his steam-engine. The same principle formed a leading feature in Newcomen's, or the atmospheric engine; the air was expelled by steam from a cylinder having a piston working in it, and the vapour being then condensed, the piston was pressed down by the atmospheric pressure on its upper surface. The latter contrivance was first suggested by Papin.

42. It is this power (atmospheric pressure) that turns the vanes of the windmill; that has been proposed to be applied to the purpose of locomotion in the "pneumatic railway;" and that raises the water in the common pump. Wind—the source of the moving power in the windmill—is produced by air rushing into spaces where the resistance of the air previously occupying these spaces has been diminished by the effects of heat—(101). In the common pump, the air is withdrawn from a tube dipping into the water to be raised, when the atmospheric pressure on the water exteriorly pushes it up into the tube, from which it is lifted by a piston working air-tight in the tube; and, as it ascends, fresh quantities of water rise. In the lately-proposed pneumatic railway, the air is withdrawn from a tube on one side of a piston, while the atmospheric air is freely admitted to press on the other side—thus motion is produced in the piston, to which the carriage is attached.

SECTION II.

REPULSION.

43. All substances contain, or have the power of producing a peculiar principle, which, applied to our bodies, excites the sensation called heat or warmth. The term "Heat" is used to express the sensation, and also the influence or substance (if it be a substance) which causes the sensation, the context shewing in which sense it is applied. To express the latter solely—the something which, coming from a fire to a person near it, causes the feeling of warmth—the term Caloric is sometimes used.

44. Caloric has the power of producing certain effects on bodies. When any substance has this power in a great degree (as a red-hot iron), it is said to be at a *high temperature;* at a *low temperature*, when in the reverse state (as a piece of ice); and the terms, *rise* and *fall* of temperature, are used in a corresponding sense.

45. Caloric has the power of moving about among bodies, and always tends to an equilibrium. *Bodies at different temperatures, placed in contact or near each other, soon come to the same temperature, the warmer bodies losing heat which the colder ones gain.* The particles of heat are highly repulsive of each other, so that they fly off with rapidity from any body in which they are accumulated in considerable quantity; but they have a great attraction for the particles of all other bodies, and enter rapidly into any body deficient in heat. This is well seen, when a hot iron, or vessel

of hot water, is placed near several other bodies at lower temperatures.

46. Coldness in any body does not arise from the total absence of heat, nor from the presence of a peculiar principle of an opposite nature, but simply from its containing comparatively little heat, so that it abstracts heat rapidly from other bodies. A cold substance applied to the skin takes away heat—a warm one communicates heat.

47. Equality of temperature would soon be established over the globe, from this tendency of heat to an equilibrium, but for three causes:—*First*, The sources of heat—whether natural, as the sun's rays and subterraneous heat, or artificial, as combustion—are unequally distributed and applied; *second*, While the passage of heat through bodies is not instantaneous, but requires time, they differ in the rate at which they transmit heat through them; and, *third*, Bodies differ in their powers of absorbing heat, and also in the degree in which their temperatures are affected by it.

CHAPTER I.

MANNER IN WHICH HEAT SPREADS.

Heat passes among bodies in two ways; by radiation and by conduction.

48. All bodies throw out (*radiate*) heat from their surfaces in straight lines, like radii from the centre of a circle. This mode of transmission of heat is called Radiation. The radiated heat moves in straight lines, till it strikes on some other body, when, according to the surface on which it strikes, it is *absorbed* and warms the body, or bounds off (is *reflected*) like a ball thrown

upon a wall—obeying the same laws of reflection as light and sound. In some cases, part is *transmitted*, that is, passes directly through the substance, without affecting its temperature.

49. Those bodies radiate most heat, and, of course, (other things being equal,) cool soonest, whose surfaces are dark, and of a rough and porous texture. Those surfaces which are bright, of a light colour, resplendent, and highly polished—as tin-plate, polished gold, brass, or silver—radiate little heat, and hence retain their heat long. Again, those surfaces which radiate most heat, absorb the greatest quantities of radiated heat; those which radiate least, throw off (reflect) the greater part of the radiated heat which falls upon them. The following table shews the comparative powers of various surfaces in radiating and reflecting heat.

Radiating Powers.		Reflecting Powers.	
Lamp-black	100	Brass	100
Water	100	Silver	90
Writing paper	98	Tin Foil	85
Rosin	96	Block Tin	80
Sealing Wax	95	Steel	70
Crown Glass	90	Lead	60
Ice	85	Tin Foil, softened by Mercury	10
Plumbago	75	Glass	10
Tarnished Lead	45	Glass, coated with wax or oil	5
Mercury	20		
Clean Lead	19		
Iron, polished	15		
Tin Plate	12		
Gold, Silver, Copper	12		

A polished surface of silver, if the metal were warm, would lose little heat by radiation, and would throw off the greater part of any radiant heat which might fall upon it. If covered with a coating of lamp-black, (by smoking it with the soot from an oil lamp or candle,) the metal would lose a great deal of its heat by radiation, and would absorb the greater part of the radiant heat which fell upon it. The application of these principles to preserve bodies warm or cool, and to the economizing of heat, is obvious. The cylinder of a steam-engine should be brightly polished, that it may lose little heat by radiation. Tubes containing steam, water, or heated air, for heating apartments, should be rough, dark, and porous in the apartment where it is intended that they should give out their heat; but bright and polished before they reach that place.

50. *Second*, Heat also passes from bodies by another mode. When a poker is put in the fire, the end out of the fire soon becomes warm; this is by the transmission of heat through its substance from particle to particle. In the same way in which heat travels along the particles of one body, it can pass between two bodies in contact. The transmission of heat in this way is called CONDUCTION.

51. Bodies vary much in their power of conducting heat—some transmitting it with great celerity, while others give it a very slow passage through them. Place a rod of wood and one of iron in a fire. The end of the iron rod not in the fire will be very hot long before the similar end of the wooden rod feels sensibly warm. The following table shews the comparative conducting powers of several bodies.

Gold . . .	1000	Tin	303
Silver . . .	973	Lead. . . .	179
Copper . . .	898	Marble . . .	23
Platinum . . .	381	Porcelain . . .	12
Iron . . .	374	Brick earth . .	11
Zinc . . .	363		

The powers of bodies in conducting heat, appear nearly in proportion to their densities. Loose, spongy substances—as fur, straw, cotton, silk, wool, are extremely slow conductors. Bad conductors take a long time to get heated, but lose their heat slowly, and hence are useful for confining heat, or excluding heat. Good conductors get quickly heated, and cool quickly. There are many interesting applications of our knowledge of these differences in the relative conducting powers of bodies, as clothing, lining for furnaces, ice-houses, &c.

52. Liquids and gases, whose particles are loose, and move freely on each other, transmit heat through their substance in the same manner as solids—but with extreme slowness, if the heat be applied at the upper part of the fluid. But they have another and very rapid way of conveying heat, *if the heat be applied below.* The heated particles rise, cold particles from above descending and pushing them upwards; these in their turn become heated and ascend, colder particles descending; and thus a set of cold descending and warm ascending currents is established, which continue till the whole fluid comes to one temperature. Heat, entering into a fluid, causes it to become larger, and, of course, lighter; and the cold and heavier particles above, necessarily descend and push the warm particles upwards. Thus the whole of the fluid is quickly heated—not by the transmission of heat from particle to particle, as in solids—but by the successive application of every part of it directly to the source of the heat. Whenever a fluid is heated currents ensue. Hence the wind (42); hence the removal of the warm and foul air expired from the lungs of animals, and the supply of fresh air to support their respiration; hence the removal of the noxious air formed by burning bodies, and the supply of pure air to keep up the combustion; hence ventilation—the most perfect method of which yet devised (that introduced into the House of Commons by Dr. D. B. Reid) consists simply in *ensuring a current* by a strong fire in a tall chimney,

the room to be ventilated being in the course of the current of fresh air which rushes to the fire in the chimney.

CHAPTER II.

EFFECTS OF HEAT.

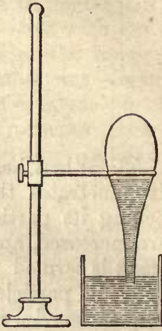
53. When heat enters a body, it makes it larger.* It penetrates through its entire substance, and, repelling its particles from each other, their distances are increased, and the body is enlarged in bulk. This effect is termed EXPANSION. When heat leaves any body, its particles approach to each other, and its bulk is diminished—an effect termed CONTRACTION. When solids are sufficiently heated, they melt, or become liquid—a change termed LIQUEFACTION; and when liquids are heated to a great degree, they become gaseous, like steam or the air—to which change the term VAPORIZATION is applied. It is, simply, a very great degree of expansion, but attended by a change in form. Liquids become solid again (congeal,) and vapours turn liquid (condense,) when they are cooled sufficiently. Heat also appears to be the cause of the ELASTIC POWER which aerial bodies possess at all temperatures, however low.

* There is no real exception to this general rule. Some bodies—as ice, iron, antimony, zinc, bismuth—diminish in bulk when they melt, from losing their crystalline form.

CHAPTER III.

EXPANSION.

Fig. 2.



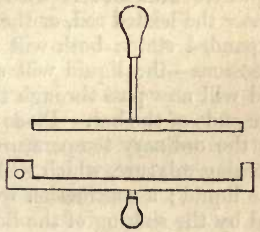
54. This may be illustrated by a very simple experiment. Take a common glass flask, about half full of water, which may be coloured to be better seen, and invert it in a vessel of water, the open mouth of the flask being a little under the surface of the water, as seen in the adjoining cut. Then pour hot water on the flask. The heat from the water will enter the cold glass, and from it will pass to the air occupying the upper part of the flask. The air thus heated will acquire increased elastic force, and expand (increase in bulk). Pressing on the water, it will cause it to descend in the neck of the flask. If the heat be great, and the quantity of water in the flask small, the liquid will be forced entirely out of the flask, and perhaps also some bubbles of the air may be expelled. Or if, when the air has been expanded to any bulk, its temperature be then kept stationary, it will remain at that bulk as long as it continues of the same temperature. The same is true of liquids and solids.

55. Here is a force or moving power procured by heating a gaseous body. This is the source of motion in an engine lately invented by Mr. Ericsson, which he has called the *Caloric Engine*—heated air pressing a piston in a cylinder, as in the steam-engine. This

is also taken advantage of in Howard's vapour engine to increase the elastic force of the steam before it is applied to effect the motion. After leaving the boiler, it is heated by contact with the flue containing the heated air from the furnace, by which a further degree of expansive force is imparted to it.

56. Take a glass tube, closed and expanded into a bulb at one end, the other being open; fill the bulb and part of the tube with spirit of wine, which may be coloured with cudbear, that the experiment may be well seen; plunge the bulb in hot water; the heat, expanding the liquid in the bulb, will cause it to press up the liquid in the stem, in which it will be seen gradually rising.

Fig. 3.



57. Take an iron rod (as in *Fig.* 3) of such length that, when cold, it will just enter between two projections at the ends of an iron bar, and of such diameter as to enter closely a circular hole in the bar. Heat the iron rod to a red heat; it will now have increased in length, so that it cannot be made to enter between the two projections; and its diameter will be enlarged, so that it is too thick to pass through the hole.

58. Had the iron rod been immovably fixed at one end, and a movable body placed in contact with the other extremity, the rod, when heated, would have pushed the movable body aside, to a distance corresponding to its own increase in length, a moving power being thus obtained. The force with which this expansion takes place, is very great, equal to the force with which it would contract on cooling (15). Had

the rod been immovably fixed at both ends, it would have become bent, to adapt itself to its expanded condition. These effects are often seen in structures where metals are used, and particularly in iron work about fire-places, where allowances have not been made for alterations of temperature, in the bending of the bars or disjointing of the stone or brick work to which they are fixed. In laying railway bars, allowances must be made for expansion and contraction attending alterations of temperature.

59. This enlarged condition of bodies remains while the caloric which caused it remains; when this leaves them, they return to their former size, the cohesive attraction taking greater effect in proportion as the repulsive influence is withdrawn. Plunge into cold water the heated rod, or the bulb with the liquid in its expanded state; both will return to their former dimensions—the liquid will sink in the tube, and the rod will now pass through the hole and enter between the ends of the bar. Place the bulb of the tube, when at the ordinary temperature of the atmosphere, in a freezing mixture, which will withdraw much heat from the liquid; a contraction will ensue, as will be indicated by the sinking of the liquid in the stem.

60. In these cases, we see the opposing action of the *cohesive* and *repulsive* powers. The former was overcome to a certain extent by the heat when the bodies were expanded, but resumed its influence, and drew the particles back to their former distances, when they were deprived of the heat which caused the expansion.

61. The heated gas also (54), when cooled, returns to its former volume, and the liquid ascends in the flask. It is more correct to say, that, as the heat leaves the gas, the liquid, forced up by the atmospheric pressure, ascends and compresses the gas to its previous dimensions. Gases are considered to have

no cohesive attraction, their particles being at such distances as to be without the sphere of this influence; *and they do not diminish in volume except from the action of some external force upon them.* This will be better understood after the perusal of Chapter IV. of this section, on the elasticity of gaseous bodies.

The Thermometer.

62. As expansion is the invariable effect of heating bodies, and a proportionate contraction ensues when they are cooled, the bulk of a body at any time is in proportion to its temperature at that time; and we may estimate its temperature by measuring its bulk. And, as two bodies always come to the same temperature by being for a short time in contact, or near each other (45), we may use *one* body as an instrument for taking temperatures; having the means of measuring the bulk of this body, we know its temperature, and the temperature of any substance to which it is for a short time applied. Hence the THERMOMETER.

63. This instrument consists of a glass tube similar to that mentioned in par. 56, but closed at the upper extremity, and having the bulb and a part of the stem filled with quicksilver or coloured spirit of wine—the substance the expansion or contraction of which is to be noted. There is a graduated scale attached to the tube, by which the height (and thereby the bulk) of the liquid is indicated.

64. The bulb is applied to the body of which the temperature is required. If it be warmer than the thermometer, heat will pass to the latter, and cause expansion in the liquid; and when they come to the same temperature, the liquid will become stationary. The bulk now occupied by the liquid, indicates its temperature, that indicating the temperature of the

body to which it was applied. If the body be colder than the thermometer, heat passes from it to the latter, when the liquid contracts, and sinks in the stem till they come to the same temperature. The diminished bulk of the liquid indicates its temperature, and that of the body which caused the contraction. Thus this useful instrument shews the comparative temperatures of bodies.

65. It is necessary, in speaking of different temperatures, that there be some fixed points or standards of reference, by which different degrees of temperature may be compared: so that, when any particular temperature is spoken of, it may be known precisely what is meant. Very convenient fixed points for this purpose are found in the temperature at which water freezes (or, which is the same, that of melting snow or ice,) and that at which it boils.

66. If a thermometer be placed in a vessel containing a quantity of snow and water, or in the water flowing from melting snow or ice, and the height of the liquid marked, it will be found to stand at that point as long as any snow remains unmelted (if kept near the snow;) and at whatever time or place the experiment be made, the liquid in that thermometer will always stand at the same point.

67. If the same thermometer be placed in boiling water, the liquid will rise in the stem until it reaches a certain point. There it will remain as long as the thermometer is kept in the boiling water; and at whatever time or place the same experiment be performed with the same thermometer, the liquid will stand at the same point as before.* If the same experiments be performed with any other thermometer,

* Not strictly true. The cause and extent of the variation, which is slight under ordinary circumstances, will be explained afterwards.

the same uniformity of temperature will be found in these two operations—the melting of ice or snow, and boiling of water. As the thermometer, when placed in water freezing, stands at the same point as in ice or snow melting, this point is called the *freezing point;* the other is termed the *boiling point.*

68. Here, then, are two constant degrees of temperature, two fixed points, easily ascertained, and to which reference can be made for comparing different temperatures. These are now universally adopted for thermometers; and the scale of degrees is numbered in the following manner:

69. On the scale at the side of the thermometer tube, the *freezing* and *boiling* points are marked. The space between them is then divided into a certain number of equal parts, called "degrees." In the thermometer in general use in this country, (Fahrenheit's) this space is divided into 180 degrees. To indicate higher and lower temperatures, the scale above and below these points is divided into degrees similar to those between the two fixed points. Fahrenheit imagined that the most intense cold which could be produced was when the liquid in the thermometer stood 32 degrees below the freezing point; accordingly, he numbered the degrees from the supposed point of greatest cold, calling it *Zero.* Thus, the number 32 is opposite to the freezing point, and 212 (180 + 32) opposite to the boiling point. 32 is familiarly known as the freezing point; 212 as the boiling point. For the numbers below zero, the sign — (minus) is used. Thus, — 10 (minus 10) signifies 10° below zero, or 42° below the freezing point.

70. In the Centigrade thermometer, much used on the Continent, a better division is adopted. The degrees are numbered from the freezing point, and the space between it and the boiling point is divided into

100 degrees; the boiling point being thus 100. One degree in the Centigrade thermometer is equivalent to 1.8 or $1\frac{4}{5}$ of a degree in Fahrenheit's thermometer. In Reaumur's, used in some parts of the Continent, the distance between the freezing and boiling points is divided into 80 degrees, and the scale commences at the freezing point.

71. As the degrees are equal to each other, and an equal increase of temperature causes an equal expansion, it will cause the liquid to ascend through an equal number of degrees; and different thermometers will give the same indications with the same temperature, however different the distances between the two fixed points and size of the degrees; for that distance is divided into the same number of degrees in all; so that, in all, the proportion of the degree to the bulk of the liquid and to the distance between the fixed points, is the same. The greater, however, the mass of matter in the thermometer to be heated or cooled, the longer time it requires to take up the temperature of the body to which it is applied.

72. The spirit-of-wine thermometer is used for low temperatures, as this liquid has never been frozen. It cannot be used for temperatures above 174°, as it boils at that temperature. The mercurial thermometer is used for considerably elevated temperatures, as quicksilver does not boil till 662°. It cannot be used for temperatures below —39°, as it freezes at that point, then contracting at a different rate.

Rate of Expansion in Bodies.

73. The following table exhibits the amount of expansion in different bodies, when heated from the freezing point of water (32°) to the boiling point (212°).

Elongation of Bars, Rods, or Wires.

Lead	1-351st.
Silver	1-524th.
Copper	1-581st.
Brass	1-532nd.
Gold	1-602nd.
Iron wire	1-812th.
Bar iron	1-819th.
Hard steel	1-927th.
Platinum	1-1167th.
Flint glass	1-1248th.

74. A bar of lead 351 inches long at 32°, becomes 352 inches at 212°. Besides this increase in length, it increases in breadth and thickness. To find the total expansion, place 3 as the numerator of the above fractions, or, retaining the same numerator, divide the denominator by 3.

75. The expansion of the following liquids, heated through the same range, (32° to 212°) is seen below. The expansion in bulk, or total expansion, is stated. The two first are taken from different points; as spirit of wine boils at 174°, and oil freezes about 36°.

Spirit of wine (8° to 174°)	1-9th.
Whale oil (60° to 212°)	1-11th.
Oil of turpentine	1-14th.
Water	1-22nd.
Quicksilver	1-55th.

76. All gases and vapours expand equally through the same range of temperature. Their expansion is very great. 1000 volumes of any gas at 32°, become 1375 volumes at 212°—expanding 3-8ths; or 1-480th for every rise in temperature of one degree of Fahrenheit.

77. Thus, in expanding bodies, heat produces the least effect upon solids, a greater effect on liquids, and has a still greater expansive power in gases. Also, while all gases undergo the *same expansion* from an

equal increase of temperature, it is very different with solids and liquids; the same rise in temperature causes *different degrees of expansion* in different solids and liquids.

78. The reasons for these peculiarities, are, the differences in the strength of the cohesive attraction in solids and in liquids, and the absence of it in gases. In expanding solids, heat is resisted by the cohesive force, which is strong in them—hence it produces a small effect. The particles of liquids are less firmly bound by cohesion, and the same increase of heat, having less cohesion to overcome, produces a greater expanding effect than in solids. The cohesive force appears to be entirely suspended in gases; heat is not resisted in its expanding power, and a great increase in bulk is produced by a small rise in temperature. The cohesive force being different in solids, and also among liquids, each opposes a different degree of force to the efforts of heat to expand them. Hence the unequal expansion of solids and of liquids through the same range of temperature. In gases, where this force is absent, the same increase of heat produces the same expansion in all.

CHAPTER IV.

OF THE ELASTICITY OF GASEOUS BODIES.

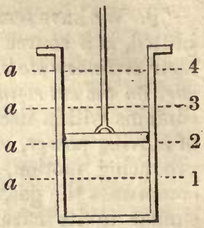
79. We have seen that the expansion of gases, when heated, is a source of moving power. *But gases in their ordinary state, at all times, exert a force or pressure on the surrounding bodies.* Every gas or vapour contains within itself a source of expansion, and hence of moving power, which is prevented from acting and producing motion, only by some other force which compresses the gas, and thus resists its action. It is similar in its nature to a compressed or wound-up spring. Its particles are constantly pressing outwards on each other, and upon the bodies around them, *and the gas is continually endeavouring to swell out in all directions, and occupy a larger space.* This power of gaseous bodies is termed their *elasticity*, *elastic power*, *or elastic force.*

80. This remarkable property of gases, which is peculiar to them—liquids and solids not possessing any such power—most probably arises from the distances of their particles, which are thus without the sphere of the cohesive attraction, so that no resistance is offered to the repulsive power of the great quantity of heat they contain, which is constantly exerting upon them its usual action—that of repelling their particles asunder. Hence, the consideration of this elastic power of gases has been placed beside the other phenomena of heat

81. Place a rather flaccid bladder in the receiver of an air-pump, and withdraw the air from the interior of the receiver; the air in the bladder will expand in proportion as the pressure upon it (from the surround-

ing air in the receiver) is diminished by the withdrawing of the air; the bladder will swell, become full and distended, and even be burst by the expansion of the contained air, if the vacuum be very complete, or the bladder have been nearly full of air.

Fig. 4.



82. In the adjoining figure, (*Fig.* 4,) shewing the section of a cylinder, with a piston moving freely but air-tight, if the space in the cylinder below the piston were filled with lead, or iron, or any other solid, and the piston were raised, the solid would remain in exactly the same situation as before, being retained by the force of gravity and the cohesion of its particles; and the space between the solid and the piston would be a vacuum. With a liquid in the place of the solid, the same would take place; the liquid would remain if the piston were raised.*

83. But if the space below the piston had been occupied by any gas or vapour, then, on elevating the piston, *the gaseous body would follow it; there would be no vacuum; the gas would expand and be equally diffused through the whole space between the lower surface of the piston and the bottom of the cylinder.*

84. This elastic force of gaseous bodies is resisted by the pressure to which they are exposed; and, therefore, these forces must be equal to each other in any gas which is in a quiescent state. Thus, in an apparatus such as *Fig.* 4 represents, if the piston be at rest at some distance from the bottom, it is clear that the

* A little vapour would rise from volatile liquids, as ether, spirit of wine, water, and be diffused through the space between the piston and the surface of the liquid; but the mass of the liquid would remain in its previous situation.

gas confined below the piston is pressing it upwards (the resistance from friction being disregarded) with a force exactly equal to that with which the piston tends downwards from its own weight, and that of any bodies resting upon it. In *Fig.* 4, if the piston be at rest in the situation *a* 2, and the force with which it tends to descend be equal to a weight of ten pounds, then the force with which the gas below presses upwards on the piston, is also equal to a weight of ten pounds. Hence, then, *the elastic force of a gas is exactly equal to the force by which it is confined.*

85. If the piston have now additional weights equal to ten pounds laid upon it, it will descend till the gas occupies only half the space through which it was at first extended; then (at *a* 1) it will remain at rest. Here, while the same quantity of gas is diminished in bulk to one-half, the force with which it presses the piston upwards is doubled, for it now supports a weight of twenty pounds. But when a given quantity of a gas is *diminished in bulk*, *its density or specific gravity is increased.* In this case, the density has been doubled, at the same time that it supports a double force. Hence, then, *the elastic force of a gas is in direct proportion to its density*, *and inverse proportion to its bulk* —that is, its elastic force increases in the same proportion in which its density is increased, or its bulk diminished.

86. This important general proposition might also be illustrated in the following ways.

87. If five pounds had been taken off the piston while at rest in the situation *a* 2, it would be forced up by the elasticity of the gas to the situation *a* 4. Here, while the volume of the gas is doubled, its density and elastic force are diminished to one-half, for it is now diffused through twice the space, and supports only half the weight.

88. If one half of the gas had been withdrawn while the piston was in the position *a* 2 and its weight equal to ten pounds; thedensity of the gas being thereby reduced one-half, its elastic force would be reduced in the same proportion, and the piston would descend to *a* 1. In this situation, the density of the gas is now the same as before any was withdrawn, and the force it now exerts against the piston is also the same.

89. If, instead of withdrawing gas, a quantity were forced in equal to what was there before, the piston (still loaded to the amount of ten pounds) would be forced up to the situation *a* 4. Twice the quantity of gas being diffused through twice the space, its density remains the same, and therefore its elastic force is also the same, or equal to a force of ten pounds pressing the piston upwards.

90. If, when this additional quantity of gas was forced in, the piston were loaded with an additional weight of ten pounds, it would have remained at *a* 2. The density of the gas being double, its elastic force is double, and it resists a double compressing force.

91. In all these cases, we have supposed the pressure downwards on the piston to be entirely within our control, and disregarded the atmospheric pressure, which would constantly press the piston downwards, with a force equal to a weight of 14.7 pounds on every square inch of its surface. For performing the experiment, the friction and atmospheric pressure might be neutralized by a counterpoise, attached to the piston by a cord passing over a pulley.

92. The following table will illustrate this general law of the constitution of gaseous bodies. Let the volume and elastic force of any given quantity of a gaseous body be represented each by the number 1, while the density is 1. With alterations of the den-

sity, the following will be the corresponding alterations of the volume and elastic force.

Density.	Volume.	Elastic Force.
1	1	1
2	$\frac{1}{2}$	2
3	$\frac{1}{3}$	3
10	$\frac{1}{10}$	10
$\frac{1}{2}$	2	$\frac{1}{2}$
$\frac{1}{4}$	4	$\frac{1}{4}$

This relation between the density and elasticity of aerial bodies, is known by the name of "the law of Marriotte," that philosopher having pointed it out. Till lately, it was supposed not to apply in high pressures; but, from the experiments of Oersted, it was found to hold with pressures so great as 110 atmospheres, and is probably universal.

93. It is to be understood as a condition in the preceding experiments, that the temperature is the same in all. Any increase in temperature increases the elastic force (54,) while this is diminished in a corresponding degree by a reduction of temperature. In any gaseous body, temperature and density remaining the same, the elastic force is also the same; and any change in either determines a corresponding change in the elastic force.

94. As gaseous bodies are thus capable of being drawn out by relieving them from pressure, and compressed by increasing the pressure, they are frequently termed *elastic fluids*, in opposition to liquids, which possess this property in a very slight degree. Water was for a long time supposed to be quite incompressible—it is almost so; its diminution in volume being only 51.3 millionths (about 1-20,000th) for every atmosphere of pressure, as determined by the experiments of Oersted and others.

95. It must be observed that this elastic force of a

gas is totally different from its weight or gravity, and in effect much greater. A hundred cubic inches of air weigh only 31.0117 grains: a column of atmosphere of one square inch transverse section, has only a weight (downwards force) of 14.7 pounds. The pressure from its weight is thus small; but its elasticity is comparatively very great, as may be easily illustrated.—The atmospheric pressure would force 14.7 pounds of mercury (30 cubic inches) into a tube of one square inch transverse section from which the air had been previously exhausted, on opening it under mercury (38). But if the tube were full of air, and the open end then plunged under the surface of the mercury, not a particle would enter, if the tube were held quite perpendicular. *Now, supposing the tube to be about* 30 *inches high, about* 10 *grains weight of air would fill it, completely resist this atmospheric pressure, and prevent the mercury from entering.* It cannot be the weight of this small quantity of air which resists a force of 14.7 pounds, about 10,000 times its own weight—it must be some other power, so that, here, the elastic force of this trifling quantity of air balances the force produced by the weight of a whole column of atmosphere of the same area.

96. In like manner, any quantity of air, however minute, introduced into the space above the mercury in the barometer tube, would, by its elasticity, exert a certain influence in resisting the atmospheric pressure, and depress the liquid in the tube. Hence an important application of the barometer. If the space above the mercury in a barometer tube communicate with a vessel containing any gaseous body, we can ascertain the elastic force of that body. It will depress the mercury in the tube, and, by noting the difference between the height of the mercury in this tube, and its height in another having no gaseous fluid above the

mercury (the common barometer,) this difference will express the elastic power of the gas pressing on the upper surface of the mercury. For every inch of difference, we may allow 0.49 pounds (3,430 grains) of pressure on the square inch to the gas which depresses the quicksilver. Thus, if the difference be four inches, the elastic force of the gas is 1.96 pounds on the square inch. In this manner, the barometer is used in the common air-pump, and in the condenser of the steam-engine.

97. On the other hand, if the gas be of an elastic force greater than the atmospheric pressure, the barometer is made in the form of a U, (see *Fig.* 15,) one end communicating with the gas, the elasticity of which is to be measured, the other being open, and of course exposed to the atmospheric pressure. When the elastic force of the gas is exactly equal to the atmospheric pressure, the mercury will be at the same height in both limbs of the tube; and when the elasticity of the gas exceeds the atmospheric pressure, the mercury will be depressed in the limb communicating with the gas and raised in the other. The difference in level of the mercury in the two limbs, will express the *excess of the elastic power of the gas over the atmospheric pressure.*

98. As the air at the surface bears the compression of a force of 14.7 pounds on every square inch, its elastic force must be exactly equal to the compressing power, 14.7 avoirdupois pounds on every square inch of surface; on every side, above, and below, as this elastic power knows no distinction of up and down. This pressure is frequently in round numbers, termed 15 pounds. For small quantities, the difference is not important; but it makes a considerable difference on high pressures. The true number is 14.6 pounds: see note, p. 14.

Gaseous Elasticity as a Moving Power.

99. Let us suppose a cylinder with a movable partition in the middle, and filled with air or any other gaseous fluid. Let this partition be light, fitting closely to the sides, so that no gas can pass from one side of the partition to the other, and at the same time capable of free motion within the cylinder. Now, if there be equal quantities of the same gas on each side of the partition, and the different portions be at the same temperature, the partition, being equally pressed on each side, will remain exactly in the middle. If, in this state of things, some of the gas be withdrawn from one cavity, the density of the gas remaining in that cavity being thereby reduced, its elastic force will be less; and the gas on the other side, now being less resisted, its particles will obey the impulse of their elasticity, motion will take place, and the partition will be pressed towards that side from which the gas was withdrawn.

100. Here is a moving power gained by withdrawing some of a gas pressing on one side of a body, while there is a quantity of confined gas on the other side. Power procured in this manner, is used in those of Watt's engines, called "expansion engines," with the view of economizing the steam.

101. The same effect would take place, were the gas in one cavity reduced in temperature, or the temperature of the other portion raised. Thus, a confined gas may be made a source of moving power in two ways:—*First*, by increasing its temperature; *second*, by removing some of the pressure by which it is confined. And the latter may be done in two ways when the pressure arises from a gaseous body:—*First*, Reducing its temperature; *second*, Withdrawing some of the gas. When the gaseous body to be withdrawn is a vapour,

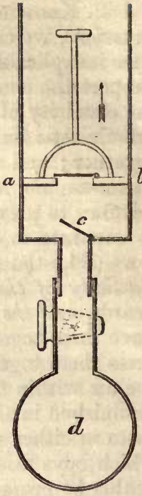
this may be done in the way described in paragraph 40, called condensation, which will shortly be explained more fully.

102. Knowing that the air possesses *elasticity* as well as *weight*, we can understand many phenomena otherwise inexplicable. Hollow vessels containing air (38) support the enormous pressure of the external air, by the elasticity of the air within. Were not air, or some other elastic fluid, within, their sides would be crushed together; and we shall see that, in the boiler of the steam-engine, it is necessary to have a particular contrivance to prevent this occurring. When we attempt to separate or press together the boards of the bellows (34,) the nozzle and valve hole being shut, the *elasticity of the air within*, tending to separate the boards, *and the pressure of the exterior air*, tending to force them together, are equal at first; but, when we press them together or separate them, the elasticity of the air within the bellows is increased in the first case, diminished in the second, and force is required to keep them in either state. In the case of the sucker with which boys raise great weights (34,) if the moistened leather be properly applied, there is no air between the leather and the stone, so that the atmospheric pressure is not resisted in its pressure on the leather.

103. The elastic power of air is taken advantage of in many machines—as Hero's fountain, the hydraulic ram, the air-vessel for producing a continuous stream in the force pump and bellows for blast furnaces, the air-gun, common lifting pump, condensing syringe, and air-pump. The latter, an important part of Watt's steam-engine, we shall now shortly describe.

The Air Pump.

Fig. 5.



104. The air pump is a machine for extracting the air from a vessel, a more difficult operation than might at first be supposed. Its action depends on the elastic property of the air to be removed. It will be understood from the annexed *Fig.* (5,) and description. Let *d* be the vessel to be exhausted of air. Let it be connected with a cylinder having a valve *c* opening upwards, and a piston *a b* with with one valve (or two) also opening upwards. Let the vessel *d* and the cylinder contain air of the usual elasticity, and the piston be near the top of the cylinder. Now press down the piston—the air in the cylinder being thus condensed, will press and keep shut the lower valve *c*, and, when it has sufficient elastic force, will press open the valve in the piston and escape. Let the piston be pushed to the bottom of the cylinder—all the air it contained will thus be expelled. Now raise the piston to the top of the cylinder: in the figure, the piston is represented ascending. Whenever the piston is raised, there will be a vacuum between it and the valve *c*, and, therefore, no pressure on the upper surface of the valve *c;* the air in *d* will therefore force it open and rush into the cylinder, and when the piston is at the top, *the air formerly in* d *will be diffused through* d *and the cylinder.* Thus a quantity of air has been removed from *d*, and, from the construction of the valve *c*, it cannot return. Also, no air can

enter the cylinder from without, as the piston valve is kept shut by the atmospheric pressure, a much greater force than that of the now rarified air pressing on the lower surface of the piston valve. Push down and raise the piston as before, and repeat this often. The air in the cylinder will be expelled as before, and the remaining air in *d* will divide itself between *d* and the cylinder, and so on—no air ever returning into *d*, as the valve *c* opens outwards. This may be continued until the air in *d* is of such weak elasticity as to be unable to push up the valve *c*. Hence, in some air-pumps, there are contrivances for lifting the valves by the power that works the pump; and in others the air is withdrawn without the aid of valves. The above, however, is the plan adopted in the steam-engine.

CHAPTER V.

VAPORIZATION.

105. It is an invariable effect of heat, then, to enlarge the dimensions of any body into which it enters. But this enlargement, in ordinary cases, is not great; gases, which expand most, must be heated through a range of about 480° Fahrenheit before their bulk be doubled.

106. There is one case, however, in which heat does produce a very great increase of bulk—*when it causes a liquid to pass to the gaseous or aerial state;* as when water boils (becomes steam). Here there is not only expansion, far greater in amount than in the former cases—there is also a change in the form or condition

of the body; it is now an elastic fluid (94,) light, eluding the sense of touch, and, in most cases invisible.

This change is called VAPORIZATION, and the elastic fluid into which the liquid is converted is called a VAPOUR.

A.—*Vaporization as a Moving Power.*

107. Take a flask, such as that represented in *Fig.* 2, and pour coloured water into it till it is almost full, leaving room for a tea-spoon full of ether, which is then to be added; then, closing the mouth of the flask, invert it, make the mouth dip under water, remove the substance closing the mouth, and get it properly supported in that position. The ether, being a light liquid, and not mixing with water, will ascend to the upper end of the flask, resting on the surface of the water. Now, pour boiling water on the flask: almost instantaneously, the ether will expand enormously, become a gaseous body, transparent and colourless, press down the water, and occupy a large part of the flask.

108. Here is a force or moving power obtained by the conversion of a small bulk of liquid into a vapour occupying a far greater space. This experiment illustrates the methods which De Caus and Lord Worcester proposed as a means of raising water, and the power used in modern steam-engines; and it is an exact representation of one part of Savery's engine.

109. Most gaseous bodies are invisible. Chlorine has a pale yellowish-green colour, and the vapour of iodine is of a fine violet hue. That the vapour of water is invisible may be seen by boiling a little water in a glass flask. The vapour between the surface of the liquid and mouth of the flask, is clear, transparent, and colourless: it is only after it is fairly out of the

flask, and is cooled and partly condensed by the cold air, that it assumes an opaque and white or grey appearance, like a cloud.

110. This phenomenon takes place with almost all liquids, when they are sufficiently heated; but at different temperatures, each having a boiling point peculiar to itself. Also, they expand differently when vaporized. The following table shows the boiling points of several liquids; the bulk of the vapour into which they expand; and the specific gravities of these vapours—that of air at 212° being 1.

	Boiling Point.	Bulk of Vapour.	Specific Gravity air, at 212° = 1.
Water . .	212°	1696*	0.623
Spirit of Wine .	174°	493	1.603
Sulphuric ether .	96°	212	2.586
Oil of Turpentine .	316°	192	5.013

The expansion of water is very nearly one cubic inch into one cubic foot (1728 times its former bulk.)

111. Vapour rises from most liquids at all ordinary temperatures, even at temperatures far below their usual boiling points; but it comes from the surface only, when the temperature is below the boiling point of the liquid.

112. The temperature of the vapour is the same as that of the liquid from which it arises, as may be easily seen, by holding a thermometer in boiling water and then in the steam arising from it.

113. Vapour is raised, and sustained in that state, solely by the influence of heat, not at all by the

* The estimate of the increase in bulk is calculated from the greatest density of water, which is at 39.39 Fahrenheit.

traction of the air, as was at one time supposed; and the quantity of vapour which can exist in any given space bears a certain proportion to the temperature (129, &c.)

B.—*Return of Vapours to the Liquid State.*

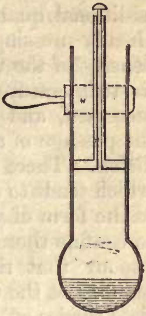
114. Vapours, when the heat which caused them to be in that state is withdrawn, return to their former bulk (the bulk of the liquid from which they were raised), and to the liquid condition. This phenomenon is called *condensation.* It is seen when steam, issuing from a boiler, strikes on any cold surface. The steam is condensed, and returns to the state of water, appearing in small globules. The heat being withdrawn by the cold body, the cohesive attraction resumes its influence, draws and retains the particles in contact, so as to form water.*

115. The colourless nature of steam, its formation, and condensation, are well shewn by a beautiful apparatus, devised by Dr. Wollaston. The annexed figure illustrates it. A glass tube is formed into a bulb at

* Thus, there are two great antagonist powers operating between the particles of matter: the influence of heat, or repulsion, tending to separate them and make bodies occupy a large space; the attraction of cohesion, tending to draw the particles of bodies closer and closer to each other, and to reduce them in bulk. When there is little of the repulsive principle present, as in ice, the attractive principle operates powerfully, and the particles are firmly bound together in the form of a solid. When the ice is heated, the heat, to a certain extent, overcomes the cohesive attraction, and the particles are loosened and become movable on each other, as in water; and, when a large additional quantity of heat is infused, the cohesive principle is overcome, and, the repulsive principle being predominant, the particles are driven far asunder, in the form of steam. Reverse these operations, and we have the steam successively passing to the state of water and ice.

one end, and has a piston within, which, with its rod, is perforated. There is a screw at the top of the piston rod, by which the aperture in the piston-rod may be opened or shut at pleasure. A little water being introduced into the bulb, it is made to boil, and, when the air has been expelled, the opening in the piston is shut. Then, if the heat be continued, and more steam formed, it will raise the piston; on allowing the tube to cool, the steam will be condensed, and the piston will be depressed by the atmospheric pressure. It will be seen that the steam, unmixed with air, is perfectly clear, transparent, and colourless.

Fig. 6.



116. The prodigious expansion of water when vaporized (a cubic inch to a cubic foot), the great reduction in bulk when condensed (a cubic foot to a cubic inch), and the ease with which steam is condensed, are the properties which render water so valuable as a means of procuring force or moving power.

C.—*Influence of Pressure on Vaporization.*

117. We have seen that pressure resists the endeavours of gases to expand (84, &c.); in like manner, pressure upon the surface of any liquid opposes the expansion of its particles into the gaseous state, and, in proportion as the pressure is great, a higher temperature is required to overcome it, and cause part of the liquid to expand into vapour.

118. When a quantity of a liquid is exposed to heat in a confined space, from which the vapour that rises cannot escape, this vapour, by its elastic power

(79), will press upon the surface of the liquid, and oppose the further vaporization of the liquid. If the heat be increased, this force will be overcome and an additional quantity of vapour will be added to that already pressing upon the surface of the liquid. The density of the vapour being thus increased, as well as its temperature (93, 101), its elastic force is further increased, and it now resists with still greater force the passage of any of the liquid into the aeriform condition. There is thus a struggle between the heat, which tends to repel the particles of the liquid asunder, in the form of vapour, and the pressure, which tends to confine these particles in a small space. When the vapour that rises is not confined, the temperature remains at the usual boiling point, as the steam that rises carries off the heat as fast as it is infused into the liquid—but when the vapour is not permitted to escape, the heat added remains in the liquid and in the vapour above it, and raises their temperature.

119. Thus, by exposing liquids to heat, in confined vessels, we may procure vapours of any density, and, hence, of *any degree of elastic force*, compatible with the strength and power of sustaining heat of the vessel, on the interior of which it thus exerts what is called a BURSTING PRESSURE.

120. Hence, liquids vary in their boiling points with the pressure to which they are exposed. In elevated situations, (as the tops of high mountains, the cities of Quito and Mexico, where the pressure of the atmosphere is less—less by the amount of atmosphere beneath the elevation,) water boils at lower temperatures than on low plains, where subjected to the pressure of the whole atmosphere. A change of one degree of Fahrenheit in the boiling point of water, indicates a change in elevation of 530 feet; or, a variation of 1.76° Fahrenheit, in the boiling point of water, takes

place with a change of one inch in the height of the barometer, between the limits of 26 and 31 inches. In the vacuum of an air-pump, liquids boil at about 140° Fahrenheit lower than when exposed to the ordinary atmospheric pressure.

121. At Quito, 9542 feet above the level of the sea, water boils at 194° Fahrenheit. At Geneva, about 1200 feet above the level of the sea, water boils at 209.4° Fahrenheit.

122. In the *Digester*, on the other hand, which is merely a stout metallic vessel (copper,) like a boiler, with a fixed lid and a stopcock attached to the tube for emitting the steam, by confining the vapour, we may retard the boiling of water, and raise it to any temperature compatible with the capacity of the vessel to bear pressure, and the action of the high temperature necessary to produce steam of such elastic power. In this manner, substances can be exposed to higher temperatures than can be procured by boiling water in an open vessel. In elevated situations—such as Quito or Geneva—the same temperatures cannot be procured by boiling water or other liquids in open vessels, as in lower situations.

D.—*Of the Force of Steam.*

123. In considering the elastic force of steam, it must be recollected that, the temperature remaining the same, the *density* and *elastic force* of a gaseous body are in direct proportion; and that an increase of either temperature or density increases the elastic force. (93, 101.)

124. *The elastic force of a vapour rising from a boiling liquid is always exactly equal to the pressure which resists* (117) *its passage to the gaseous state*, or, as it is usually expressed, *equal to the pressure under which*

it is raised. In fact, a liquid does not boil until it has sufficient elastic force to balance and overcome this pressure.

125. There is a constant force—the atmospheric pressure—resisting the expansion of liquids into vapours; hence the elastic force of any vapour produced from a liquid boiling in an open vessel while the barometer is at thirty inches, is 14.7 pounds to the square inch, and varies with the height of the barometer (the index to variations in atmospheric pressure), the boiling point varying also, as the following table illustrates —

Barom.	Boiling Point of Water.	Elasticity in pounds in the square inch.
28	208.43	13.72
29	210.19	14.21
30	212	14.7
31	213.76	15.19

126. The following more extended table will illustrate better the condition of watery vapour at different temperatures, the proportion between the temperature and density, and the correspondence between these two and the elastic force or pressure. The manner in which the elastic force of a vapour is ascertained may be judged of by referring to paragraphs 96 and 97.

Temperature, Fahrenheit.	Specific Gravity, air at 60° being 1.*	Weight in Grains of a Cubic Foot.*	Pressure in inches of a column of Mercury.	Pressure, in pounds on the square inch.
Degrees.				
60.00	0.0115	6.10	0.55	0.2695
77.00	0.0202	10.70	1.00	0.49
98.70	0.0388	20.50	2.00	0.98
123.00	0.0744	39.00	4.00	1.96
147.60	0.134	71.00	7.50	3.675
178.00	0.255	135.00	15.00	7.35
197.40	0.371	196.	22.50	11.025
212.00	0.484	254.7	30.00	14.7
220.00	0.553	292.0	35.00	17.15
233.80	0.687	363.0	45.00	22.05
242.50	0.81	427.0	52.50	25.725
250.20	0.915	483.0	60.00	29.4
274.70	1.33	700.0	90.00	44.1
320.60	2.5	1317.0	180.00	88.2
350.00	3.61	1910.0	270.00	132.3
450.00	10.75	5670.0	900.00	441.0

The following table is the result of an inquiry instituted by the Academy of Sciences at Paris, in which Arago and Dulong were engaged. Up to the pressure of twenty-five atmospheres, the table gives the results of actual experiments. The temperatures and corresponding pressures above that were obtained by calculation. The first column shews the force of the steam, expressed in atmospheres; and, in the second column, the figures express the corresponding temperature in degrees of Fahrenheit. Thus, steam formed at 263.84 has an elastic force of $2\frac{1}{2}$ atmospheres; or, a pressure on the square inch of 36.75 pounds = 14.7 lbs. × $2\frac{1}{2}$.

* The weight of a cubic foot of air at 60 F., 30 Barom., is 535.8821 grains; 100 cubic inches weigh 31.0117 grains. A cubic foot of air at 212° F., 30 Barom., weighs 413.6832 grains; and, if the specific gravity of air at 212° be termed 1.000, that of steam formed at 212° is 0.624.

Elasticity in Atmospheres.	Temperature.	Elasticity in Atmospheres.	Temperature.	Elasticity in Atmospheres.	Temperature.
1	212.	7½	336.86	20	418.46
1½	233.96	8	341.96	22	427.28
2	250.52	9	350.78	24	435.56
2½	263.84	10	358.88	25	439.34
3	275.18	11	366.85	26	443.16
3½	285.08	12	374.00	28	450.38
4	293.72	13	380.66	30	457.16
4½	300.28	14	386.94	32	463.64
5	307.5	15	392.86	34	469.78
5½	314.24	16	398.48	36	475.64
6	320.36	17	403.82	38	481.24
6½	326.26	18	408.92	40	486.59
7	331.70	19	413.78	45	499.14
				50	510.60

127. From these tables, it appears that, if a quantity of water were heated to 320° Fahrenheit by confining the vapour, a cubic foot of the vapour at that temperature would weigh 1317 grains (about three ounces avoirdupois ;) its specific gravity, compared to air at 60° as 1, would be 2.5, weighing, therefore, two and a half times as much as an equal bulk of air ; if communicating with a closed tube, like a U, containing mercury, would support a column of that fluid metal 180 inches (fifteen feet) high ; or 150 inches if the tube were open, the atmospheric pressure being equivalent to thirty inches of the column ; and would exert on every square inch of surface of the vessel containing it, a pressure equal to that of a weight of 88.2 pounds avoirdupois—*i.e.*, a pressure of six atmospheres.

128. This table might be continued downwards—

as, at lower temperatures still, vapour can be sustained; of diminished density and elastic force, but never losing elastic power while it retains the form of vapour. At 32° Fahrenheit, according to Dalton, watery vapour will have an elastic force equal to 0.2 inch of mercury (.098—nearly one-tenth of a pound of pressure on the square inch); and a cubic foot of such vapour weighs 2.3701 grains. At fifty degrees Fahrenheit, the force of vapour, according to the same author, is 0.375 inches of mercury (.183 of a pound pressure on the square inch); and a cubic foot of such vapour weighs 4.2819 grains.

129. Any given space, then, can contain only a certain quantity of vapour at a certain temperature; the vapour is sustained in that state solely by the influence of heat; and its quantity bears a constant proportion (which has been determined by experiment) to the temperature.

130. Hence, if a quantity of vapour, in a confined space, be reduced in temperature, the space having contained as much vapour as it could at the previous temperature (being *saturated* with vapour), a certain quantity of vapour will now return to the liquid state, and *the remainder will expand and be spread through the whole of the space—much reduced, however, in density and elastic force;* tables such as that in paragraph 126 shew how much. For example, if a cubic foot of steam, at 212° Fahrenheit, and of elastic force of 14.7 pounds to the square inch, being of the specific gravity 0.484—*i.e.*, 254.7 grains of steam (all that can be sustained in vapour at that temperature in such a space)—be reduced in temperature to 60° Fahrenheit; 248.6 grains will return to the liquid state, and 6.1 grains will remain in the state of vapour, diffused through the entire cubic foot, having a specific gravity

of 0.0115, and an elastic force of 0.2695 pounds (about a quarter of a pound) on the square inch.

131. Thus, the condensation of vapour by cold can never produce an absolute vacuum—some vapour will remain, though of greatly diminished elasticity. This vapour will be rare, and of weak elastic force, just in proportion to the intensity of the cold employed to reduce the rest to the liquid state. This must be kept in mind in studying the steam-engine, and also for understanding the history of its progress from the first rude attempts to its present more perfect form.

132. From these tables, then, it will be seen that vapour rises from water at all temperatures; that its density increases with the temperature, and its elastic force with the density.

133. Steam of the same elastic force as the atmospheric pressure is called *low-pressure steam*, no pressure above that of the atmosphere being required to produce it. To produce steam of greater elastic force than that of the air, a close vessel must be used, the lid being kept down by weights proportioned to the strength of steam required. To procure steam having twice the elastic pressure of the air, we must confine it by twice the force, or 29.4 pounds to the square inch. The atmospheric pressure furnishes 14.7 pounds of pressure (a pressure of *one atmosphere*, as it is termed;) and, to provide the other atmosphere of pressure, we must lay such weights on the lid of the vessel, that there are 14.7 pounds for every square inch of the opening which admits the lid. In this manner, we procure steam of any required pressure greater than the atmospheric pressure, and it is called *high-pressure steam*. Steam of only a few pounds' (five or six) pressure higher than that of the atmosphere is still usually termed *low-pressure steam*.

134. In the preceding paragraphs, we have spoken of steam when in contact with its water of generation. In this condition, it obeys a different rate of decrease or increase in elastic force from that of steam cut off from communication with water. In the first case, when the vessel is heated, the elastic force of the steam is increased by two causes:—*First*, By the increase of heat; *second*, by the increase in density from the addition of more steam, and *vice versa*, when the temperature is diminished. But, when not in contact with any water to generate more steam, addition of heat increases its elastic force from the increased temperature only, no increase of density taking place.

135. Thus, the conditions, liquid and gaseous, do not seem to be absolute and essential to the constitution of any body, but relative to and depending on the temperature; so that it is likely that all liquids might be vaporized, even liquid metals, could we procure temperatures sufficiently high; and that all aerial bodies might be condensed, by simply abstracting heat from them, could we procure temperatures considerably lower than we can at present command.

136. There are some bodies which are known to exist only in the gaseous state; such are oxygen, hydrogen, nitrogen, and a few others. These, which cannot be reduced to the liquid state by a reduction of temperature, are called *gases;* while the aerial bodies which are formed by the influence of heat upon liquids, and which return to the liquid state when they are cooled, are exclusively called *vapours*.

137. Some aerial bodies, which cannot be rendered liquid by the mere abstraction of heat, have yet been reduced to the liquid state by pressure. As pressure retards the passage of a liquid to the aerial state, so it tends to reduce an aerial body to the liquid condi-

tion. The particles are thus approximated, and brought within the sphere of action of the cohesive attraction. The following gases have been liquefied by the pressure stated after each, as determined by Dr Faraday.

Sulphurous acid . .	2 atmospheres,	at 45° F.
Suphurettted hydrogen .	17 . . .	50°
Carbonic acid . .	36 . . .	32°
Chlorine	4 . . .	60°
Nitrous oxide . .	50 . . .	45°
Cyanogen . . .	3.6 . .	45°
Ammonia . . .	6.5 . .	50°
Muriatic acid . . .	40 . . .	50°

CHAPTER VI.

LATENT HEAT.

138. When water is made to boil in an open vessel, if a thermometer be placed in the liquid, it will be found, as would be expected, that the temperature of the water will gradually rise until it reaches the boiling point (212°.) After this, however strong be the heat applied to the water, however long the water be kept boiling, no further rise in temperature will take place; the thermometer will remain at 212° as long as the water continues to boil. Also, it will be found that, after the water has begun to boil, and as long as it is boiling, the steam arising from it will be at the temperature of 212°.

139. Here is a striking circumstance. The water

must continue to receive heat after it has begun to boil, as well as *before*, but nevertheless the temperature of the water and the steam remains stationary. What has become of the heat which entered the water after it began to boil? It has entered into the steam in a CONCEALED OR LATENT state, and has been removed by the steam flying away as fast as it is formed. That this is the case, may be inferred from so much heat having disappeared, and may be proved *by recovering it from the steam.*

140. Let a tube be adapted to a flask or other vessel in which water is made to boil, and convey the steam arising from the boiling water into cold water. Let a known weight of *water, in the form of steam,* pass into the cold water, which must also be of an ascertained quantity and temperature. Note the temperature to which the water has been raised by transmitting the steam into it. Now, add to a like quantity of water at the same temperature, a quantity of *boiling water* equal to that which had been passed in the form of steam into the first portion of cold water, and observe the temperature of the mixture. It will be found that the water to which the steam was added will be at a far higher temperature than that to which the boiling water was added—that is, the steam has given out more heat than the boiling water. But the steam and boiling water were equal in quantity and temperature—therefore, the steam must have contained more heat. We now see what has become of the heat which entered the water after it began to boil. It entered the steam; and, being in some peculiar relation to the water, becomes *hid*, or not discoverable by the thermometer, the usual test of the presence of heat. When the steam returns to the state of water, it restores this heat which it had absorbed into the concealed state; and, giving out the heat which it had

as boiling water, and the additional heat which it had absorbed on becoming steam, must produce a much greater heating effect than the same weight of water at the same temperature.

141. Heat which thus eludes the thermometer is called LATENT HEAT. Heat which is discoverable by the thermometer, is termed FREE or SENSIBLE HEAT, or HEAT OF TEMPERATURE.

142. The quantity (or rather proportion) of heat which becomes latent when water passes into the state of vapour, has been ascertained with considerable precision. This may be done in two ways:—

143. *First*, By estimating how long water requires to be heated (*i.e.*, how much heat must be added) after it has been brought to the boiling point, to dissipate it entirely in vapour, and comparing this with the time required to raise it to 212° from any given point. To convert a given quantity of water at 212° into vapour, heat must be applied about 5⅝ times as long as to raise the same quantity of water from 32° to 212° (*i.e.*, 5⅝ times the quantity of heat must be added to the water.) From 32° to 212° is 180°; 180° multiplied by 5⅝ gives 1000° as the heat of conversion of water into steam.*

144. *Secondly*, the same may be estimated by transmitting a known quantity of steam into a quantity of water of a known weight and temperature, and observing how much the temperature of the latter is raised. In this way, it is found that the heat absorbed by a given quantity of water at 212° in becoming steam, will raise 5⅝ times the quantity of water at 32° to 212°.

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* Any one may easily satisfy himself of this by experiment. Expose a quantity of water to a steady source of heat; note how soon the temperature of the water rises to 212°—how long before it is entirely vaporized.

180°, multiplied by $5\frac{5}{9}$, gives 1000° Fahrenheit, as the proportion of latent heat contained in steam.

145. The same takes place during the melting of solids and their congelation, or return to the solid condition. In melting, they absorb heat which does not raise their temperature; in congealing, they give out this heat into the free or sensible state. The latent heat of water is 140° Fahrenheit.

146. It thus appears that that heat which is engaged in effecting a change in the condition of a solid or liquid, is combined with it in such a way as not to affect its temperature. These general laws of caloric may be expressed in a few words. When solids become liquid, and when liquids become gaseous, they absorb a quantity of caloric, which does not raise their temperature. They evolve this caloric into the free or sensible state, when they return to their former condition. These laws of heat were developed by the celebrated Dr Joseph Black.

147. Though of high interest and importance in other applications of heat, and in relation to precise calculations as to the quantity of heat required to produce a certain effect, they are not essential to an understanding of the principle of the steam-engine, nor was it by a knowledge of them that Watt effected his grand improvements, as has been erroneously supposed. "These improvements," says Watt, "proceeded upon the old-established fact, that steam was condensed by the contact of cold bodies, and the later-known one, that water boiled *in vacuo* at heats below 100°." It will be seen, as we go along, that Watt's improvements have no connection with the laws of latent heat, and would as readily have occurred to him though these laws had never been known.

148. When water boils at temperatures lower or higher than 212°, it appears that still the same

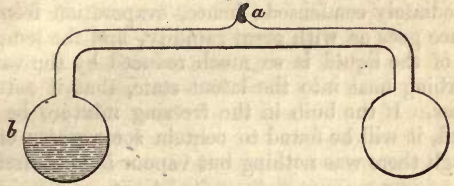
quantity of heat is always required to vaporize the same quantity of water; the latent heat being as much greater as the sensible heat is less, when the water is made to boil at low pressures; and as much less as the sensible heat is greater, when water is boiled at high pressures: the sum of the free and latent heat of steam at all pressures, being 1180°—that is, at 212°—1000° of latent, and 180° (reckoning from the freezing point) of sensible caloric. Hence, there would not be any economy of heat in raising steam at low temperatures, as was at one time supposed.

149. It appears that equal weights of different bodies require different quantities of heat to raise them to the same temperature, a fact generally expressed by saying that the *specific heats of bodies are different.* A body which requires much heat to raise its temperature, is said to have *a high specific heat*, or a great *capacity for heat* and *vice versa.* Now, the specific heat of an aerial body is greater as its volume increases, continuing the same in quantity or weight; increasing with the bulk, decreasing as the density and elasticity increase. Hence, when aerial bodies are rarified, to satisfy their increased specific heat, they absorb heat into the latent state. When condensed—having now a less specific heat—they give out heat into the sensible condition. Thus, rarefaction of a gaseous body causes cold; compression causes heat. Hence the cold in the upper regions of the atmosphere, where the air is rare, and, therefore, requires more heat to raise its temperature than the dense, lower strata of air. Hence a thermometer sinks in temperature when placed in the receiver of an air-pump, from which the air is quickly withdrawn. Hence the syringe for procuring a light, which is simply a cylinder in which a piston works; the latter being suddenly forced down, compresses the air, and

the heat thus evolved kindles some tinder in the cylinder.

150. Several of the phenomena of heat are well illustrated by a beautiful instrument, devised by Dr. Wollaston, called the Cyrophorus, or Frostbearer. It

Fig. 7.



consists of a glass tube, expanded into a glass bulb at each extremity, and containing only pure water and watery vapour. Before it is closed, the water is divided between the two bulbs, and made to boil in each—the vapour escaping by the aperture in the middle of the tube, so that the vessel cannot contain any air. While the liquid is boiling briskly, the aperture is suddenly closed by directing the flame of a blowpipe across it.

151. With this instrument, the following striking experiment may be performed:—Collect all the water in one bulb, and place the other in a freezing mixture. In a short time, the water will be frozen; illustrating three points in the phenomena of heat:—*First*, That water evaporates rapidly as the pressure on its surface is diminished; *second*, That it evaporates at very low temperatures; and, *third*, That, during evaporation, an immense quantity of heat is absorbed into the latent state, the adjoining liquid being robbed of sensible heat to supply this demand.

152. The vapour in the bulb being condensed by the freezing mixture, the vapour in the tube and upper

part of the other bulb expands and rushes into the bulb in the freezing mixture. The pressure upon the surface of the liquid being thus reduced, and the space above it containing less vapour than its temperature can support, evaporation takes place from the surface. But any vapour which rushes into the other bulb is immediately condensed: hence, evaporation from the surface goes on with great rapidity, and the temperature of the liquid is so much reduced by the vapour absorbing heat into the latent state, that it actually freezes. If the bulb in the freezing mixture be examined, it will be found to contain some water or ice, though there was nothing but vapour in it at first.

PART II.

CHEMICAL RELATIONS OF WATER, COAL, AND IRON.

CHAPTER I.

WATER.

153. Water, in its purest state, consists solely of two elementary bodies, Oxygen and Hydrogen. These two substances are met with in the aerial state when uncombined with other bodies, or each other; they are clear, colourless, and transparent; and are incapable of being reduced to the liquid or solid form by cold or pressure, or both combined. The following tables will illustrate the composition of water.

COMPOSITION OF WATER.

Name of Gas.	Weight.	Bulk.
Oxygen	8	0.5
Hydrogen	1	1.0
Steam at 212°	9	1.0

Proportions necessary for forming water in 100 parts of the gases.

	By weight.			By measure.		
Oxygen .	88.9,	or	8	33.34,	or	1
Hydrogen .	11.1,	or	1	66.66,	or	2
Mixed .	100.0		9	100.00		3
Combined .	100.0		9	66.66		2

154. When the gases combine, a condensation ensues. They are reduced 1-3rd in bulk. The steam formed occupies only the bulk of the hydrogen. Thus, when steam is decomposed (its elements separate), there must be an increase in bulk of *one-half*. Also, the gases into which it is formed *are not condensible* by cold, as steam is. Thus, while steam is easily condensed, and made the means of procuring a vacuum, its uncombined elements are totally unfit for such a purpose.

155. Some of the metals, as iron and zinc, possess the property of decomposing water when they meet at a high temperature. The metal abstracts the oxygen, with which it unites and forms a solid crust of metallic oxide at its surface. The hydrogen thus eliminated, assumes that form which is proper to it when uncombined, and becomes a clear, colourless, incondensible gas, equal in bulk to the steam from which it was formed. The hydrogen is inflammable; and, if it meet with the necessary quantity of free oxygen (as in air) and a sufficiently high temperature, will burn, uniting with the oxygen, and forming vapour of water. When hydrogen and oxygen unite, great heat is evolved, and the gases are thereby enormously expanded for a moment, some have said so much as to occupy fifteen times their former bulk. At all events, they expand with very great force, causing a loud report when the experiment is performed with the proper proportions of the gases in a stout glass jar.

156. But water such as we have been just speaking of is nowhere met with in nature. It is pure distilled water, found only in the laboratory of the chemist. Common water contains in solution small quantities of air, and of any soluble earthy matters it may have been in contact with, as sulphate of lime, &c. The water of the Clyde contains, in an imperial pint ($34\frac{1}{2}$ cubic inches, or about 8750 grains), 1.14 grains of earthy matters, and about 1-35th of its bulk of gases. The earthy matters consist chiefly of muriate of magnesia, sulphate of soda, common salt, silica or flinty earth. Of the gaseous matters, 1-20th is carbonic acid, and the remaining 19-20ths are common air. The proportions of these ingredients vary in different streams; but all contain some earthy matters and gases in solution; besides what may be present, mechanically suspended in the liquid.

157. Sea-water contains a much larger proportion of earthy matters. The water of the Atlantic, as analyzed by Dr. Marcet, consists, in 1000 parts, of

Pure matter of Water	956.84
Common Salt (chloride of Sodium)	26.6
Sulphate of Soda	4.66
Muriate of Lime	1.99
Muriate of Magnesia	9.91
	1000.00

This gives, as nearly as possible, 1-23rd of saline and earthy matter, and 22-23rds of pure matter of water; or about forty-three parts in the thousand are saline and earthy matter. The water of the Frith of Forth, examined by Dr. Murray, contained, in 1000 parts—

Pure matter of Water	969.691
Common Salt	22.001
Sulphate of Soda	3.316
Muriate of Lime	0.784
Muriate of Magnesia	4.208
	1000.0

This analysis gives about thirty parts in the thousand as saline and earthy matter; or, nearly 1-33rd—the proportion of saline matters being less, as might be expected, near the shore and mouths of rivers, than out in the ocean.

158. When water containing any gases and earthy matters is boiled, the gases rise in the gaseous form with the first portions of vapour that are expelled; so that the steam of common water always contains a small portion of air. When the steam condenses into water, this air does not entirely condense along with it: a great part retains the gaseous form, as water cannot absorb much air when warm, and the water formed by the condensed steam is very warm at first. The earthy matters remain in the vessel in which the water is boiled; and, when there is not sufficient water left in the vessel to retain them in solution, fall down in the solid form. If the same vessel be used for boiling successive portions of water, and be not frequently cleaned out, a crust of these earthy matters will form at the bottom, which will gradually thicken, and may lead to injurious consequences, as the earthy crust is a slow conductor of heat—that is, takes heat slowly from bodies, and gives off heat slowly—in short, gives heat a very slow passage through it. This will be explained more particularly in the chapter on iron.

CHAPTER II.

FUEL.

159. The fuel used for the production of heat to vaporize water for steam-engines, is—CHARCOAL, COKE, COAL, ANTHRACITE, TAR, or REFUSE WOODY MATTER, such as *saw-dust*, *tanner's spent bark*, *peat*, &c. Of all these the chief combustible ingredient is carbon. It forms the principal part of charcoal, coke, and anthracite—the latter (called also blind-coal, glance-coal, stone-coal) contains a considerable proportion of earthy matters, silica, &c., which remain as ashes after combustion. It is the mineral chiefly used as fuel in the States of North America. Coal contains, besides carbon, hydrogen, a combustible ingredient, and also oxygen and nitrogen. Tar and wood also contain hydrogen. Where the fuel contains hydrogen, it burns with a yellow flame, and then with a steady red light, like cinder. Where there is no hydrogen, the fuel burns more steadily, and a more uniform heat is sustained. Such a fuel is found in charcoal and coke. The former is prepared by heating wood in close vessels; the latter from coal, by a similar process. Anthracite contains no hydrogen. A new composition called "prepared fuel" has lately been introduced. It is composed of screened coal (coal otherwise too small for use), river mud, and tar, formed into blocks of the same size and shape as a common brick; and is said to present the advantage, so important in steam navigation, of concentrating a great quantity of combustible matter in a small compass.

160. The following tables of the composition of the different kinds of coal, and quantity of coke and ashes they yield, are from analyses by Dr. Thomson.

	Caking Coal.	Splint Coal.	Cherry Coal.	Cannel Coal.
Carbon . .	75.28	75.00	74.45	64.72
Hydrogen . .	4.18	6.25	12.40	21.56
Nitrogen . .	15.96	6.25	10.22	13.72
Oxygen . .	4.58	12.50	2.93	0.00
	100.	100.	100.	100.

	Volatile Products.	Weight of Coke.	Incombustible Ash.
1000 parts of Caking Coal give	226	774	15
Splint Coal . give	352	647	95
Cherry Coal . give	477	522	100
Cannel Coal give	600	400	110

In the last table, the volatile products, and coke, make up the 1000 parts. These kinds of coal differ considerably in composition in different places, which accounts for the discrepancies in the analyses given by various chemists.

161. In the combustion of fuel, a chemical action goes on, in which the carbon and hydrogen unite with oxygen, furnished by the air; so that a free and ample supply of air is essential. It has been estimated that a pound of coal requires about two-and-a-half pounds of oxygen for combustion. This is about twenty-nine cubic feet of oxygen. This quantity of oxygen will be contained in 145 cubic feet of air. About a third of the air which enters the furnace, passes through without aiding in the combustion; so that, to furnish the necessary quantity of oxygen, about 217 cubic feet of air are required for the complete combustion of every pound of coal.

CHAPTER III.

IRON.

162. Iron is the material used for all large steam-boilers, interposed between the heat and the water to be boiled. Malleable iron is generally employed. It will bear a considerable heat without injury; but, if too strongly heated, it will oxidate, or rust—a crust of brittle oxide forming upon its surface, whether exposed to air or to water. It is not improbable that malleable iron much in contact with the carbonaceous matter of fuel, and at a high temperature, may combine with some carbon, and thereby become impaired in its tenacity, acquiring the properties of cast iron. Iron is a good conductor of heat, and, when employed as a boiler, is in no danger of rusting, (or burning, as it is sometimes termed,) if there be plenty of water in contact with it, to carry off the heat in the form of vapour, and the vapour have free exit. If the vapour be confined, however, from any cause, its temperature will rise, and the heat, not being carried off, will tend to accumulate both in the vapour and the boiler, and thence to corrode the boiler. If the water be entirely dissipated, then also, the heat, not being carried away in the latent state by vapour, will accumulate and burn the boiler—that is, enable it to combine with the oxygen of the air, which it does not do at a moderate temperature. Or, if there be an earthy crust lining the boiler, this (a slow conductor) will transmit the heat so slowly through it, and give it off so slowly to the water, that the boiler will be apt to be destroyed from the action of the fire. Where, from any of these causes, the boiler is at a very high temperature,

it has been conjectured (though never proved to have taken place) that the iron may decompose the steam in the interior, and replace it by the incondensible gas hydrogen, retaining the oxygen, in the crust of oxide formed.

Many seem disposed to consider this a common cause of the explosion of steam-boilers. The difficulty here is to account for the supply of oxygen to form an explosive mixture with the hydrogen. Hydrogen is not separated from steam by a hot metal, except the oxygen of the steam be abstracted by the metal, in which case the oxygen is fixed down in the form of a solid crust of oxide. If explosions ever take place from this cause, the necessary quantity of oxygen must be derived from a leak in the boiler admitting atmospheric air, which can hardly be supposed to be the source of the oxygen for an explosion, so that we may regard it as next to impossible that the decomposition of the steam can ever lead to the formation of an explosive mixture in a steam-boiler. Besides the above considerations, it is to be borne in mind, that, even supposing the necessary quantity of oxygen to be present, there would be no explosion from two causes—1. The want of a sufficiently high temperature; 2. The presence of the steam in large quantity in the gaseous mixture.—The American Committee gave it as their opinion, from experiments instituted, that this is not a cause of explosions in steam-boilers.

Danger may also arise from a deficiency of water, when the sides of the boiler may become red-hot, and, if water then come suddenly in contact with them, an explosion may ensue. This, there is reason to believe, is a frequent cause of the explosion of steam-boilers.

PART III.

HISTORY AND DESCRIPTION OF THE STEAM-ENGINE.

163. It is very interesting to trace the progress of a great invention, from the first rude attempts, till it attains a somewhat perfect form—to mark the successive changes it undergoes, and observe how often men have been on the very brink of the discovery, and yet allowed it to escape them; and there is perhaps, no better or easier way to understand the later and more complex forms it assumes, than tracing it from the first simple conception, and at each stage contrasting it with its previous condition. We shall, therefore, prefix, to the description of the modern engine, a brief sketch of the progress of the invention from the earliest records.

SECTION I.

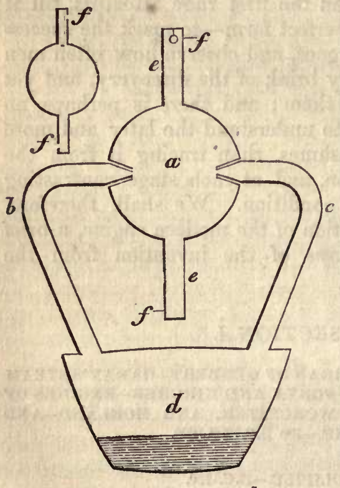
ÆOLIPILE OF HERO—ORGAN OF GERBERT—GARAY'S STEAM BOAT—FOUNTAIN OF PORTA AND KIRCHER—ENGINES OF DE CAUS, BRANCA, WORCESTER, AND MORLAND—AND PAPIN'S FIRST ENGINE.—130 B.C. TO 1690.

ÆOLIPILE.—B.C. 130.

164. The first instance on record of the force of steam being applied to produce motion, is that of the

Æolipile, a philosophical toy, described in the writings of Hero of Alexandria, who flourished during the reign of Ptolemy Philadelphus, about 130 years before the birth of Christ. This writer was distinguished for his mechanical knowledge. Besides the Æolipile, described in the next paragraph, he also was acquainted with the forcing-pump for raising water, (the invention of Ctesibius;) the beautiful contrivance for an artificial fountain, still called Hero's fountain; a machine for producing a rotatory motion by a jet of heated air; and many other curious mechanical inventions. The following cut will explain the action of the Æolipile.

Fig. 8.



165. This consists of a globular metallic vessel, *a*, revolving on two pivots, the pointed extremities of the tubes, *b*, *c*, and having two tubes, *e*, *e*, proceeding from it at right angles to the line of the pivots. The tubes, *b*, *c*, proceed from a steam-boiler, *d*, and, by small apertures at their extremities, convey the steam which is generated into the globe *a*. The tubes *e e* are closed at the extremities, but have each an aperture at one side, by which the steam issues. One tube (*e*) would do; but where there are two, the apertures must be on the oppo-

site sides of the tubes, as seen in the little figure at the side. Or, instead of apertures, the tubes *e e* may be open at the ends, if they be bent near the extremity at right angles, and in directions opposite to each other. The steam will issue with great force at the apertures, and, acting on the side of the tube opposite to the aperture, will cause it and the globe along with it, to move in a direction opposite to that in which the steam issues; and, the supply of steam being kept up, a continuous rotatory motion of the machine will be induced. There may be several tubes (*e e e.*)

166. The same may be effected in a simpler way, by forming the steam in the vessel *a* itself, the globe being removed from the boiler and tubes *b c*, and made to revolve on supports, by rods projecting from its surface in the line of the notches. This was proposed in a book published at Leipsic in 1597, as a means of turning a spit for roasting meat.

167. The principle of the Æolipile—the same as that which produces the motion in the machine called Barker's Mill—has not till lately been made use of in any modern engine; but it unquestionably exhibits motion produced by the force of steam, and which might be transferred to machinery for some useful purpose. It has the merit of great simplicity, and has lately been proposed as a moving power by an American engineer. See "Avery's Engine," in the chapter on Rotatory Engines.

168. Hero also describes a machine for raising water (it would do so, certainly—but in drops only) by the action of the sun's rays on the air in a globe two-thirds full of water, the air expanding and pressing the water through a tube. And this description seems to have suggested to Baptista Porta the contrivance described in paragraph 172, (which is, in fact, a steam-engine,) and

to De Caus some of his ingenious machines for indicating the heat of the weather, raising water by the sun's heat, &c.

ORGAN OF GERBERT.—12TH CENTURY.

169. In his "Historical and Descriptive Anecdotes of Steam-Engines," and of their inventors and improvers—a very interesting work—Mr. Robert Stuart has pointed out a passage in Malmsbury's "History," from which it would appear, that, about the 12th century (1125), there was at Rheims an organ, in which steam (*heated water* is the term) was in some way instrumental in producing the sounds. The passage is as follows:—"In the church of Rheims, are still extant, as proofs of the knowledge of Gerbert—a public professor of the schools—a clock constructed on mechanical principles, and an hydraulic organ, in which the air, escaping in a surprising manner by the force of heated water, fills the cavity of the interior of the instrument, and the brazen pipes emit modulated tones through the multifarious apertures." It does not appear whether steam was actually used, or the heated water only employed to expand the air, as the words would almost indicate; if the former, this is certainly the first useful application of steam.

STEAMBOAT OF GARAY.—1543.

170. At Barcelona, in the year 1543, a Spanish sea-officer called Blasco de Garay, propelled a vessel on the water without sails or oars, "by an apparatus, of which a large kettle filled with boiling water was a conspicuous part." From the reports and records, it

appears that the experiment—which was done by order of the famous Emperor Charles V.—was considered as successful, and that Garay was promoted and rewarded. But it went no further—perhaps, as Dr. Renwick remarks, because he was "too far in advance of the spirit of his age to be able to introduce his invention into practice;" and it died with him, as he kept his plan strictly secret. If this account be authentic, Garay must have possessed, considering the times, an extraordinary degree of knowledge of the properties of steam and of mechanical skill.

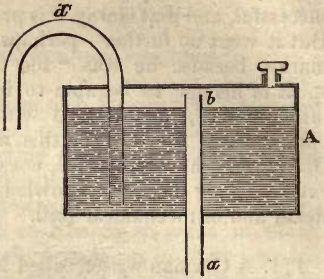
171. A German writer, called Mathesius, in a volume of sermons published in 1571—a rather singular place, certainly—describes an apparatus somewhat resembling a steam-engine, and speaks of the "mighty effects could be produced by the volcanic force of a little imprisoned vapour." Between that time and the end of the next century, when Savery constructed his engine, there are many notices by various authors of the effect of heat upon water—"the power of imprisoned vapour"—and hints for the construction of engines founded thereon. We shall allude to Porta, De Caus, Branca, Worcester, Morland, and Papin.

BAPTISTA PORTA.—1606.

172. The celebrated Baptista Porta, an Italian philosopher, inventor of the Camera Obscura, was the author of several ingenious works, and, among others, a commentary on the "Pneumatica" of Hero, in which he describes and gives a drawing of a *steam-fountain*, which wanted nothing but the "idea of such an application," and a proportional magnitude, to form

a steam-engine for raising water. It will be understood from the adjoining cut. A tube (*a b*) coming from a boiler or retort in which steam is formed, and open at the extremity, passes into a cistern (A) nearly filled with water, the end of the tube being above the level of the water. The steam

Fig. 9.



from the boiler is thus conducted into the space above the water, and, pressing on the water by its elastic power, forces it through the tube *d*. This, which was afterwards taken up by Kircher, in 1656, is the exact idea of De Caus', Lord Worcester's, and of one part of Savery's engine. The steam is formed in a separate vessel from that containing the water to be raised. Porta, however, did not propose to apply it, or follow it out in any way. He also describes the rushing of water into the vacuum formed by the condensation of vapour. He thus had knowledge sufficient to have invented Savery's engine, but perhaps never turned his mind particularly to the subject.

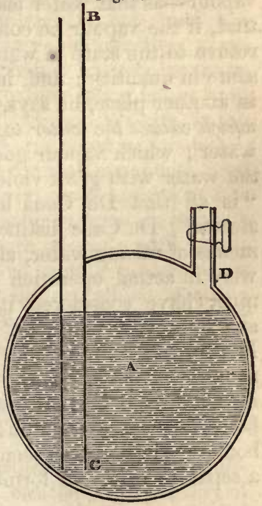
DE CAUS.—1615.

173. Solomon De Caus was an engineer and architect to Louis XIII. of France; he was an eminent mechanic, and author of several works on practical mechanics, of which the principal, published in 1615, treats of the theory of moving forces, and describes a number

of machines, and, among others, one for raising water by fire—*perhaps the first instance in which steam was proposed to be used as a moving power on the large scale, in the manner in which it is now applied—namely, by its elastic force when confined.*

174. His Theorem V. is, "Water may be raised by the aid of fire higher than its own level;" in illustration of which, he gives the following figure and description.

Fig. 10.



"The third method of raising water is by the aid of fire; whereby divers machines may be made. I shall here give the description of one. Take a ball of copper (marked A), well soldered at every part: it must have a vent-hole (marked D), to put in the water, and also a tube (marked B C), which is soldered into the top of the ball, and the end (C) approaches near to the bottom, without touching it. After filling this ball with water through the vent-hole, stop it close, and put it on the fire; then the heat, striking against the said ball, will cause all the water to rise through the tube B C."

175. The steam formed by the vaporization of the water, having no exit, will accumulate until it has sufficient elastic force to press on the surface of the water so strongly as to cause part of the water to ascend

through the tube, and, by continuing the heat thus, all the water may be expelled, as De Caus says. This experiment is exactly similar to that described in paragraph 107.

176. It has been doubted whether De Caus knew precisely the cause of the ascent of the water, or attributed it entirely (as it is certainly in part owing) to the expansion of the air above the water. But this can hardly be, as he knew so much of the nature of vapour—as that water loses when part is evaporated—that, if the vapour be confined and cooled again, it will return to the state of water, and the water will be the same in quantity; and, in describing this experiment in another place, he says, "The violence of the vapour *which causes the water to rise*, proceeds from the same water; which vapour goes out through the cock after the water with great violence." "This," says Farey, "is all that De Caus has left us on the subject of steam." De Caus distinctly mentions this power as a means of raising water, along with other plans which were in actual operation for that purpose; so that he must have considered it fit for purposes of utility, and thus, very probably, has given the hint to others. His apparatus might be used on the large scale, but not profitably—the water to be raised must in the first instance have been transferred by manual labour (so far as we learn from his description) into his copper boiler. He does not seem to have thought of having a separate vessel for forming the steam.

ENGINE OF BRANCA.—1629.

177. We now come to what appears to be the first proposal to use steam as a moving power, which was accompanied with a specific plan, and published. It is that of Giovanni Branca, an Italian engineer; and his

invention is described, with a drawing, in a work he published at Rome in 1629.

178. His engine was a sort of steam windmill, consisting of a boiler with its spout directed towards a wheel, so that the steam which issued from it struck forcibly against the flat vanes in its circumference, and thus caused a rotary motion in the wheel; and the continuous motion thus produced, could easily be transmitted to any machinery connected with the wheel. He proposed to apply it to grind the materials for gunpowder, raise water by buckets, &c.; and has given descriptions of machinery for effecting these purposes. The idea may probably have been taken from observing the force with which steam issues from the mouth of a common kettle. Bishop Wilkins, in his "Mathematical Magic," 1648, proposed a somewhat similar plan for turning a spit for roasting meat.

179. These machines, however, could have very little power, as from the low specific gravity of steam, it has little impetus, even though moving with great velocity; and, moreover, it is so rapidly condensed by cold, and so much resisted by the air, which is about twice as heavy, that it can have very little force of percussion. Accordingly, this mode of applying steam has never come into practice.

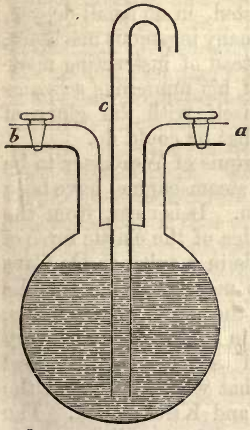
WORCESTER.—1663.

180. Edward Somerset, Marquis of Worcester, published, in 1663, a small 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," &c. In this work, (in which, he says, the descriptions are "in such a way as may sufficiently instruct me to put any of them in practice;" thus apologizing for their brevity, while he promises, in some

future work, which never appeared, however, to give instructions for executing his designs,) the following passages occur, of which the first, and, there is every reason to believe, the others, refer to a steam-engine: —"LXVIII. An admirable and most forcible way to drive up water by fire, not by drawing or sucking it upwards—for that must be, as the philosopher calleth it, *intra sphaeram activitatis*, which is but at such a distance. But this way hath no bounder, if the vessels be strong enough; for I have taken a piece of a whole cannon, whereof the end was burst, and filled it three quarters full of water, stopping and screwing up the broken 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 strenghtened by the force within them, and the one to fill after the other, I have seen the water run like a constant fountain stream, forty feet high; one vessel of water, rarified by fire, driveth up forty of cold water. And a man that tends the work is 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 self-same person may likewise abundantly perform in the interim between the necessity of turning the said cocks." This is termed a fire-water work in the index.—Article XCVIII. "An engine so contrived that, working the *primum mobile* forward or backward, upward or downward, circularly or cornerwise, to and fro, streight, upright, 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, I call this *a semi-omnipotent engine*, and do intend that a model thereof be buried with me." This versatile *primum mobile* must, surely, be steam; and, in article C., he speaks of a water-work, "by many years' experience and labour, so advantageously by me contrived, that a child's force bringeth up, an hundred feet high, an incredible quantity of water, even two feet diameter, so naturally, that the work will not be heard even into the next room."

181. This engine is supposed to have consisted of a boiler, having two steam tubes proceeding from it to two vessels, which had apertures to admit alternately the water to be raised, and the steam to raise it—these apertures being governed by cocks to be alternately opened and closed. The annexed cut represents one of these forcing vessels, in which *a* is the steam tube from the boiler, *b* the tube for admitting the water to be raised, and *c* the tube by which the water is forced out of the vessel. It has been questioned by some whether he ever had constructed such an engine as he describes. Of this there can be no doubt, however, from the report of a foreigner, Cosmo de Medicis, (who saw it in operation), from the exertions his widow made to get it introduced into use, (from which we may infer, at least, that she had some ocular proof of its efficacy,) and other circumstances.

Fig. 11.



182. Lord Worcester was a devoted adherent of the

Charleses I. and II., in whose cause he had lost his fortune and estates. He was in exile after the ascendancy of Cromwell, till 1656, when, coming to London on some secret mission from Charles, he was discovered and imprisoned in the Tower, whence he was liberated at the Restoration. During his confinement, he prosecuted his mechanical studies, which were not new to him, however, as he had always had a taste for mechanics. In the dedication of his book to the Parliament, he speaks of an "unparalleled workman, both for trust and skill, Caspar Kaltoff, who hath been these five-and-thirty years as in a school under me employed." Lord Worcester was evidently a man of considerable mechanical genius and knowledge; and, had he done more and talked (or boasted) less—had he explained clearly, and published any of his numerous schemes—he might have assisted, in no small degree, in forwarding the invention of many ingenious machines, now come into use. But, instead of instructing mankind how to carry any one of his numerous schemes into effect, he contented himself with the glory of blazing forth a catalogue of what he could do.

183. The claims of the Marquis of Worcester to be considered the inventor of the steam-engine, have been the subject of much discussion. It is clear, from the description, that he had the idea of the elastic force of steam, pressing water upwards in a tube, as De Caus and Porta had; indeed, it is most probable that he derived his knowledge from the work of De Caus, which was published at Paris in 1623. There is every reason to believe that he had used a separate vessel for forming the steam from that which contained the water to be raised, as Porta and Kircher had. The separate boiler was a most important addition to De Caus' plan. Moreover, he constructed an engine, and proclaimed its applicability, as a moving power, to a

variety of purposes. But his description is so meagre and obscure that it is doubtful if it were intelligible to others at that time. It is extremely probable that Papin, who spent a long time in England, had seen the "Century;" and, although that philosopher had much precise knowledge of the nature of steam, was the inventor of the Digester, and was labouring to introduce steam in its two modes of action, (by its elastic force and its condensation,) in an engine for raising water; yet he seems never to have entered on the track which the "Century" must have pointed out *very clearly, if understood at all.* Worcester never exhibited his engine to any public body; never gave an intelligible account of it. It is not clear, from the notice in the "Century," whether he meant two forcing vessels and one boiler (as is generally supposed;) two boilers and one forcing vessel; one boiler and one forcing vessel; or two vessels with fire applied alternately to each; and it is questionable if any engine adapted to his description, on the most favourable construction, could ever have come into general use—the quantity of fuel consumed would have been so great. Indeed, the only part of Savery's engine (which embraces Worcester's) which has turned out workable, is that in which the water is raised by the atmospheric pressure—a plan which Worcester does not seem to have been aware of. In proposing the application, he made a step in advance of Porta; the separate boiler was a step in advance of De Caus. But, as he kept his plan secret, did not develop the principle, did not give directions for applying it, far less taught mankind how to work it profitably, he can have no claim to be considered the inventor of the steam-engine. All we can say of him is, that, most probably, *he knew* an improved form of De Caus' plan for raising water.

MORLAND.—1683.

184. About the above period, Sir Samuel Morland is said to have exhibited before Louis XIV., at St Germains, a method of raising water by means of steam; and, although there is no record extant of the particulars of his plan, it is evident, from the following extract from a work which he wrote in French, in 1683, and which is preserved in manuscript in the Harleian Collection of MSS. in the British Museum, that he was aware of that most valuable property of steam, its elastic power when confined; and must have experimented on the subject in a way which would indicate that he had actually constructed an efficient steam-engine for raising water.

"*The Principles of the New Power of Fire, invented by Chevalier Morland, in the year* 1682, *and presented to his Most Christian Majesty*, 1683.

"Water being evaporated by the force of fire, these vapours shortly acquire a greater space (about 2000 times) than the water occupied before; and, were it to be closely confined, would burst a piece of cannon. But, being regulated according to the rules of statics, and reduced by science to measure, weight, and balance, then they carry their burden peaceably, like good horses, and thus become of great use to mankind, particularly for raising water, according to the following table, which shews the number of pounds that can be raised 1800 times per hour, to six inches in height, by cylinders half filled with water, as well as the different diameters and depth of the said cylinders." These tables need not be given here.

PAPIN.—1690.

185. Denis Papin, a Frenchman, Professor of Mathematics at Marburg, and author of many philosophical papers and ingenious mechanical inventions, has been claimed by the French as the inventor of the steam-engine; and there are certainly some grounds for this claim, or, at least, for assigning to him a considerable share of the merit. There is no one individual, except James Watt, who can be termed the inventor of the steam-engine. Among those who preceded Watt, and who each contributed a little, Papin is certainly one of the foremost in point of inventive power. Although his apparatus was so clumsy and troublesome that it may be said to have been almost impracticable for use on the large scale, he was yet the first who shewed that *a piston working tight in a cylinder might be raised by boiling a little water under it; and that, when raised, by cooling and condensing the vapour which had raised it, a vacuum would be formed below it, when the atmospheric pressure would force it down.* In some of his writings in the "Acta Eruditorum" of Leipsic, of 1690, he describes this engine, and says—"Water has the property, when changed into vapour, to spring like the air, and afterwards to recondense itself so well, by cold, that there remains no appearance of this force or spring." And this engine was noticed in the "London Philosophical Transactions," for 1697, in the following words:—"A method of draining mines, where you have not the conveniency of a near river to play the aforesaid engine—[one with air-pumps and cylinders, connected by an air-pipe]—where, having touched upon the inconveniency of making a vacuum in the cylinder for this purpose with gunpowder (according

to his first scheme of 1687), he proposes the alternately turning a small surface of water into vapour, by fire applied to the bottom of the cylinder which contains it, which vapour forces up the plug [piston] in the cylinder to a considerable height, and which (as the vapour condenses from the water cooling when the fire is taken away) descends again by the air's pressure, and is applied to raise the water out of the mine."

186. Thus, Papin seems to be the first who suggested the grand idea of using steam to produce a vacuum by its condensation, thereby giving effect to force acting on a movable piston. The alternate application and removal of the fire, however, would render the machine very inconvenient. If his own inventions were unsuccessful, however, he did much in preparing the way for others.

187. This might be regarded as a rude sketch of the atmospheric-engine of Newcomen, who was acquainted with and studied Papin's designs—so very near it, indeed, that there is every probability that Papin would have invented the atmospheric-engine, had his attention not been drawn to other researches. Indeed, he gives some calculations as to the power of a large engine on this plan, and suggests it as applicable to raising water, and propelling vessels against wind and tide—*so that he certainly gave the first idea of the atmospheric engine*, and must be regarded as one of the pioneers who prepared the way for the steam-engine.

188. Papin had proposed to make the pressure of the air effective as a source of moving power, by producing a vacuum in a cylinder by an air-pump, the air-pump being worked by a water-wheel; and, by tubes connected with the part where the vacuum was formed, he proposed to transfer to other machinery at

a distance the power thus got from the fall of water. He also tried the explosion of gunpowder for producing the vacuum; and then the idea of using the vapour of water for this purpose occurred to him.

189. Papin was the inventor of the SAFETY-VALVE, and of the DIGESTER, known by his name, and in use at the present time; the safety-valve was devised for the digester, but has now come into general use for more important purposes. In the Digester (see paragraph 122), by confining the steam, a greater heat is procured than can be had from water allowed to boil in an open vessel; and which, as he himself says, "extracted marrowy nourishing juices from bones and beef, even the oldest and hardest cow-beef; and other meats, whose horny and shrivelled fibres baffled the skill of the most experienced cooks to prepare for mastication with common boilers, when done in his Digester, came forth succulent and pulpy." We shall have to recur to Papin.

SECTION II.

SAVERY.—1698.

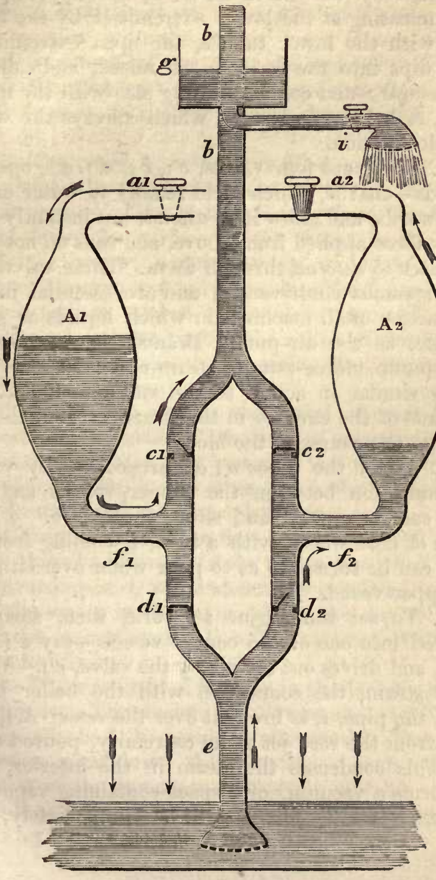
190. Of those who proposed to raise water by the force of steam applied directly to the water—a plan ultimately found unprofitable, and abandoned—we must award the greatest share of merit to THOMAS SAVERY, the first who came before the public with an intelligible plan of an engine fit for practical purposes, worked by steam. All previous to Savery only threw out hints, or constructed experimental models, useless on the large scale. BRANCA and PAPIN were on totally different tracks from Savery, Worcester, and De Caus.

191. PORTA'S Fountain shewed that confined steam might be made to raise water for a jet; DE CAUS proposed to apply this power to raise water for purposes of utility, giving no plan, however, except the very inconvenient one of the apparatus used to illustrate the principle; WORCESTER, if he did anything, talked of an improvement of the method of De Caus; and, *what these had talked about, and that obscurely too*, SAVERY DID; *adding the application of the atmospheric pressure, which none of these had thought of.* It is impossible to know how far each was original, or only improved upon a previous plan; and it is difficult to assign to each his just due of praise; but when one (Porta) points out a principle, another (De Caus) suggests its application to practice, a third (Worcester) says that he knows how to apply it, and a fourth (Savery) instructs men how to apply it, the latter, surely, is entitled to the chief share of the merit.

192. Savery's engine is a very beautiful and ingenious invention. He got a patent for it in 1698, calling it an invention for "raising water, and occasioning motion to all sorts of mill-work, by the impellent force of fire;" exhibited a model before the Royal Society in 1699, and published, in 1702, a small work, called "The Miner's Friend; or, an Engine to Raise Water by Fire, Described; and the Manner of Fixing it in Mines; with an Account of the Several Uses it is applicable unto, and an Answer to the Objections made against it. Printed at London, 1702. By Thomas Savery, Gentleman." Savery was Treasurer to the Commissioners for Recovering the Sick and Wounded, and was called "Captain" by the miners—this term being often applied by them to superintendents or engineers engaged about mines.

193. Savery's engine will be understood from the annexed cut and description.

Fig. 12.



Let A_1 A_2 represent sections of two large copper vessels, connected with the boiler in which the steam is formed by the tubes a_1 a_2 at the upper part; communicating at the lower extremities by the tubes f_1 f_2, with the lower tube *e*, the open extremity of which dips into the water to be raised, and called a *suction-pipe;* and communicating also with the upper tube *b*, called the *force-pipe*, which conveys the water to its destination.

194. There are four valves, c_1, c_2, d_1, d_2, opening upwards—that is, which yield readily to water pressing upwards, and allow it to *ascend*, but instantly shut by any force applied from above, and thus do not permit water to *descend* through them. These valves are most ingenious contrivances, and are essential in the construction of all machines in which liquids or gases circulate, as the air-pump, Bramah press, common water-pump, force-pump, steam-engine. They are exactly similar in action to the valves found at the apertures of the cavities in the hearts of animals, for *directing* the course of the blood.

195. Upon the tubes a_1 a_2 are cocks, by which the connection between the copper vessels and the boiler can be opened and shut at pleasure. *g* is a cistern of cold water, with a tube, *i*, coming from it, which can be turned so as to pour water over either of the copper vessels.

196. To set the engine at work, then, steam is admitted into one of the copper vessels—say a_1. It enters, and drives out the air by the valve, c_1. When full of steam, the connection with the boiler being closed, the pipe, *i*, is brought over the vessel A_1, and water from the rose jet at its extremity, poured upon A_1. This condenses the steam in the interior, and thus forms a vacuum, or a space containing vapour of very small elastic force (131). Immediately, the

water (pushed by the atmospheric pressure) rushes up in the *suction pipe e*, forces open the valve *d* 1, and, passing through *f* 1, enters the vessel A 1, and ascends in it until it attains such a height that its own pressure, together with the elastic force of any uncondensed vapour, balance the atmospheric pressure. This is the first part of the process, exactly similar, it will be seen, to the experiment described in paragraph 40.

197. The vessel A, being thus filled, or nearly filled, with water, the connection between it and the boiler is again opened. The steam, issuing from the boiler, presses upon the surface of the water in A 1, and expels the water, which, having no other course, is forced through the valve *c* 1, into the force-pipe *b*, where it ascends, and is removed as required. This is the second and last part of the action of this engine, exemplifying, on the large scale, the experiment described in paragraph 107.

198. These two vessels were used alternately for the preceding operations—the force of steam emptying one (A 1) of water, by pressing the water up the force-pipe; while, in the other (A 2), the vacuum was being formed, and the atmospheric pressure was filling it with water. Then, the first (A 1) being full of the steam which had forced out the water, the jet of water was turned upon it, while steam was admitted to press upon the water in the other (A 2), the engine being thus kept in continual action, or, at least, with very little intermission.

199. There is little of interest in the boiler used for this engine. The boilers of Newcomen and Watt's engines, will be fully described afterwards. The guage pipes for ascertaining the quantity of water in the boiler, were the invention of Savery, and he applied to his boiler the safety-valve, which was contrived by Papin for his Digester.

200. Savery's engine is a very beautiful piece of mechanism; but, as it never came extensively into use, and, though afterwards improved by Desaguliers and others, was abandoned upon the appearance of Newcomen's, we shall do little more here than point out briefly the defects under which it laboured, as well as the merits of its ingenious inventor.

201. By condensing the steam, and thus giving effect to the atmospheric pressure, he raised water cheaply and easily to a height of about twenty-six feet above its level, a clear gain of power; and, by the force of steam, he was able to elevate this water sixty-four feet higher; thus raising it, in all, by the combination of the two modes, ninety feet above its level, certainly a great step in advance of any previous method.

202. Savery suggested the application of his engine, also, to raising water for working mills, raising water to houses for domestic purposes, and extinguishing fires, supplying cities with water, draining fens and marshes, propelling ships; but he does not appear to have drawn out or published a plan for any other application, except that of raising water. Savery died about 1717. He was much esteemed and well spoken of by his contemporaries. He had the satisfaction of seeing his invention applied to practice. His engine was actually applied to draining mines and raising water for gardens, as we learn from statements by himself and others.

203. But it laboured under considerable disadvantages. One of the principal of these was, that it must be erected not more than about twenty-seven or twenty-six feet above the level of the water to be raised. Were the vacuum perfect in the copper vessel the atmospheric pressure would fill it with water, if its upper part were 33.87 feet above the water to be

raised. But the vacuum is never perfect; some vapour always remains, opposing the atmospheric pressure; so much that it was found that the water could not be raised much above twenty-six feet. Here, then, was a great drawback on the engine; so near the bottom of a mine, it would be very apt to be destroyed by the water rising, especially if, from any cause, its action should be suspended for a day or two.

204. Next, engines would be required at every 90 feet, as the vessels could not bear the enormous pressure of steam (nor the boilers the heat) which would force water up to a height greater than 64 feet. 64 feet added to the 26 feet which the water was raised by atmospheric pressure, make 90. To balance the atmospheric pressure, the steam which acts on the water in the copper vessel must have an elastic force of 14.7 pounds on the square inch. Of course, it exerts no force in pressing the water up the force-pipe *till it exceeds the atmospheric pressure.* As the atmospheric pressure is equal to a column of water, 33.87 feet high, the steam must acquire the elastic force of another atmosphere—14.7 pounds per square inch more—to force the water to a height of 33.87 feet in the force-pipe; and 14.7 pounds more, to raise it 67.74 feet; in all, 44.1 pounds on the square inch, an enormous pressure on the boiler and copper vessels. 14.7 pounds of this are balanced by the external atmospheric pressure, leaving a *bursting pressure* of 29.4 pounds on every square inch. The vessels cannot with safety bear more than this—so that the action of the engine is limited to raising water 90 feet above its level; hence in mines, an engine would be required for every 15 fathoms (90 feet,) and the whole would be suspended when one got out of order. Indeed, Mr Savery himself recommended that the engines should not be applied for a lift of more than from 60 to 80 feet.

205. In the third place, the engines required to be small—large ones could not be made sufficiently strong—so that they raised but a small quantity of water, and, at each 15 fathoms, several would be required.

206. Lastly, the expense of fuel for these engines was very great, from two causes:—*First*, The high pressure of the steam, which (by the table in par. 126,) would require to be of the temperature 274° Fahrenheit, in order to produce an effective pressure of 44.1 pounds on the square inch; and, *second*, from the waste of heat in the alternate cooling and heating of the copper vessels, and in the condensation of the steam before it heated the surface of the water in the copper vessel up to its own temperature. There was also considerable risk of explosion.

207. The part of Savery's engine, however, in which water is raised by atmospheric pressure, has been advantageously applied to raise water short distances, as twenty to twenty-five feet. In this case, the engine was made self-acting, and there was an air-valve by which the air which entered with the steam and water was blown out—this was necessary that the vacuum might be as complete as possible. Several engines were constructed upon this plan by Mr Rigby in Lancashire, and one in London. The water raised turned an overshot water-wheel by which the machinery was impelled in the usual way. In some situations, Savery's engine might still be used with advantage. See paragraphs 212—14.

SECTION III.

PAPIN AND DESAGULIERS.

PAPIN.—1707.

208. In 1707, Papin published, at Cassel, a tract entitled "New method for Raising Water by the Force of Fire." His plan was essentially the same as that of one part of Savery's—that in which the water was raised by the elastic force of the steam. The chief differences were, that the vessel in which the steam acted on the water was cylindrical, and that the steam did not come into direct contact with the water, but was separated from it by a movable float or piston. This was a decided improvement, less steam being thereby lost by condensation. The steam, after acting on the water, was permitted to escape into the air. This engine does not possess much merit: not using the steam for making a vacuum thereby to take advantage of the atmospheric pressure, it was decidedly inferior to Savery's, and never came into use.

209. Papin proposed this engine as a means of giving motion to a water-wheel, the water raised being made to fall upon the floats of the wheel, and turn it round in the usual manner. That the stream might be continuous, an air-vessel was interposed between the opening from which the water issued to the wheel and the receiver from which it was expelled by the steam. The air became compressed in the air-vessel, and by its elastic force in expanding again, pressed out the water in a continuous stream. The work in which this engine was described, was not published till nine

years after the date of Savery's patent, and in it Papin admits that he had seen the engravings of Savery's engine ; so that, considering how little it is superior to the engines of De Caus and Worcester, and how far inferior to that of Savery, which certainly had the advantage in point of priority of discovery, Papin cannot on account of *this engine*, be entitled to a place among the inventors of the steam-engine. His claims to a place in that list must rest on his first contrivances, described in paragraphs 185—189.

DESAGULIERS.—1718.

210. Desaguliers—well known as the author of a work on natural philosophy, entitled, "Course of Experimental Philosophy," published in 1743—made some valuable improvements in Savery's Engine, which gave it as great efficiency, perhaps, as it was capable of, and enabled it to be employed in some circumstances with advantage. He employed only one receiver, and condensed the steam by throwing a shower of water within the receiver, instead of upon its external surface. He thought that, by employing only one receiver, and confining the steam in the boiler while the receiver was being filled by the atmospheric pressure, the steam would acquire such strength that, upon being turned into the receiver, now filled with water, it would press up a considerable portion of water even before the upper surface of the water had become much heated ; and that thus there would be less loss of steam than in the original plan, where the steam acted without intermission, being thrown into one receiver immediately after it had pressed the water out of another. It is then weak, requires some time to recover its force, and in this time must heat to a considerable depth the stratum of water at the surface.

In experimenting on the subject with a model that could be worked either with one or two receivers, it was found that one receiver could be discharged of water thrice in the same time in which two receivers could be discharged one each. The simple engine would only cost about one half of the engine with two receivers, and would do about one-third more work.

211. About the year 1718, Desaguliers made one of these engines for the Czar, (Peter the Great,) which was erected in his gardens at St. Petersburgh. This engine raised water twenty-nine feet by suction, (the atmospheric pressure,) and eleven feet by the force of steam—forty feet in all. With others, used for forming artificial fountains in gardens, &c., water was raised fifty-three feet in all—twenty-nine by the atmospheric pressure, twenty-four by the force of steam.

212. "Savery's Engine," says Farey, "may be usefully employed for raising water to a height of thirty or thirty-five feet, which can be done principally by suction, with only a very slight pressure for the remainder. Several small engines have been erected upon this plan; and, where the water which is raised requires to be immediately heated, they are very capital machines; because all the loss of heat being thrown into the water warms it, before it enters the boiler in which it is to be heated, so as to economize the whole of the heat—for instance, for the purpose of raising water into the evaporating boilers of a salt or alum work, or for a brewery; they are also particularly applicable for raising water for warm baths.

"A small engine of this kind was made by M. Genjembre, of Paris, in 1820, for raising water for a floating bath in the river Seine, and answered the purpose completely."

213. Desaguliers observes of his engine—in con-

trasting it with Newcomen's, then coming into general use—"Savery's Engine, on my plan, consists of so few parts that it comes very cheap in proportion to the water it raises; but has its limits. Newcomen's Cylinder-Engine has also its limits the other way: it must not be too small; for then it will have a great deal of friction, in proportion to the water that it raises, and will cost too much, having as many parts as the largest engines."

214. For small quantities of water to be raised moderate heights (twenty-five feet), and heated, Savery's engine, working by the atmospheric pressure only, is still advantageously employed. The first cost is trifling; and it is little liable to go out of order, or need much for repairs. There are five in France.

SECTION IV.

NEWCOMEN AND CAWLEY.—1705–13.

Atmospheric Engine.

215. The disadvantages under which the engine of Savery laboured, notwithstanding the ingenious advances he made in the application of steam, were such as greatly limited the sphere of its action, and rendered it of not much value towards the great object for which steam was at first applied as a moving power—raising water from deep pits and mines.

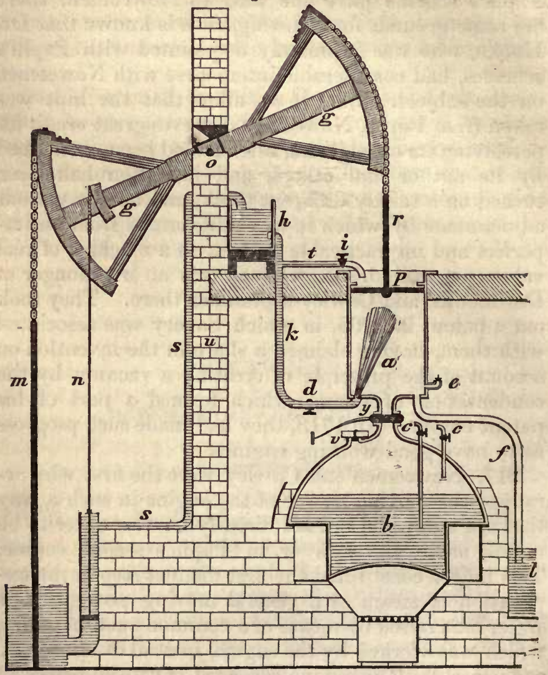
216. In the next great improvements effected on the steam-engine, those of Newcomen and Cawley, the plans formerly in use were abandoned, and recourse

was had to the method suggested by Papin's first project—viz., that of a piston pressed down in a cylinder by the atmospheric pressure, a vacuum having previously been formed below the piston by filling the space with steam, which was then condensed. That Papin's scheme gave the hint to Newcomen, there are some grounds for believing, as it is known that Dr. Hooke, who was intimately acquainted with Papin's schemes, had considerable intercourse with Newcomen on the subject. But, if we allow that the hint was taken from Papin, Newcomen deserves great credit for perceiving its capabilities, after it had been abandoned by its author and others, and invention had been turned on a totally different track, and for the various adjustments by which it was transformed from an imperfect and impracticable project, to a machine of real value to mankind. Newcomen was an ironmonger at Dartmouth, and Cawley a plumber there. They took out a patent in 1705, in which Savery was associated with them, having claimed a share in the invention on account of the principle of creating a vacuum by the condensation of steam, which formed a part of his patent engine. In 1713, they had made such progress as to have good working engines.

217. Newcomen and Cawley were the first who arranged the moving power of the engine in such a way that the steam did not act directly on the water to be raised, as in Savery's or in Papin's second engine. This indeed constituted the first distinct step in the application of steam as a general moving power. The water was raised by means of a common suction pump, which was worked by the engine, instead of by horses, as formerly. The engine consisted of THREE principal parts: 1*st*, THE BOILER, a separate vessel in which the steam was generated; 2*nd*, THE CYLINDER, in which the steam was condensed; and, 3*rd*, THE BEAM, whose

movements followed the alternate admission and condensation of the steam, and which communicated the motion to the rod of the pump. The figure below (*Fig.* 13) represents, in section, Newcomen's or the Atmospheric Engine.

Fig. 13.



218. The boiler (which is seen in the accompanying diagram, below the cylinder, and marked *b*) is a large iron vessel, of proportionate strength and thickness. It

is placed over a furnace, and in it the water is heated and converted into steam. From the upper part of it, a tube proceeds to a cylinder (*a*) conveying the steam there, to be condensed. This tube has fitted to it, a valve or sliding plate (*y*), which can be opened and shut with facility, and is called the *regulator*, or *regulating valve.* By it the communication between the cylinder and boiler is opened or closed as may be required.

219. In the boiler, two tubes, or *guage-pipes* (*cc*), each furnished with a stop-cock, are placed vertically, for the purpose of ascertaining the quantity of water in the boiler. It should contain water to the height of about two-thirds from the bottom; that is, supposing the boiler three feet deep, the water in it should be about two feet deep. One of these pipes descends into the boiler somewhat lower than one-third from the top, being more than a foot long within the boiler, supposing it to be of the size first-mentioned. The other descends to a little less than one-third from the top. In short, the guage-pipes are made of such length that the extremity of the short one is a little above, and that of the long one a little below the proper level of the water. Accordingly, when the boiler is heated, if the water be at its proper level, on opening the cocks of the two guage-pipes water will be discharged from the longer one, and steam from the shorter one. If the water be too low, steam will issue from both pipes; if too high, water will be discharged from both pipes. The water rises in and is discharged from the pipes by the elastic force of the steam which occupies the upper part of the boiler. This method of ascertaining the level of the water, was proposed by Savery. It is still in use.

220. On the side of the boiler opposite to that of the guage-pipes, is the safety-valve (*v*), loaded to the

necessary extent, but not much in this engine, (about 1 lb. per square inch,) as it works at a low pressure. The action of the safety-valve will be explained in the description of Watt's engine.

221. Immediately above, and communicating with the boiler, by the tube between them, is the CYLINDER (*a*). In this works the PISTON, by the descent and ascent of which the motion is procured. The piston is a solid cylinder, broad and shallow, and fitting accurately into the large cylinder; the surfaces of each being very smooth, so that the piston can slide easily up and down; but so closely fitted tnat no air or steam can pass between them. The cylinder is open at the top, and has three apertures below, besides the opening of the tube from the boiler. The first of these apertures, that at the left, is the mouth of the tube (*k*) which conveys the water to condense the steam. It is supplied with a valve, or stop-cock (*d*), called the injection cock, which can be opened or shut at will; and it leads from a cistern (*h*) in which there is a constant supply of cold water, brought there from the well by the action of the engine itself. This water is pumped by the rod *n*, seen attached to the beam, and the water rises to the cistern through the tube *s s*. The water thus thrown into the cylinder, would gradually accumulate, along with that produced by the condensed steam, and impede the action of the piston; it is, therefore, removed by a pipe (*f*) called the eduction-pipe, leading from the second aperture, at the bottom and opposite side of the cylinder, to a cistern of water below (*l*.) The eduction-pipe proceeds from the lowest part of the cylinder, and descends to a considerable depth. It has, at its lower extremity, a valve opening outwards, so that no water can return from the cistern *l*, into the eduction-pipe. Another aperture technically

called the *blowing valve*, or *snifting valve* (*e*), is situated nearly opposite to the mouth of the injection-pipe; it is supplied with a plug, or valve, opening outwards, and permitting the exit, but not the entrance, of any fluids. Through it the air is expelled before the engine is started, and also any air entering along with the steam (158), and that may remain in the cylinder after each condensation of steam. In order effectually to expel this air, the steam requires to have an elastic force somewhat greater than the air's pressure. From the cold-water cistern (*h*), which supplies water for the purpose of condensation, a small pipe (*t*) leads to the top of the cylinder, discharging water on the piston, to preserve it air-tight, on turning the stop-cock (*i*.)

222. On the large support (*u*) is placed a lever, or beam, which turns as on an axis at its centre or pivot (*o*,) like the beam of a common balance. At the one extremity of it, is an arch-head, to which a chain is attached. The lower extremity of this chain is connected to the piston-rod (*r*), which, being fixed to the piston (*p*), these parts will move simultaneously up and down.

223. At the other extremity of the beam, which has a similar arch-head, another chain is attached to it; so that it is heavier and more than a balance for the piston-rod, piston, and friction of the piston in the cylinder; and, accordingly, if other forces which may tend to elevate or depress the piston be in equilibrio, the weight will draw down the end of the beam to which it is attached, and elevate the other extremity of the beam—in which position they are shewn in the figure, page 102. The rod *n*, which works the pump for supplying water to the cistern, for condensing the steam, is attached to this part of the beam, near the end.

224. It now remains to describe the mode in which the engine is worked. The piston being at the top of the cylinder, and the latter full of air, the regulating-valve (*y*) is opened, so as to admit the steam to the cylinder. The force of the air and steam push open the snifting-valve (*e*), through which the air and steam escape together. Soon, the cylinder contains steam only. When this is the case, the connection between the cylinder and boiler is closed; and the injection-cock (*d*) is opened, by which means a jet of cold water is thrown in upon the steam. This jet strikes upon the piston, and falls from it like a shower through the cylinder, and, by condensing the steam, produces a vacuum in the cylinder below the piston. The atmospheric pressure, acting downwards on the upper surface of the piston, not being now resisted by air, or vapour of any considerable force, presses down the piston to the bottom of the cylinder; the atmospheric pressure on the upper surface of the piston being more than a balance for the effects of the forces tending to depress the other extremity of the beam. The piston-rod pulls down one end of the beam, and, of course, raises the other, which elevates the pump-rod, and thus lifts the water from the mine. The outer extremities of the eduction-pipe and snifting-valve, having valves or plugs that open outwards, the atmospheric pressure closes them effectually when the condensation in the interior takes place.

225. The piston, having now reached the bottom of the cylinder, the force of the atmospheric pressure (amounting to 14.7 pounds on every square inch of its upper surface) will keep it there, if no means be employed to counterbalance this pressure. But, if force be applied on the lower surface, so that the pressure on both sides of it be made equal, it will be raised again by the greater weight of the pump-rod, which,

descending, causes the piston to ascend, just as in a pair of scales, nicely adjusted, any excess of weight thrown upon one causes the other to rise. For this purpose, the valve (*y*) in the tube leading from the boiler to the cylinder, is opened, and the steam, which has been accumulating and acquiring strength during the descent of the piston, rushes in, blows open the snifting-valve, aids in expelling the water through the eduction-pipe, and presses upon the lower surface of the piston. By balancing the atmospheric pressure on the surface of the piston, the elastic force of the steam gives effect to the weights attached to the other end ot the beam, which will then pull down the beam at that end, and elevate the piston. The beam, piston, &c., are now in the position shown in *Fig.* 13.

226. By the successive repetition of these operations, the engine is steadily worked.

227. The condensed steam, and the water employed to condense it, are removed by the eduction-pipe *(f)* to the cistern *(l)*, from whence, by a tube passing into the boiler, and opening near the bottom, the boiler may be supplied as required. The water thus supplied to it is warm, containing the heat of the condensed steam; and it thus carries back a part of the heat which the steam conveyed from the boiler. This plan was first employed by Beighton, and is now practised in Watt's engines.

228. The condensation of the steam had, at first, been effected by cooling the cylinder externally, as in Savery's Engine. The cylinder was enclosed by another cylinder, with a space between, into which space cold water was poured. Latterly, this was accomplished by the injection of cold water into the interior of the cylinder, the water thereby coming into direct contact with the steam to be condensed—a much more efficacious method, and which is still employed. The

discovery of this simple and effectual plan of condensation was the result of accident, according to Desaguliers. "One thing," says he, "is very remarkable. As they at first were working, they were surprised to see the engine go several strokes, and very quick together, when, 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, whereas, before, they had always done it on the outside." This hint was followed up by the condensing pipe for injecting water into the interior of the cylinder; and thus the clumsy expedient of the double cylinder was avoided. There is no substance which answers so well for condensing steam as water. Water has a high specific heat (requires a great deal of heat to raise its temperature—see paragraph 148), and, therefore, rapidly withdraws much heat from the vapour.

229. The vacuum in this engine is produced by the condensation of steam below the piston. The steam, therefore, is not the direct cause of the power, but becomes so indirectly, furnishing, by its condensation, an easy method of forming a vacuum, which gives effect to the atmospheric pressure. As the pressure of the atmosphere, then, is the real moving power in Newcomen's Engine, it has been termed the ATMOSPHERIC ENGINE. At one stage of the action of this engine, however, the steam *is* used to give power—namely, where it is admitted to act on the lower surface of the piston when at the bottom of the cylinder, neutralizing the atmospheric pressure by its elastic power, and thereby giving effect to the weight at the pump-rod, which then raises the piston. In fact, being of an elastic force greater than that of the air's pressure, it actually does aid, though slightly, in pressing the piston upwards.

230. As the pressure of the air acts with a force

equal to 14.7 pounds on the square inch, the force exerted by this engine will be in proportion to the number of square inches in the surface of the piston. But the full amount of the atmospheric pressure cannot be taken as the exact measure of the force exerted —(admitting the vacuum to be complete, which is never the case). The effect of friction between the piston and cylinder will diminish the power. Also, the weight attached to the pump-rod, in order that it may counterbalance the piston, the excess of which over the weight of the piston must be neutralized, will, to the extent of that excess, diminish the power to be procured from the descent of the piston. Further, as water, even at a low temperature, and rapidly under diminished pressure, passes into vapour, vapour will remain in the cylinder, and, by its elastic force, will tend to resist the descent of the piston, and diminish the force of the engine. It has been estimated that the elasticity of this vapour would be about four pounds per square inch, the temperature being from 140° to 160° within the cylinder. Subtracting this, and the effect of the other obstacles to the full force of the air's pressure being rendered effective, it has been estimated that a power would remain equal to about seven or eight pounds on each square inch of the surface of the piston. In general, this engine has been worked in such a manner as to raise a load of seven, or seven and a half pounds, for every square inch of the surface of the piston.

231. In this manner, Newcomen's Engine worked. At first, there was one serious difficulty under which it laboured, in common with Savery's—the necessity of a constant attendant to open and shut the valves (the regulator-valve and injection-cock), as the piston ascended and descended; for, unless this was done with great regularity, the engine would not work with

any steadiness or precision. These valves were worked by levers, which were raised by the attendant when necessary. One of them, the injection-cock, was, according to Desaguliers, worked by the engine itself. He says—"They used to work with a buoy to the cylinder, enclosed in a pipe, which buoy rose, when the steam was strong, and opened the injection." Then he mentions that a boy, named Humphrey Potter, who attended the engine in 1713, "Added (what he called *scoggan)* a catch, that the beam always opened." Potter, to save himself the trouble of constant watching, seems to have contrived to make the engine work the levers of the valves by strings attached to the beam, which, by its movements, caused the strings to open and shut the valves. Further improvements were made by Beighton, an engineer, who fixed to the beam a rod called a plug-frame, with pins or catches in it, which opened and shut the valves with great precision and regularity, so that no attendant was required for that purpose, and the engine thus worked itself. A plan similar to Beighton's was at first employed by Watt to work the valves of his engine. Making the engine itself work the valves was a very great step towards the formation of an efficient engine.

232. The engine was afterwards (1772) improved in many subordinate matters by the celebrated Smeaton. He applied his skill and scientific knowledge to determine the proper proportions of the various parts, and thus constructed engines which performed more work than any previous ones. Otherwise, no very material changes were effected upon it, excepting the adapting to it a crank and fly-wheel, to procure from the reciprocating vertical motion of the piston a continued circular motion. This was done about the year 1780.

233. The principal advantages of the atmospheric engine are—the almost unlimited extent of the power which could be commanded, as this depended solely on the range of surface of the piston; the low degree of temperature and pressure at which the steam was produced (about 216° F., and not greater than one pound on the square inch above the atmospheric pressure), consequently there would be little risk of explosion, or of injury to the boiler from the temperature applied; the simple mode in which the condensation was effected; and, lastly, its self-acting power in opening and closing the valves.

234. The leading defects of Newcomen's engine were—*First,* The alternate heating and cooling of the cylinder, during which a great quantity of steam was lost. When the cylinder has been cooled down by the cold water thrown into it for the purpose of condensing the steam, it must again be raised to the temperature of steam before any steam can remain in it. In effecting this, there must necessarily be a great loss, as the steam which effects this rise in temperature in the cylinder will be condensed in so doing, until the cylinder becomes so hot as not to condense it any more. *Secondly,* The quantity of air which rushes in during the depression of the piston by the atmospheric pressure, will, in like manner, tend also to cool the cylinder. A similar effect results from the action of the water poured on the piston to keep it tight. The total amount of heat lost in the atmospheric engine was estimated by Watt at three times as much as was applied to the efficient action of the engine. *Lastly,* in consequence of the temperature of the cylinder in which the condensation takes place, vapour of considerable elasticity exists in it, and, by its elastic force, resists the descent of the piston. The vacuum might be made more complete by throwing in a very

large quantity of injection water, and thereby cooling the cylinder more completely; but, then, there would be a very great waste of steam in heating it up again, while the great quantity of injection water required would be inconvenient. After many experiments and observations, it was considered that it was most economical to work the engine so as to have an effective pressure of seven to eight pounds on the surface of the piston; the vapour in the interior of the cylinder having an elasticity of about four pounds to the square inch.

235. The merit of Newcomen's engine lay, not in invention, but in the adoption and happy combination of contrivances already known, so as to produce an engine, which, *as a whole*, might be regarded as entirely new. Tredgold, speaking of Newcomen's adjustments, says "that they produce all the difference between an efficient and an inefficient engine." Newcomen's engine was the first really efficient steam-engine—that is, the first engine which could be applied *profitably* and *safely* to the more important purposes for which such machines were required at the time of its invention. It is still occasionally ordered, for situations where fuel is cheap, the first cost being comparatively small. It is fitted with a condenser, separate from the cylinder, by which its action is much improved.

236. Though now superseded by Watt's, Newcomen's engine ought not to be forgotten. Even had it never come into use, its value, as a great step in the progress of invention—as the raw material out of which Watt constructed his admirable engine—cannot be too highly estimated. But it was a machine of great practical utility. It came into operation about 1712, and continued to be used exclusively for about sixty-two years (till 1774); and for a considerable

time afterwards was much employed. In 1797, it was still so much in use and so much esteemed, that a work was written upon it by Mr. Carr. Thus, for nearly a hundred years, it was the chief hydraulic machine; and it was a century of unusual activity—of awakening energy in arts and manufactures. When it was first introduced, many valuable mines could not be worked on account of the accumulation of water. This engine not only rendered these available, but enabled others to be deepened and new ones to be opened, which could not have been done without some powerful means of raising water, cheap, safe, and manageable; which was not known till Newcomen's engine appeared. His engine was soon applied and continued to be used with great advantage in the coal-mines of the north of England, the tin and copper mines of Cornwall, and the lead mines of Cumberland, &c. It was employed in cities for supplying the inhabitants with water; in 1752 and afterwards, it was used for raising water to drive water-wheels for mills; it was used for blowing the air into the blast-furnaces for smelting iron ore; and was soon taken advantage of on the Continent for similar purposes. When these things are borne in mind, we must admit that society is under no small obligations to the inventor of a machine which, for so long a period, was an essential agent in procuring an adequate supply of materials absolutely necessary to a people advancing rapidly in numbers and civilization.

SECTION V.

JAMES WATT.—1765.

237. In describing the engine of James Watt, the next to Newcomen's in the progress of invention, and that engine which is now known and used as The Steam-Engine, we shall proceed at once to explain it in its more perfect form, reserving to the close of the section a sketch of its history and progress from the first conceptions of its author on the subject, and a short notice of his life.

238. The chief defect of the atmospheric engine was the great waste of steam, arising principally from the alternate cooling and heating of the cylinder; also, the vacuum was never complete, so that there was a considerable resistance by vapour within the cylinder to the descent of the piston. In the year 1763, while engaged in repairing a model of an atmospheric engine for the University of Glasgow, the attention of Watt was directed to the study of the steam-engine. He performed a good many experiments on the subject, and found that, when much water was thrown in, to make a very complete vacuum, there was a great power obtained, but a great waste of fuel in heating the cylinder after being so much cooled—while, when little injection water was thrown in, vapour of considerable elasticity remained. Hence he sought for some method of *condensing the steam without cooling the cylinder;* and in the year 1765, it occurred to him "that, if a communication were opened between a cylinder containing steam, and another vessel which was 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 esta-

blished 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, a separate vessel for condensing the steam, was Watt's grand improvement on the steam-engine.

239. By detaching the apparatus for condensation—that is, by having, separate from the cylinder, a vessel in which the steam was to be condensed, he accomplished the two grand objects of preserving the cylinder at an uniform high temperature, and of having a perfect vacuum within the cylinder, so that little resistance was offered to the descent of the piston. By preserving the cylinder constantly at the necessary temperature, no steam was wasted in raising its temperature, as in the atmospheric engine; and thus was solved the great problem in the steam-engine—*forming a vacuum without cooling the cylinder;* thereby saving all the steam which was formerly used in heating the cylinder from the condensing point up to the boiling point, after each condensation.

240. This separate vessel, called THE CONDENSER, communicates freely with the lower part of the cylinder by a tube of considerable diameter. The condenser is kept constantly cold by being immersed in a well or cistern of cold water, which is withdrawn as it becomes heated, and fresh water supplied; and the rapid and constant condensation of the steam is insured by a jet of cold water, which continually plays into the interior of the condenser. By these means, the temperature in the interior of the condenser is kept at about 100° Fahrenheit; the vapour then having a force of only about 0.97 lbs.—less than one pound to the square inch. And, in that part of the cylinder which communicates with the condenser, the elasticity of the vapour will be equally low.

241. The injection water, the water formed by the condensed steam, and the air which enters along with the steam (158), would soon accumulate, and fill up the condenser. This is prevented by establishing a communication between the lower part of the condenser and an AIR-PUMP, which is worked by the engine itself, withdraws the water and air which would otherwise have accumulated, and preserves the condenser always in working condition. The air-pump acts exactly on the same principle as that explained in paragraph 104.

242. In Newcomen's engine, a cooling effect was produced by the cold air following the piston in its descent. It was necessary that this should be avoided, if the cylinder were to be preserved at a uniform high temperature. Accordingly, the cylinder was closed at the top, the piston-rod moving through an air-tight and steam-tight aperture.

243. The air being thus entirely excluded, *the descent of the piston was effected by the introduction of steam above it;* and the elastic force of steam from the boiler was substituted for the atmospheric pressure in pressing down the piston. Thus the engine became really a STEAM-ENGINE. Steam was employed to form the vacuum, and steam was employed to give the force or moving power.

244. In the atmospheric engine, the cylinder was considerably reduced in temperature by the action of the surrounding air. To prevent loss of heat from this cause, Watt enclosed the working cylinder in another (called a jacket) of wood, or some substance which gave heat a slow passage through it, and thus tended to confine the heat in the cylinder.

245. From the employment of steam to press the piston down, this advantage also was gained—the engine was not limited to one degree of force—that of

the atmospheric pressure; but its power might be increased or diminished, according to the force of the steam used to effect the motion, which, within certain limits, could be varied considerably.

246. In Newcomen's engine, the piston was kept air-tight by water poured over its surface. This was inapplicable in Watt's method, where the piston was moved by the force of steam, and the cylinder was closed above, as, if any water entered the hot cylinder, it would cool it, and condense the steam so as to diminish its force; or at another time, pass into vapour, and retard the production of a vacuum. He, accordingly, preserved the piston air-tight by melted tallow, wax, and oil.

247. In Newcomen's engine, there was only a downward motion of the piston available as a force: the piston was pulled upwards by the clumsy expedient of a weight attached to the other end of the beam, and gave no impulse in ascending. In the double-acting engine of Watt,—which we are now describing,—by the beautiful contrivance of *causing the steam to enter alternately* ABOVE *and* BELOW *the piston*, and, at the same time, *forming the vacuum alternately* BELOW *and* ABOVE *the piston*, a moving force was communicated to the piston in ascending as well as in descending, and thus a continuous moving power produced.

248. Lastly, by machinery which will be presently described, Watt converted the up-and-down (alternate rectilinear) motion of the piston, into a continued circular motion, and insured steadiness and regularity in the motions of the engine, so as to adapt it for impelling machinery.

249. The leading changes effected by Watt in the steam-engine, and which were such as entirely to alter its character, are those just mentioned; it may be well briefly to recapitulate them here.

1. Condensation of the steam in a separate vessel.
2. Removal of the air and water from the condenser by an air-pump.
3. Producing the movement by the aid of steam instead of the atmospheric pressure.
4. Giving the piston an impulse or moving power in ascending as well as in descending.
5. Converting the alternate rectilinear motion of the piston into a continued circular motion, so as to adapt the machine for impelling machinery.
6. Watt also introduced a very ingenious method of working the steam, so as to economize it considerably. This, which is termed working the steam expansively, will be described afterwards.

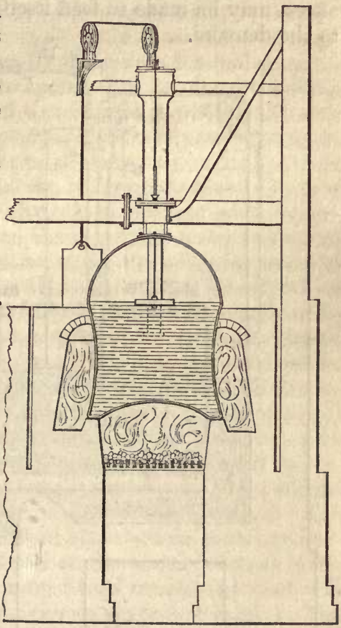
250. Many other arrangements were introduced to render the action of the engine regular and uniform, and thus fit it for machinery, and to give it a self-acting power, so that, when once set in motion, the least possible amount of attendance might be necessary to preserve it in continued action. We shall now describe these in detail, commencing with the boiler.

THE BOILER.

251. This is the vessel in which the steam is generated, and forms an exceedingly interesting part of the steam-engine. Nothing can be more beautiful than those adjustments of the boiler and cylinder to each other, by which the engine itself regulates the supply of steam to the cylinder, of water to the boiler, and of heat to the furnace. It thus, in a manner, itself proportions the supply to the demand; and with so much regularity and precision, that the engine in its movements almost rivals the voluntary motions of living beings. The boiler now to be described is that of land

engines, acting on the principle of condensation; *low-pressure engines or condensing engines*, as they are generally termed. The boilers of marine condensing engines are similar in their construction, varying a little in form. These, and the boilers of high pressure engines will be described afterwards.

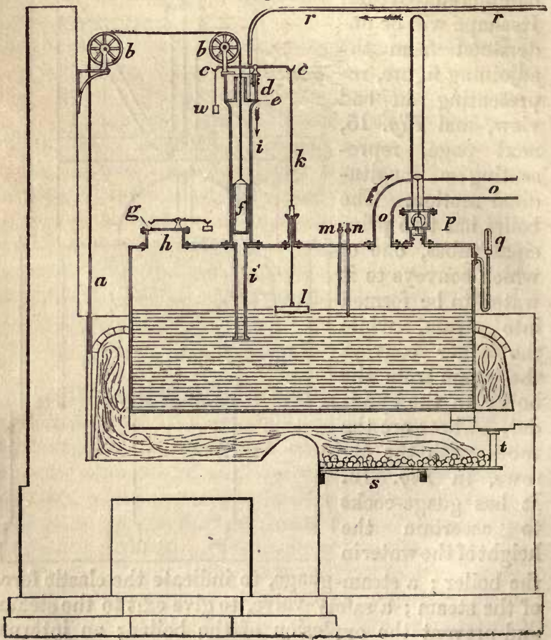
Fig. 14.



252. The boiler is a large vessel formed of sheet-iron plates hammered together. Its shape will be understood from the adjoining figure, representing an end view, and *Fig.* 15, next page, representing a longitudinal section. The boiler has two principal tubes, one of which conveys to it water to be formed into steam, while the other conveys the steam from the boiler to the cylinder. These are the tubes with the arrows, in *Fig.* 15. It has guage-cocks to ascertain the height of the water in the boiler; a steam-guage, to indicate the elastic force of the steam; a safety-valve, to give exit to the steam, and prevent the explosion of the boiler; an internal safety-valve, to give access to the air, and prevent

the compression of the sides of the boiler by atmospheric pressure, should the elastic force of the steam in the interior be suddenly much diminished from any cause; and a man-hole, by which admission may be had to clean the boiler when necessary. The boiler is placed upon a furnace, supplied with a self-acting damper; and, by Brunton's and other contrivances, may be made to feed itself with fuel, according to the demand.

Fig. 15.



253. *The Feed-pipe.*—The tube (*i i*) which conveys the water into the boiler is termed the feed-pipe. It proceeds from a cistern *d* placed above the boiler, and terminates a little lower than half-way between the top and bottom of the boiler. The cistern *d* is freely supplied with hot water by the pipe *r r*, which proceeds from the hot well, and conveys (by a pump worked by the engine) the warm water of the hot well to the cistern *d*. The water thus conveyed to the cistern would fall directly down into the boiler by the pipe *i i*, were it quite open. But as the demand for steam is not always the same, and it will not therefore do to have a *constant* quantity of water supplied to the boiler, too much water might enter the boiler; or there might be too little, and the boiler might then be injured by the heat. The feed-pipe, to prevent such irregularities, and proportion the supply of water to the demand, is rendered self-acting in the following manner. At the bottom of the cistern a valve (*e*) is placed, which opens *upwards* when the rod which attaches it to the lever *c c* is raised, and admits water from the cistern to the tube *i i* below it. The lever, as will be seen, moves on a fixed point at the upper part of the cistern. To one extremity of the lever a small rod or wire (*k*) is attached, which passes through an air-tight aperture into the boiler, supporting a stone-float at its extremity. This stone-float is counterpoised by a weight (*w*) attached to the other end of the lever *c c*. The weight is such as to balance the float *in water*, and accordingly, when the level of the water becomes lower from so much being formed into steam, the float will descend (as the weight cannot support it in air.) The float descending will pull down the arm of the lever to which it is attached, elevate the other arm, and thus open the valve in the cistern, so that water will pass from it into the boiler. When the float has been thus

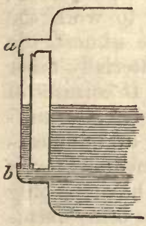
raised sufficiently, the weight will then pull down its arm of the lever and shut the valve, so that no more water will enter. In this manner the water is kept always near the same level in the boiler. The cistern is supplied abundantly with water by the pipe (*r r*) from the *hot well*, as it is called, the water in which is warm; so that there is a gain of heat proportioned to the excess of the temperature of the water thus pumped in over the usual temperature of water: this will be explained in the description of the engine.

254. Connected with the feed-pipe of the boiler, there is a contrivance of great ingenuity called the *self-acting damper*. If the quantity of water supplied be uniform, the amount of steam produced will vary according to the intensity of the fire. If the fire be too strong, more steam will be formed than is required —if weak, too little steam will be produced. By a *damper*, which contracts or enlarges the throat of the flue of the furnace, the strength of the fire may be increased or diminished, and the quantity of steam will vary accordingly. As the steam in the boiler presses on the water, this water will rise in an open tube to which it has access to a height proportioned to the pressure. The feed-pipe *i i* is such a tube: in it a weight (*f*) is suspended, connected by a chain with the damper *a*. The chain passes through a separate tube in the cistern *d*, and over two pulleys (*b b*.) The weight *f* is such as just to balance the damper *a* when immersed to a certain extent in water in the tube *i i* forced up by the elastic force of the steam. Let the weight and damper be adjusted to the required force of the steam, and be in a state of rest. They will remain so until some change in the strength of the steam arises. Should its elastic force be increased, the water will be forced up in the tube; the weight (or a greater part of it) being now supported by water will be

lighter in relation to the damper, which is entirely suspended in air; the damper will therefore descend and contract the throat of the flue of the furnace; the draught will thus be diminished, the fire moderated, and less steam formed. Should the elastic force of the steam be diminished, the water will sink in the tube, the weight will descend, the damper will be raised, the draught be increased, the fire burn more briskly, and more steam will then be formed.

255. GUAGE COCKS.—The guage-cocks (*m n*) used to ascertain the height of water in the boiler are the same as in Newcomen's engine, and have been already described, (219.) Another method of ascertaining the height of the water in the boiler will be understood from the annexed figure. There are two apertures in the side or end of the boiler, one near the top, and another near the bottom. These are connected by a glass tube placed outside the boiler, *a b*, in which, communicating freely with the steam above and the water below, the level of the liquid will always be the same as that of the body of water in the boiler; and thus the height of the latter may be ascertained in a moment by a glance at the glass tube.

Fig. 16.



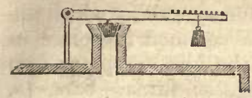
256. STEAM-GUAGE.—This is seen at *q*, at the right of the boiler, *Fig.* 15, page 120. It is fixed into the boiler, or some tube freely communicating with it, and is open at both ends,—to the interior of the boiler at one end—to the atmosphere at the other. It is curved, in the form of the letter U, and contains a quantity of mercury. The atmospheric pressure acts on the mercury in the limb open to it, with a force of 14.7 pounds per square inch. If the steam act with the same force, the mercury will be at the same level in both

limbs. If the steam be of higher elastic power than the air's pressure, it will depress the mercury in the limb on which it acts, and force it up to a corresponding height in the limb open to the air. The difference will indicate the excess of the force of the steam over the air's pressure. The tube may be of glass or iron. In the latter case, a float with a long rod rests upon the surface of the mercury exposed to the air, which rises or falls with the mercury; and, the upper extremity of the rod having a scale adjoining, it acts as an index, and shews the height of the liquid within the tube.

257. Safety Valve.—The object of this valve is to permit the escape of steam, should it accidentally become stronger than the boiler is intended to bear, and thus prevent the bursting or explosion of the boiler. It is a valve so loaded as to open with a pressure of steam, a little more than is necessary to work the engine, and considerably less than the utmost the boiler can bear. This valve does not materially differ from that used in Newcomen's engine. It consists of a lever, the joint or fulcrum of which is set on a support at the side of a short tube or pipe, communicating with the boiler. From the lever immediately over the aperture of the tube, a rod descends, having a plug attached, which closes the tube. To the other extremity of the lever, weights may be attached, at different distances from the fulcrum, which will have power in keeping down the valve or plug, in proportion to their distance from the fulcrum. The force of the steam will tend to push up the plug, (valve), and permit the escape of the steam; the atmospheric pressure, and the weight attached to the lever, will tend to press down the plug, and prevent the exit of steam. The valve will be open or shut, according to the relative strength of these forces acting on it in opposite directions. Its action will be understood from the figure

below. In steam-boat engines, a conical plug is used, from which a rod rises, on which circular weights are placed, perforated so that they can easily be slipped off or on the rod. The weights are thus placed above the valve, and when set, cannot shift. In the steel-yard valve, the weight slips along the arm of the lever, and thus acts with greater force; just as if more weights had been laid on.

Fig. 17.



258. Internal Safety-Valve.—The valve just described opens outwards. There is another which opens inwards, therefore termed the *internal safety-valve.* The use of this valve is to admit the air to the interior, should the steam be suddenly condensed from any cause. Were there no such contrivance, the atmospheric pressure on the external surface of the boiler (14.7 lbs. on every square inch) might crush the boiler (termed *collapse*) on any sudden diminution of the elastic force of the steam. But the internal valve yields and admits air when the internal pressure on it is much diminished, and thus produces an equilibrium. The internal safety-valve is shewn at *g*, at the left of *Fig.* 15.

259. The Man-Hole.—The large opening at *g*, *Fig.* 15, is to give entrance to the interior of the boiler, for the purpose of cleaning it. This is an operation performed at longer or shorter intervals, according to the quality of water employed for the production of the steam. If the water contain much saline matter, the boiler must be cleaned frequently, otherwise there is a great waste of fuel in heating the water through the crust which forms at the bottom, and also a risk of burning the boiler, as, if the heat is not quickly carried off from the boiler in the form of steam, the metal becomes too hot, and then is more apt to oxidate

(rust). Also, from being too hot, it causes risk of an explosion.

260. The Furnace.—The furnace, above which the boiler is placed, differs from a common fire-place in being entirely excluded from the air, except at two parts:—*First*, At the grating, or furnace-bars, (*s*, *Fig.* 15,) on which the fuel rests, and between which air enters and supports the combustion; *second*, At the throat at the bottom of the chimney, where the smoke and products of the combustion quit the furnace. Thus, no cold air is admitted into the chimney or above the fire, as in a common fire-place; and hence the draught is more powerful, air supplied more quickly to the fuel, and the heat produced more intense. In *Fig.* 15, *t* is the door of the furnace, by which fuel is introduced, and at which air can be admitted, if necessary. The damper, by which the current of air is increased or diminished, is shewn at *a*.

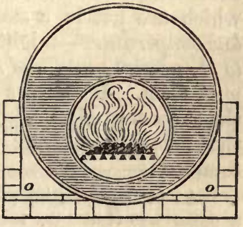
261. There are many contrivances for preventing smoke. This is affected by constructing the furnace so that the fresh coal is introduced *below* the ignited coal, by which the smoke arising from the fresh coal is burnt or consumed as it rises. Considerable saving is effected in this manner, as the smoke contains much charcoal in suspension, in fine powder—much fuel being thus lost in ordinary smoking furnaces. The principle of Witty's smoke-consuming furnace will be readily understood, if we conceive a common fire to be mended by pushing fresh coals in *below*, instead of laying them on at the top.

262. A very ingenious furnace has been constructed by Mr Brunton of Birmingham, which may be termed a self-feeding furnace. He made the furnace circular, and connected to it a hopper placed above, which supplied it with coals. The furnace was made movable, and caused to revolve, by being connected with the

steam-engine; and thus a very uniform supply of heat was supplied to the boiler above. In each revolution, the hopper opened, and discharged coals into it, and this feeder was regulated by communication with the damper; so that the coal supplied was increased or diminished according to the demand of the engine. Another furnace, having similar objects, is much used in Lancashire.

263. With the view of saving fuel, by exposing more of the boiler to the action of the heat, the furnace is often placed inside the boiler. The boiler is made very long and cylindrical, an inner cylinder, continued along its whole length, containing the furnace, and forming a great part of the flue, as in *Fig.* 18, shewing a cross perpendicular section, which will convey at once an idea of the form of such boilers. This is termed the *cylinder boiler*, and is much used in Cornwall. The flues, *o o*, passing along the sides of the boiler, convey the heated air from the inner cylinder to the chimney, by which a considerable amount of heat is turned to account.

Fig. 18.



264. The economy of fuel in steam-boilers, and means of consuming smoke, have lately occupied a good deal the attention of practical engineers. Among the many schemes suggested for attaining these ends, three appear particularly deserving of notice, viz., those of Mr. Parkes, Mr. Bell, and Mr Ivison.

265. It is a well-ascertained fact in chemical science, that combustion, in air containing even a large portion of free oxygen, is checked by the presence of a moderate quantity of carbonic acid, the very gas produced by combustion. A candle does not burn in air, if it

contain *one-fifth* of its bulk of carbonic acid. Hence, a large quantity of the air which enters a furnace, being mixed with this gas before it reaches the part where it should be of service, is thereby rendered unfit for combustion, carbonic acid gas being produced by the previously burned coal. And not only is the air thus contaminated of no use, but it is positively detrimental, carrying off a considerable quantity of heat. Also, it is found that air does not support combustion until it be heated up to a certain point; and that if the air be cold, a quantity of heat is consumed in raising its temperature up to the necessary point; which heat, when it has to be taken from the fuel, may in some cases check the combustion altogether. From these two circumstances, it follows that many combustible bodies which are not in a state *to burn in impure air at a low temperature*—might burn freely, *if the air supplied to them were pure, and heated before it comes in contact with them.* It appears to be upon these principles that the success of Mr Parkes' scheme, which is detailed in the following extract from the Mining Review, is founded:—

"At a recent meeting of the Institution of Civil Engineers, a paper was read 'On the Evaporation of Water in Steam Boilers,' by Josiah Parkes. In the course of a series of experiments, undertaken with the view of diminishing as much as possible the loss and the nuisance arising from the volumes of unconsumed smoke and soot which are emitted from the chimney, *the author discovered that, for effecting this purpose, the air necessary to render the smoke combustible must be given to the uninflamed gas, and not allowed to become vitiated by passing over inflamed fuel; and also that it must be administered at the point of the greatest heat, the temperature of incandescence, at least, being necessary for its inflammation.* Under these circumstances the furnaces were reconstructed and the air admitted at the bridge; and this alteration was attended with great success. The effect of different modes of firing being observed, it appeared that less smoke was emitted from less frequent than from more frequent firings; that somewhat more water was evaporated by the same weight of fuel; that fewer cinders and less scoriæ were produced. Following out this principle, Mr Parkes was led to work the engine with but two charges of coals per day; the furnace being loaded at first in the morning, as rapidly as keeping up the steam would permit, and then again at dinner-time. On this plan great economy was obtained, which was increased still further by enlarging the furnaces, so as to enable them to contain the entire fuel for the day's consumption. The result of these alterations was, that from seven o'clock in the morning no smoke was visible; the dampers were kept very close down, and the steam did not vary one-eighth of an inch in height during many hours. At dinner-time the dampers were as closely shut as safety would permit, and as much water was pumped into the boilers as the firemen knew by the usual practice would be boiled, and allow the steam to rise to its point at the starting time. The author then describes in detail the method of firing which he had been led to adopt, and which was attended with such beneficial results; and by pursuing which he was enabled to evaporate more than 10 lbs. of water, at a temperature of 212° by 1 lb. of coal, whereas the mean of the ordinary system of firing is only 7½ lbs. evaporated by 1 lb. of coal. The author observes that, in order to raise the steam with economy, the surface of water in the boiler ought not to be less than ten square feet per horse power; the usual allowance in Lancashire is seven and a half square feet, and five feet by Messrs. Bolton and Watt. The surface exposed to heat in waggon-shaped boilers is respectively about double the above, exclusive of any internal flue. The system above described was subsequently made the subject of a patent, and applied to more than 500 furnaces, but has fallen in a great measure into disuse, simply from the fact that it depends on the fireman; and the master will not take the trouble of understanding it in order to save a few coals."

266. Mr Bell's plan consists in passing hot air (not the heated air from the fire) in tubes through the

boiler, and using also heated air for the cumbustion of the fuel in the furnace. Tubes pass through the furnace, or an iron box is placed immediately behind the fire, in such a situation as to receive a great deal of heat which would otherwise be wasted. These are connected in front with a circular blower, by which air is propelled into them, and then conveyed in tubes through the boiler. The air is heated to about 600°, and after passing through the water, escapes at 212°; the heat it had above 212°, being communicated to the water.

The heat in this air which comes from the tubes in the boiler is not allowed to be lost. It is turned to good account by being conducted to the ash pit and passed into the furnace, aiding the combustion of the fuel greatly by the temperature it had acquired (265). Mr Bell has calculated that by these two improvements, a saving of fuel to about 33 per cent. may be effected —8 pounds instead of 6 pounds of water being evaporated by one pound of Newcastle coal. The box, or tubes in the furnace, are little injured, the constant current of air protecting them: and the power for propelling the air is trifling—the draft, when the air is passed into the ash pit closed, being sufficient.

267. Mr Ivison's process is very effectual in preventing smoke: and it is said there is a considerable saving of fuel effected by it. It is conjoined with Mr Bell's, and the saving by the two combined is found to be very great. Mr Ivison's process consists simply in injecting steam (about 1-10th of that generated) into the furnace. The smoke consists mainly of charcoal in suspension in fine powder, and which, not meeting with a ready supply of gaseous matter to combine with, is separated in the solid state. The steam is most probably decomposed, its ingredients, oxygen and hydrogen, combining with the charcoal readily in the

nascent state (that is, in the moment of separation). The carbon is thereby formed partly into carbonic acid gas by union with the oxygen, and partly into carburetted hydrogen gas, in which latter case, it is more ready to enter into combustion; and even though not consumed, escapes in the gaseous state instead of being in suspension in fine powder, forming smoke. Thus, the smoke is almost entirely consumed. The following extracts from a report of various experiments, convey full information of the details of this interesting subject.

I. *Extract from Report of Police Commissioners of Edinburgh on the consumption of smoke.*

"The result of the experiment has not only satisfied your Committee of the complete efficacy of the plan pursued at the Castle Mills for the consumption of smoke, but they have reason to believe that the same is not attended with any loss of fuel; on the contrary, it appears to your Committee that there is considerably less fuel consumed by this process than by the ordinary methods of heating furnaces.

"Upon the whole, therefore, your Committee beg leave to recommend that the clause of the statute before referred to be enforced, by obliging parties in fault to consume their smoke, either by the mode adopted at the Castle Mills, or any other method equally efficient for that purpose."

II. *Extracts from Report on Ivison's Patent, by Drs. Fyffe and Reid.*

"The boiler and furnace are those of the Castle Mills Engine, where Ivison's Patent has been in use for upwards of sixteen months.

"The boiler is 18½ feet long, by 3½ in diameter,—the flues pass only along the outside,—it stands in an open shed,—2½ feet of its upper surface, to the length of 17 feet, are not covered by the building, nor by matting, nor by any other substance,—the steam-pipe is 2⅛ inches in diameter, and is lapped with one ply of rope, but no other precautions are used. The chimney is 28 feet high, and 14 inches by ten inches capacity. The furnace is of the ordinary size; the fire bars being 5 feet 2 inches long.

"The steam is conveyed from the boiler to the furnaces in a half inch wrought iron pipe; the steam-cock of which is never above one-third part open. The steam distributor, or fan attached to it, is perforated with 5 holes, each 1-12th of an inch in diameter, and as they transmit more steam when the cock is fully open, than as it is usually worked, we are satisfied that the steam injected into the furnace is less than these orifices are capable of transmitting.

"The water was supplied to the boiler by a force pump in the usual way, being in its passage heated by the waste steam of the engine. The average temperature was found to be 143°.

"The whole quantity of coal used was 6 cwt., that is, 672 lb., and the whole quantity of water evaporated was 8360 lb., being 12.44 lb. of water evaporated for each pound of coal consumed.

"During the whole of the time there was not the slightest appearance of smoke, excepting when fresh coal was thrown on the fire, and even then it was just visible for a few seconds.

"The coal used was of the description of ordinary Scotch coal from Sir George Suttie's colliery. The day being rainy, the coal lying outside was wet.

"The pressure was taken every quarter of an hour, and the average of all the trials was found to be 25·7 lb.

"We enclose copies of certificates from engineers, showing that the boiler has not suffered in the least degree from the use of the patent."

When the boiler was worked without the patent, 1 lb. of coal evaporated 6.66 lbs. of water.

III.—*Statement by Mr Bell.*

EVAPORATION OF WATER BY IVISON'S PATENT.

"The following table shows the result of twenty-three several experiments detailed below, and certified respectively by Professors Forbes and Traill, Dr. Fyffe, Messrs Slight, Hamilton, and Dougall, engineers, the editor of the Mining Journal, and Mr Casey, The experiments were performed with common Scotch coals. In the table the results are also stated in English caking coal, (on the ordinary proportion of four of Scotch to three of English caking coal,) in order to contrast them with the best results on record which were performed wish English coal, and these last are also converted into Scotch in the first column; but even irrespective of the difference in the strength of the coal, *the average* given in the last line gives 4·62 lb. of *Scotch coal,* while the *best* by the ordinary method, gives 5·32 lbs. of *English* coal to the cubic foot of water, or the horse power of engines per hour.

	EXPERIMENTS.	lbs. water to 1 lb. of *Scotch* Coal.	lbs. water to 1 lb. of English Coal.	lbs. English coal to cubic foot water, or horse power per hour.	Cubic feet of water to 84 lb. English coal.	Cubic feet of water to 112 lb. English coal.
Former methods.	Watt's average, ...	5.55	7.4	8.4	10.	13.33
	United Mines Loam (Ed. Ph. Jour., July, 1839),	6.9	9.58	6.23	12.93	17.24
	Parkes of Warwick's method, . . .	7.72	10.32	6.03	13.9	18.5
	Huel Towan (Ed. Phil. Jour., July, 1839),	7.91	10.55	5.9	14.23	18.97
	Mr Henwood's former experiment, . .	8.9	11.87	5.32	15 8	21.
Ivison's.	Average of 8 experiments, certified April 13, 1839,	11.41	15.21	4.09	20.5	27.4
	Average of 3 experiments, certified May 10, 1839,	13.94	18.58	3.35	25.	33.46
	Average of 12 workings, certified July, 1839.	13.25	17.66	3.52	23.91	31.78
	Maximum result of do., ...	14.72	19.62	3.12	26.47	35.3
	Average of the four preceding lines, . .	13.43	17.96	3.46	24.02	32.3

268. In a work in Wales, where a large engine is used, smoke from the chimney is almost entirely prevented by placing a pot of water at the back of the furnace, and interposing a horizontal flue between the pot and the bottom of the chimney. The steam from the water mixes with the smoke, moistens the solid matter it contains, which is deposited in the horizontal flue, and the gaseous matters pass up the chimney and emerge nearly free from smoke.

269. We here conclude the description of the boiler, and shall now proceed to explain the engine, begging the reader to bear in mind that there are two points of connection between the boiler and the engine :—*First*, the steam-tube (*o o*, *Fig.* 15), which conveys steam *from the boiler to the engine ;* and, *second*, The hot-water pipe (*r r*, *Fig.* 15,) which conveys hot water *from the engine to the boiler*.

THE ENGINE.

270. In describing the engine, it may be naturally divided into two parts :—*First*, That which is directly connected with the steam, embracing the cylinder, condenser, air-pump, and hot-well ; and, *Second*, That part which is engaged in trasmitting and regulating the motion, embracing the beam, crank, fly-wheel, governor, &c. In *Figures* 19, 20, the piston, belonging to part first, is represented detached from the boiler and other parts of the engine. In *Fig.* 21, the condenser and apparatus connected with it are shewn. The point of union between these two figures is the tube, the extremities of which are marked *m n* in each.

271. In the steam-engine which is now to be described, *the double-acting engine*, the steam causes

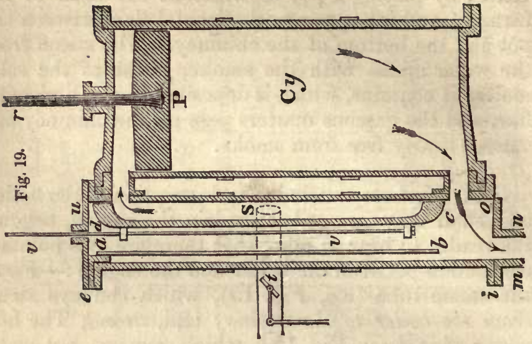


Fig. 19.

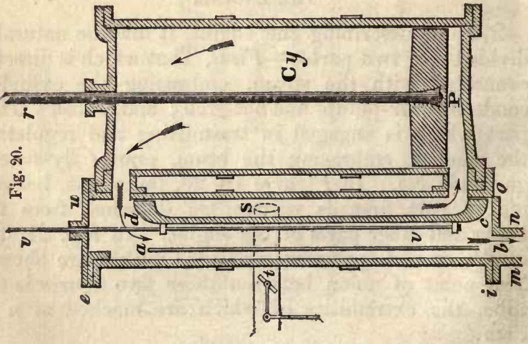


Fig. 20.

both the ascending and descending motions of the piston. For this purpose, it must be admitted alternately above and below the piston; and the vacuum, to give effect to its pressure, must be made alternately on each side of the piston. This is brought about by the following very ingenious method, illustrated by *Figures* 19 and 20. The steam is conveyed to the cylinder from the boiler by the large steam-pipe, *t* S. The quantity of steam admitted is regulated according to the demand, by the throttle-valve *t*, which, as will be easily understood, admits more steam in proportion as it is more inclined. The action of this valve will be explained under the head GOVERNOR. It is supposed to quit this pipe at the point S, and is then directed upwards to the top of the cylinder, or in an opposite course to the bottom of the cylinder, according to the position of the valve. C *y* is the cylinder, having two apertures, one above and one below, by each of which steam may be admitted to the cylinder from the steam-pipe, or withdrawn from it to the condenser. P is the piston, to be moved alternately up and down; *e i o u* is a box at the side of the cylinder, in which the valve works, and into which the steam enters first; and *a b c d* is the valve, *which is a tube*, capable of being moved up and down from the position in *Fig*. 19, to that shewn in *Fig*. 20. These two figures are alike in all respects, *except the position of the movable bodies—the valve and piston.* The valve is moved by the engine itself, in the manner that will be explained afterwards: it is by the rod *v v* that it is worked. There are many kinds of valves. That shewn in these figures is one of those called *slide-valves*, and is now very generally employed. By the tube *m n*, at the lower part of the valve-box *e i o u*, the steam passes to the condenser, after it has performed its office in the cylinder. The condenser, &c., is shewn in *Fig*. 21, page 139, but had better be disregarded at present, confining our attention to what passes on in the valve and cylinder, and simply bearing in mind that there is a constant vacuum in the condenser, *and, consequently, in that part of the cylinder which communicates with it.*

272. Let us suppose, then, that the steam has just pushed the piston up to the top of the cylinder; the object now is to remove the steam which fills the cylinder, cause a vacuum in the cylinder, and admit steam *above* the piston, which steam not being resisted by any force below the piston, will easily press that body to the bottom of the cylinder. For this purpose, the valve is raised to the position shewn in *Fig.* 19. In this position of the valve, the communication between the lower part of the cylinder and the condenser (by the tube *m n*) is free, and the steam rushes to the condenser, as shewn by the course of the arrows; thus the vacuum is formed in the cylinder below the piston; at the same time, it will be seen that, from the construction of the valve, the passage from S to the cylinder, by its *upper aperture*, is now open, so that steam enters the cylinder above, and, exerting its elastic force on the upper surface of the piston, while there is a vacuum below it, presses it down to the bottom of the cylinder. Thus, the *downwards* motion is produced; steam being the moving power, and steam, by its condensation, the means of forming a vacuum to give effect to this moving power.

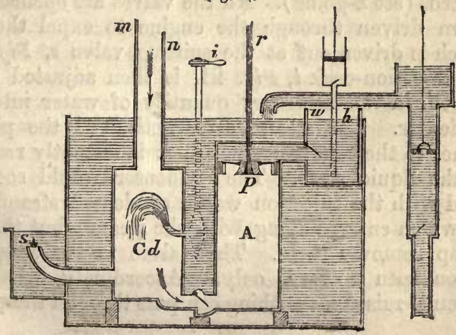
273. The manner in which the upwards motion is effected, will be easily understood, with the aid of *Fig.* 20. The piston is there represented as it would be, after being acted on by the steam with the valve in the position shewn in *Fig* 19. To raise the piston, let the valve be brought down to the position given in *Fig.* 20. Then, the steam in the cylinder above the piston will rush to the condenser, *passing out by the upper opening in the cylinder*, and through the tube of the valve, which communicates freely with the con-

denser, following the course shewn by the arrows in the figure. Thus, a vacuum is formed in the cylinder *above* the piston. This new position of the valve, at the same time admits steam from S to the *lower opening of the cylinder;* it enters, and presses up the piston to the top of the cylinder.

274. Thus, by the movements of the valve, steam is admitted alternately on each side of the piston; while the steam on the other side is removed by a communication being at the same time opened with the condenser; and, by this beautiful adjustment, a steady alternate rectilinear motion is produced. We cannot help remarking here how perfectly the action of the steam, in producing motions of the same body alternately, in two directly opposite directions, illustrates Worcester's graphic description of the powers of this versatile agent, (page 82.)—The connection of the piston-rod, the medium by which the motion is transmitted from the cylinder, with the other parts of the engine, will be explained afterwards. We shall now trace the course of the steam after it leaves the cylinder.

275. *Fig.* 21 represents the condenser and apparatus connected with it. *Cd* is the condenser: above,

Fig. 21.



it communicates with the cylinder by the pipe *n m*, and, at its lower part, with the air-pump A, by the valve between them. This valve, as will be seen in the figure, is of such a construction as to permit the passage of fluids from the condenser to the air-pump; but not from the air-pump to the condenser. The condenser and air-pump are surrounded with cold water, a jet of which is continually playing into the interior of the condenser. The piston *(p)* of the air-pump, is alternately raised and depressed by the beam of the engine, to which its rod is attached, and thus draws the fluids out of the condenser; the air-pump piston and cylinder piston moving simultaneously in the same direction. At the right of the air-pump, is the hot-well (*wh*), into which the piston of the air-pump throws the liquids which it draws from the condenser. To the extreme right of the figure, is the pump (worked by the engine) which draws cold water to surround and supply the condenser. At the left of the figure is a tube leading from the condenser, with a plug (*s*) permitting the exit of any fluids; but not the entrance. This is the *snifting valve.*

276. Let us now suppose that the engine is to be started, (set a-going). All the valves are opened, and steam driven through the engine to expel the air, which is driven out at the snifting valve *s*, *Fig.* 21. The injection-cock *i*, *Fig.* 21, is then adjusted so as to pour in the necessary quantity of water into the condenser. The steam, after acting on the piston, rushes to the condenser, where it is instantly reduced to the liquid state. The condenser would soon be filled with the injection water, condensed steam, and air which entered along with the steam; but the air-pump removes these. The valves in the air-pump piston open upwards only. Accordingly, when the piston is raised, as nothing can pass through the piston

from above downwards, there is a vacuum below the piston. The valve at the bottom of the condenser being pressed by the fluids in the condenser, and opening towards the air-pump; and that pressure not being resisted in the air-pump, the valve is forced open, and the fluids rush from the condenser to the air-pump. When the piston of the air-pump descends, it tends to press the fluids back into the condenser; but, from the construction of the valve, they cannot return. Being pressed, then, by the descending piston, they force open its valves; and pass through it to the upper side of the piston, where they accumulate. When the piston ascends again, they are lifted by it and transferred to the hot-well (*w h.*) By this series of actions, regularly continued while the engine is at work, the fluids in the condenser are withdrawn from it, and thrown out into the hot-well. The water removed from the condenser being warm, (having received much of the heat of the condensed steam,) is not altogether thrown away; but part is returned to the boiler, being conveyed, by a pump dipping into the hot-well, to the cistern at the top of the feed-pipe. Thus, a part of the heat which the steam carried from the boiler is returned to it. This pump is worked by a rod from the beam of the engine. The cold water is supplied, and the whole apparatus kept cool, by water pumped by the engine, also by a rod from its beam. This is the cold-water pump, at the right of the figure, page 139.

Connected with this part of the engine, there are four contrivances—the *Indicator*, the *Condenser Guage*, the *Eccentric Rod*, and the *Governor*, which will be most conveniently described at present.

277. THE INDICATOR.—This extremely useful piece of apparatus is attached to the cylinder, and points out the state of the steam in the cylinder, showing the difference between the strength of the steam in the

boiler and that in the cylinder—between the vacuum in the condenser, and that in the cylinder.

The indicator consists of a brass cylinder attached by a tube to the grease cock of the steam-cylinder. There is a stopcock on this tube, by opening which and the grease cock, the indicator cylinder is open to the steam-cylinder. The indicator cylinder contains a piston which works in it, and the motion of which is resisted by a spring, which yields a tenth of an inch for every pound of pressure applied to the indicator piston. An index is attached to the piston rod, which, shewing the situation of the piston, indicates at the same time, the degree in which the spring is compressed. By means of a pencil attached to the indicator's piston rod, and a cylinder with a card or piece of drawing paper round it, which is connected with the indicator cylinder, *the motions and successive situations of the indicator piston are represented by lines drawn on the card by this pencil.* The cylinder with the paper has a connection with some moving part of the engine (as a radius bar) which causes it (the paper cylinder) to revolve *once* during *one* stroke of the steam piston.

When the steam is above the piston, it forces up the indicator piston, and the line drawn on the paper shews the height of that piston, and consequently the strength of the steam at different parts of the stroke. When the steam is below, and the vacuum above the piston, the pressure of the air on the indicator piston depresses it, in proportion to the degree of exhaustion in the cylinder, and thus indicates the extent of the vacuum there.

It is found by the indicator that the steam attains its maximum effect almost immediately on entering the cylinder; while the condensation does not reach its greatest extent, until some little time after the communication has been opened between the cylinder and condenser. Hence, the eduction pipes require to be much larger and more capacious than the induction or steam pipes.

278. CONDENSER GAUGE.—The object of the condenser gauge is to shew the elastic force of any vapour that may remain in the condenser—to judge of the extent of the condensation there. As water retains the state of vapour at very low temperatures, *some* vapour will exist in the condenser, however cool; and its elastic force may be judged of in the usual manner, by communication with a bent tube containing mercury, open to the air at one end and to the condenser at the other. If the vacuum were perfect, there would be a difference of 29.8 or thirty inches in height between the mercury in the tube open to the air, and that in the other extremity open to the condenser, the mercury in the latter being pressed up by the atmospheric pressure on the surface of the liquid in the other limb of the tube. But the vapour in the condenser resisting the atmospheric pressure, depresses this column a little, reducing it to about 26 to 28 inches in general. The temperature of the vapour in the condenser is generally about 100° Fahrenheit, at which it has an elastic force of about two inches of mercury.

279. ECCENTRIC ROD.—The object of this rod is to work the valve—to communicate an alternate rectilinear motion to the rod *v v*, so that the valve may be made to assume alternately the positions shewn in *Figures* 19 and 20. This is done in the following manner. The axis on which the fly-wheel (the large wheel in *Fig.* 28) turns, has a continued circular motion. By means of the eccentric rod, and one or two bent levers interposed between this axis and the rod of the slide-valve, the latter is moved as required. The construc-

tion of the eccentric rod and its motions will be understood from the following figures (22, 23.)

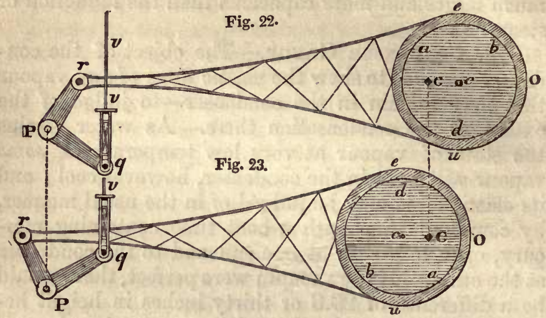


Fig. 22.
Fig. 23.

Let C in both figures be the rod or axis which by its revolution gives motion to the eccentric rod (*e r u o.*) C, although revolving, always remains in the same point. This is shewn in the two positions of the eccentric rod in the figures, by C being in the same perpendicular line. To C is fixed a disk or plate (*a b d*), which revolves along with C, *with its centre c at some distance from the point* C *on which it turns.* Hence the name eccentric (*ex*, out of, the centre.) Fitting close to this plate, there is a ring (*e o u*), within which the plate has free motion, but fitting closely to each other. The rods *e r*, *r u*, fixed to the ring, are attached to the free end of one limb of the bent lever *r* P *q* : to the extremity (*q*) of the other limb, the rod of the valve *v v* is attached. P is the fixed point, (or rather rod, for the two arms of the lever are attached to different points of one rod, necessarily represented as *one* in the figure) on which the lever turns. That it is fixed, is shewn by P in both figures being in one perpendicular line—the dotted line. It is clear that, when the plate *a b d* makes a half revolution from the position shewn in *Fig.* 22, it will carry the eccentric rod and levers into the position shewn in *Fig.* 23. This raises the end of the lever (*q*) to which the valve-rod is attached, and therefore elevates the rod. When it has completed another half revolution, the end (*q*) of the lever will be depressed, and will pull down the valve-rod along with it. The action will be very easily understood, if it be kept in view that C and P are fixed points.

280. This apparatus is not always so simple as represented in the figure, another lever being often interposed. But the action is perfectly the same, and, however complex, will be understood at once by any one who has studied the preceding figure.

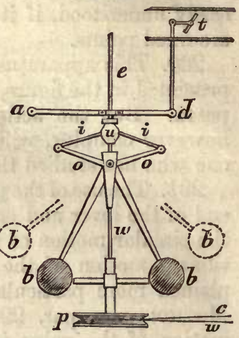
281. The use of the part (*q v*) interposed between the end of the lever and end of the valve-rod, is to adapt the circular motion of the end of the lever to the rectilinear motion of the valve-rod. This will be explained more particularly under the head Parallel Motion: see par. 292. In steamboat engines the motion of the valve is brought about by machinery very closely resembling that shewn in the above figure. In some engines the eccentric rod is applied to many other purposes besides working the valves. It is applicable wherever an alternate rectilinear motion is required, and the motion from which it can be most conveniently procured, is a continuous circular motion.

282. In Watt's first engines, the valves were worked as in Beighton's plan. Catches attached to the rod of the air pump, were so adjusted as to raise at proper times levers which opened and shut the valves.

283. Governor.—The object of the governor is to determine the quantity of steam to enter the cylinder, and thereby regulate the action of the engine, should it happen to work too vigorously, either from the

increased activity of the fire or diminished resistance; or to work languidly from the opposite causes. The *throttle valve* (*t*), in the steam-pipe *t* S, *Fig.* 19, regulates the quantity of steam which passes through, by the degree in which it lies parallel to or across the tube; and it is by the governor that the direction of this valve is determined.

Fig. 24.



284. The motion of the governor is derived, in the first instance, from the engine itself, by a cord, strap, or chain, *c p w*, running round the axis of the fly-wheel, and communicating its motion to a pulley, *p*, *Fig.* 24. This figure represents the governor. The pulley is fixed to the upright rod or spindle (*e w*). To the spindle, two balls are attached (*b b*), of course revolving with the spindle, but having also a joint by which they can be raised or depressed, so as to recede from or approach the spindle. The rods of the balls are connected with levers (*o o*), which move freely on other levers (*i i*), which, at their other extremities, are attached to a ring of metal (*u*), capable of free motion up and down the spindle. Above this ring is another lever (*a d*), fixed at *a*, and fitting loosely round the spindle *e w;* and from the extremity (*d*) of this lever, proceeds a bent lever (*d t*), at the extremity of which is the *throttle valve* of the steam-pipe. Now, when the axis of the fly-wheel is moving with too great velocity, its increased rate of motion will of course be communicated to the spindle of the governor. It will revolve more rapidly, and the balls attached to it will (from

their increased centrifugal force) fly out further from the spindle. The effect of this will be to depress the levers *o o*, when the levers *i i* and the ring *u* will also fall. Hence the lever *a d* will slip a little down the spindle (or be pulled down if attached to the ring *u*); and this, from the construction of the bent lever *d t*, will bring the *throttle valve t* more across the steam-pipe, so as to contract it; less steam will now enter the cylinder, and the action of the engine will be moderated. Should the engine be working too slow, the balls would fall, the throttle-valve be opened, and more steam admitted.

285. This regulator or governor was used by millers to regulate the rate of motion of the grind-stones, and adopted by Watt for the purpose above described. In steamboat engines, the levers of the throttle-valve are under the immediate control of the engine-man, who acts as the governor.

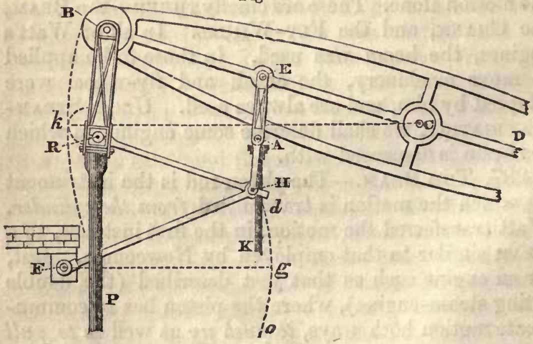
286. Having described the parts of the engine immediately connected with the course of the steam, we shall now quit the steam, and proceed to consider those parts of the engine which are concerned in adjusting the motion alone. These are chiefly THREE—the BEAM, the CRANK, and the FLY-WHEEL. In all of Watt's engines, the beam was used. In those to be applied to move machinery, the crank and fly-wheel were adopted by him, and are always used. Under STEAM-NAVIGATION, we shall describe some engines in which the beam is dispensed with.

287. THE BEAM.—The piston-rod is the instrument by which the motion is transmitted *from the cylinder.* Watt transferred the motion, in the first instance, to a BEAM similar to that employed by Newcomen. But, for an engine such as that just described (the double acting steam-engine), where the piston has to communicate motion both ways, *to push up* as well as *to pull*

down the beam, the connection of the ends of the beam and piston, by a flexible chain, would not answer. The chain could not communicate an impulse; it was therefore necessary that the piston should be connected immediately to the end of the beam, or that some rigid inflexible bar should be interposed. Here, a difficulty presents itself. The end of the piston-rod must move in a straight line; otherwise, the aperture through which it works in the top of the cylinder, must be wider than the diameter of the piston-rod, to allow for its play sideways. But, the piston-rod must move air-tight through this aperture. The head of the beam, on the other hand, describes a segment of a circle. These motions must be adjusted, so that the beam shall not press the piston-rod outwards in the first half of its descent—so that there shall be no lateral strain on the piston-rod.

288. Parallel Motion.—This was effected by Watt, in the manner which will be understood from the following figure (25.)

Fig. 25.

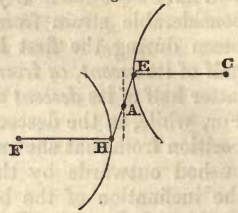


Let R be the head of the piston-rod P R; B the end of the beam. B describes a segment of a circle, and R moves vertically up and down. These motions are adjusted so as to harmonize with each other by the following contrivance. Let a fixed point (F) be taken, as near as possible to the line in which the piston-rod moves. From the points B and E of the beam, let inflexible bars B R and E H hang down, moving freely on pivots at B and E. Let the extremities R and H of these bars be connected by a transverse rod R H; and let another rod pass from H to F—all having free motion on pivots at both extremities. Let the head of the piston-rod be attached to the pivot at R—then it will have a motion nearly vertical, at least without any considerable strain from the *outward* motion of the beam during the first half of its *descent* and the first half of its *ascent*, or from its *inward* motion during the latter half of its *descent* and the latter half of its *ascent*. For, while, in the descent of the beam to the horizontal position from that shewn in the figure, the bar B R is pushed outwards by the beam (as will be seen from the inclination of the bar, and from considering the motion of the point B, moving on the centre C), the rod R H counteracts this, by pulling the point R in an opposite direction, the end H of the rod R H being preserved at a proper distance from the required line of motion of the piston-rod, by the rod H F, which, fixed at F, describes with its extremity H the arc *d g*, which bends inwards as much as the arc described by B bends outwards, and thus preserves the point R moving almost vertically. When the beam has come to the horizontal position (shewn by the dotted line C *k*), the bar B R will then hang perpendicularly, and the rod F H will also be horizontal, as in the dotted line F *g*. In the latter part of its descent, the point B will evidently bend *inwards*, and tend to push inwards the head R of the piston-rod ; but the rod F H then bends *outwards* (describing the arc *g o*); and thus (by the rod R H) resists the inwards thrust of the beam.

289. In ascending, similar adjustments take place between the beam and the piston-rod, and the latter is preserved nearly vertical, and all strain in one direction neutralized by the opposite action of the rod R H.

290. The same machinery serves to give a vertical motion to the rod of the air pump A K, which is worked by the beam. The extremity A of the air pump rod is attached to the middle point of the bar E H. If this bar connect the free extremities of two rods F H, and C E, being attached to them by pivots; if these rods be of such length that, when horizontal, E H be perpendicular, (or nearly so) to both; then, if these rods be moved up and down on pivots or centres (F and C), the middle point (A) of the connecting bar (E H) will move in a direction nearly vertical (truly a peculiar curve of a high order, but practically not far from the perpendicular), while the extremities of the bar describe each a segment of a circle.

Fig. 26.



The figure above, is an exact copy of that part of *Fig.* 25, to which the same letters are attached. To the point A the air-pump rod is attached ; and, while the extremities E and A incline alternately to the right and left, the point A, about which they oscillate, preserves a vertical motion.

291. It has been said that Watt first conceived the idea of attaching the head of the piston-rod to the

point A, (E being in this case the end of the beam,) but found it more convenient—and to answer equally well—to use the point A for the pump-rod, attach it by a bar to a point between the centre and extremity of the beam, and by the bar B R, parallel to E H, and the rod H R, to give R a motion parallel to that of A; whence, as well as from the bars R B, E H, being parallel, this beautiful piece of mechanism has acquired the name of PARALLEL MOTION.

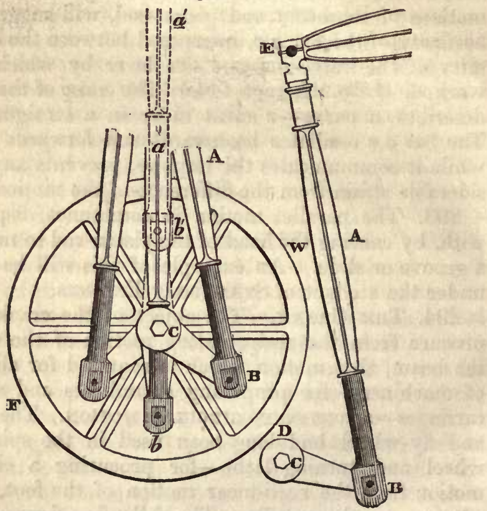
292. The above description of the adjustment of the motions of the beam and piston-rod, will suggest the necessity of the bar *q v*, interposed between the extremity of the valve-rod and the lever by which it is worked. (*Fig.* 22, page 144.) The end *q* of the lever describes a curve—*v* must move in a straight line. The bar *q v* oscillates backwards and forwards; and, while it communicates the impulse, prevents any considerable strain from the difference of the motions.

293. The parallel motion is sometimes dispensed with, by causing the head of the piston-rod to move in a groove or slide. An example of this will be given under the account of STEAMBOAT ENGINES.

294. THE CRANK.—The object of the crank is to procure from the reciprocating motion of the end of the beam, that motion which is required for all sorts of machinery, for propelling steamboats and steam-carriages—a CONTINUED CIRCULAR MOTION. The crank and fly-wheel had long been used in the spinning-wheel and turning lathe—for procuring a circular motion from the rectilinear motion of the foot, in its pressure on the treadle. The following figure, (27), which will be easily understood, will illustrate the crank. Let E be the extremity of the beam, moving up and down in an arc of a circle, and C the rod, shaft, or axis, to which it is desired to communicate a regular continuous circular motion. Let a short bar (D B) pro-

ceed from the rod to be turned, and play upon a pivot (B), to which is attached, playing also freely upon it, a long bar, or rod (E B), the other extremity of which turns on a pivot (E), at the end of the beam. It will easily be understood how the rod (E B), descending as the beam descends, and moving up along with it, will turn round the crank (B D), the extremity B describing a circle round C, which is necessarily turned along with the crank B D, to which it is immovably fixed.

Fig. 27.



The rod (E B) descends on one side of the centre (C), and ascends on the other side; and thus, from the alternate rise and fall of the beam, a continous rotatory motion is communicated to the axis C.

295. There are two points in the revolution of the crank, called dead-points, where the engine has no

action upon the crank, in turning it, but pulls or presses it vertically, the crank being in such a position that it has no tendency to turn the axis. This will be readily understood from the figure. When the end of the beam is at its highest elevation, the rod hangs perpendicularly from it, *and the crank is in the same line*, (in the position *a′ b′*, *Fig.* 27). The beam then tends to *depress* the crank and axis, but not to *turn* either. When the end of the beam is at its lowest point, the rod hangs perpendicularly from it, and *the crank then also is in a line with the rod*, (in the position *a b*, *Fig.* 27). In this position, also, the beam has no action in *turning* the crank or axis; but tends to pull them straight upwards. These are the two dead points, or critical points. From these, it is carried by the inertia of the crank—that is, by the tendency a body in motion has to continue moving until some sufficient resistance checks it. Every one knows that a body in motion (as a ship or carriage), does not stop the moment the impelling force ceases—that it continues for a little, until friction, and the resistance of the air or water, gradually overcome it. In like manner, the motion acquired by the crank before it reaches the critical points, carries it beyond them, and when a very little past them, the beam resumes its usual action. The fly-wheel also aids in carrying the crank past the dead points.

296. Although, however, the crank is carried easily by its inertia out of the critical situations, it exerts little or no force in turning the axis while in them. The crank moves slowly when about the critical points—more rapidly in the other situations, where the beam acts directly in turning it. Hence, an inequality in the motion of the axis, and any machinery which derives its motion from it. This is remedied by the fly-wheel.

297. The Fly-Wheel. (W. *Fig.* 27.)—In apply-

ing the steam-engine to drive machinery, it is particularly necessary that the engine should work with a perfectly steady and uniform force; that there should be no irregularities in its action; or, if unavoidable, that these should be transmitted very gradually to the machinery; that there should be no abrupt transition from slow to quick, or the reverse. Such inequalities might arise from the diminution in the impetus of the crank at the two critical points, from changes to a certain extent unavoidable in the strength of the fire, or from a change in the resistance given by the machinery from some of the work being stopped, or more work thrown on. By means of the governor and throttle-valve, the adjustments of the feed-pipe and the damper, a proper proportion is preserved between the supply of steam and the demands of the engine. *But these require a little time to come to an adjustment;* and, before that could be effected, in case of any sudden change, considerable injury might be done.

298. This is prevented by the action of the Fly-Wheel. This is a large wheel with a heavy rim, formed of iron, and fixed to the axis which the crank turns, and revolving along with it. By its weight, it acts as a drag on the engine, should it have a tendency to go too fast; and, by the great impetus which its weight gives to it, carries on the machinery with the usual, or a *gradually* decreasing force, when the proportion of the resistance to the power becomes augmented, and the engine has a tendency to move slow. The fly-wheel equalises, by its weight, any irregularities on either side, being a sort of reservoir of power, which it absorbs, and distributes gradually when the power is too great, and restores and gives it out when the power is diminished or the resistance increased. A heavy body of this kind attached to the axis, and interposed between the power and the resistance, by its inertia slow to move, and equally slow to cease

moving or to change its rate of motion, is of the greatest value in equalising the motion in those engines which are applied to move machinery.

299. There was another cause of inequality in the rate of motion in some, particularly the single acting engines (302). The piston moved more rapidly (with an accelerated motion) towards the end of each stroke, than at the beginning, in consequence of the accumulation of its motive inertia, while the steam continued to act upon it with the same force as at first. At the commencement of the stroke, the steam has to overcome the friction between the piston and the cylinder, as well as the inertia of the mass. When it is once set in motion, its inertia (the impetus it has acquired) continues it in that state for a time, independently of the action of the steam—friction only being now to be overcome. Hence, if the steam continue to act as forcibly as at first, it will communicate additional motion to the piston, and it will, therefore, perform its stroke with an accelerated velocity. Watt cut off the supply of steam after the piston had descended a certain length (about one-third.) The remainder of the descent was effected partly by the impetus the piston had already acquired, and partly *by the expansion of the steam already in the cylinder;* for, there being little or no resistance on the other side of the piston, the steam expands and presses the piston; its force from this source becoming less just in proportion as the space it occupies increases—that is, just in proportion to the extent to which it moves the piston along the cylinder. Thus the motion of the piston is, to a considerable extent, equalised. The action of the steam in full strength sets it in motion—the small and decreasing force requisite to continue the motion at an uniform rate is furnished by the expansion of that steam. If the stroke of the piston from the top to the bottom of the cylinder be eight feet, and the farther

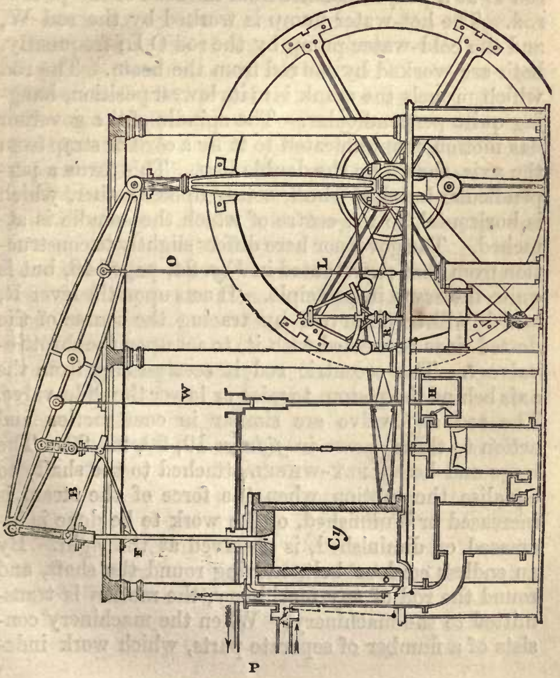
supply of steam be cut off when the piston has descended two feet, and if the original strength of the steam be 14 lbs. per square inch on the piston, it will be 7 lbs. when the piston has descended to four feet; $4\frac{2}{3}$ lbs. when it has descended six feet; and 1-4th of its original power, or $3\frac{1}{2}$ lbs., when the piston has descended eight feet, and has arrived at the bottom of the cylinder.

300. But, what is of greatest importance, and applicable in all engines, there is considerable economy of steam when it is applied in this manner: this was the view with which Mr Watt first adopted the plan of working by the expansion of the steam. He states, in the specification of his patent of 1782, that, when the steam is cut off at one-fourth of its descent—"when only one-fourth of the steam necessary to fill the whole cylinder is employed—the effect produced is more than one-half of the effect which would have been produced in filling the whole cylinder full of steam, by admitting it to enter freely above the piston during the whole course of its descent." If a certain quantity of steam produced an effect equal to 4, the effect of one-fourth of that steam acting expansively would be more than 2; or by the following table—

If the steam be stopped at	The effect of that admitted is multiplied
One-half	1.69 times.
One-third	2.10 ...
One-fourth	2.39 ...
One-eighth	3.08 ...

Having now gone over the steam-engine in detail, it only remains to exhibit a view of the various parts as they appear when connected, and give such explanations as may be necessary to the understanding of the relation of the several parts to each other when the engine is in action. *Fig.* 28, in the following page, represents a steam-engine, a side view being presented.

SKETCH
OF THE
DOUBLE-ACTING STEAM-ENGINE
OF
JAMES WATT,
IN ITS PRESENT FORM,
(INVENTED BY HIM IN 1782.)
Fig. 28.



301. At the left is seen the great steam tube, admitting steam to the cylinder (C *y*), by the throttle-valve (*t*); and a smaller tube, conveying warmed water to the boiler, from the hot well (H). The piston is at the top of the cylinder, the end of the beam connected with the piston in its most elevated position, and the air-pump piston also at its highest elevation. The fixed point for the parallel motion is F, the rod proceeding from which keeps the inner extremity of the rod B at a proper distance from the head of the piston-rod. The hot-water pump is worked by the rod W, and the cold-water pump by the rod O L; frequently, both are worked by one rod from the beam. The rod which propels the crank is in its lowest position, hanging quite perpendicular. The spindle of the governor has motion communicated to it by a cord or strap from the axis, shewn by the double line. This turns a perpendicular bevelled wheel, acting upon another, which is horizontal, to the centre of which the spindle is attached. The governor here differs slightly in construction from that represented in *Fig*. 24, page 146, but is quite the same in principle. It acts upon the lever R, which will be observed, by tracing the course of the dotted lines connected with it, to act upon the throttle-valve *t*. The eccentric rod is seen passing from the axis behind the piston, to raise or lower the slide-valve. The rod and valve are similar in construction and action to those shewn in *figures* 19, 20, 22, 23. The large and heavy FLY-WHEEL attached to the shaft, to equalise the motion when the force of the steam is increased or diminished, or the work to be done is increased or diminished, is observed at the right. By an endless cord or belt, moving round the shaft, and round the rod of any machinery, the motion is transmitted to the machinery. When the machinery consists of a number of separate parts, which work inde-

pendently, and require to be frequently stopped, or set in action at different times, belts or straps are provided for each, which can be slipped off or on in a moment.

302. This is the DOUBLE-ACTING engine of Watt. But his first invention was a SINGLE-ACTING engine—that is, one in which the piston was only propelled downwards by the force of steam, being pulled upwards by a weight attached to the other extremity of the beam, as in Newcomen's engine. The steam was admitted *above* the piston, the vacuum made below it. When the piston reaches the bottom, the connections between the cylinder and boiler, and between the cylinder and condenser, are shut, and by the side tube a communication is opened between the lower and upper part of the cylinder. The piston is then equally pressed in both directions by the steam, and the weight at the other end of the beam turns the balance, and pulls up the piston, the steam passing from *above* to *below* the piston during its ascent. Then the opening is formed to the condenser, steam admitted again above the piston; and thus the motion is regularly continued.

303. The single-acting engine answered very well for raising water; and although the *single-acting engine* and the *atmospheric engine* had been adapted for machinery by the addition of a crank and fly-wheel, these were found insufficient to give that smoothness and uniformity of motion requisite. This was from the piston acting only in its descent, and a heavy fly-wheel or weight being necessary to carry the crank round during the intermission of the power. But still the atmospheric engine was in considerable use for this purpose. Mr Smeaton recommended that, instead of applying a crank and fly-wheel to the

atmospheric engine, to produce a continued circular motion, the engine should be used to raise water, which should be applied in the usual manner to turn a water-wheel, from the axis of which the circular motion would be procured. In 1781, he proposed the same with one of Boulton and Watt's single-acting engines, for a corn mill. Watt, in 1778, turned his attention to the subject, and, in 1782, he took out a a patent for the DOUBLE ACTING ENGINE. He says— "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; but, as the rotative motion is produced in that machine by the impulse given to the crank in the descent of the foot only, it requires to be continued in its ascent by the energy of the wheel, which acts as a fly; being unwilling to load my engine with a fly-wheel heavy enough to continue the motion during the ascent of the piston (or with a fly-wheel heavy enough to equalise the motion, even if a counterweight were employed to act during that ascent), I proposed to employ two engines, acting upon two cranks, fixed upon the same axis, at an angle of 120° to one another, and a weight placed upon the circumference of the fly-wheel, at the same angle to each of the cranks, by which means the motion might be rendered nearly equal, and only a very light fly-wheel would be requisite."

304. "The method," says Farey, "of combining two cylinders to act with two cranks formed upon the same axis, has since been brought into use, with great advantage, in the modern engines, for propelling carriages, and for steamboats. It is an excellent plan, and

has also been applied to turn-mills." The atmospheric engine was also applied in this way—two cylinders, each with a piston, being employed. The pistons had one common rod, the cylinders being placed one over the other: the air acted alternately on them, pushing one piston down, and the other up, the cylinder of the latter being *inverted*—closed above and open below. Thus a double action was given to the piston.

These, and other contrivances for double engines, have been superseded by Watt's beautiful invention—the DOUBLE-ACTING SINGLE CYLINDER ENGINE.

305. Having now concluded our account of the chief of the inventions and improvements by Watt, and these being such as to give to the *fire-engine* a power and extent of usefulness quite unexampled, to confer on his engine the peculiar distinction which it still retains, of being THE STEAM-ENGINE, we shall present a short sketch of the life of its illustrious author, who stands forth as one of the brightest examples of that which is above all entitled to honour and respect—talent successfully applied to produce works of utility to mankind.

306. JAMES WATT was born at Greenock, in the west of Scotland, in the year 1736. His father was a block-maker and ship-chandler there, and was much respected by his townsmen. Watt was educated at the Grammar-school of Greenock. After being some time with a mathematical instrument maker, he went to London in 1754, and there continued the same profession. About 1758, he returned to Scotland, and commenced business on his own account in Glasgow. The professors of the University there, being anxious to promote the art of making philosophical instruments, appointed Watt philosophical instrument maker to the University, and gave him apartments there, for carrying on his business. "My attention was first directed

says Watt, "in 1759, to the subject of steam-engines by Dr. Robinson, then a student in the University of Glasgow, and nearly of my own age. Robinson at that time threw out the idea of applying the power of the steam-engine to the moving of wheel-carriages, and to other purposes; but the scheme was not matured, and was soon abandoned on his going abroad." He then states that, in 1761 and 1762, he made some experiments on the force of steam in a Papin's Digester, and with it, and a syringe with a solid piston, formed a species of steam-engine (very like Leopold's), which he found could be made workable; but abandoned it, 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."

307. In the winter 1763-4, his attention was again directed to the steam-engine, from being engaged in repairing a model of Newcomen's engine, used in the class of Natural Philosophy in the University. In examining its action, after being put in order, he found that a very great quantity of steam was required for it; and this leading to further inquiries and experiments, he found that the waste arose from the alternate heating and cooling of the cylinder. In 1765, the grand idea occurred to him of preserving the cylinder at a uniform high temperature, and condensing the steam by opening a communication between the cylinder and a separate vessel always kept cool, termed a condenser. He constructed some models upon this plan; and took out a patent in 1769. About that time, he formed a connection with Dr. Roebuck of the Carron iron-works, and who had rented large coal-works at Kinneal. The first of his engines was erected there. It had a cylinder of eighteen inches diameter; and

was altered and modified in various ways, until it was advanced to a state of considerable perfection. In consequence of embarrassments in his business, Dr. Roebuck, in 1773, transferred his interest in Mr. Watt's projects to Mr. Boulton of the Soho manufactory at Birmingham.

308. In consequence of the time and expense necessary to bring the engine to a tolerable working condition, and the obstacles to their introduction, from apathy or prejudice, Mr. Watt found that the term of his patent would expire before he could have reaped any considerable advantage from it, or even been remunerated for the time and money spent in completing his project. He therefore applied to Parliament for an extension of his privilege, which was granted in an act passed in 1775, whereby the exclusive right of "making, constructing, and selling the said engines within the kingdom of Great Britain, and his Majesty's colonies and plantations abroad," was vested in James Watt, his executors, &c., for twenty-five years from the passing of the act—to 1800. Thus secured in the just reward of his genius and application, and aided by the capital, skill, and activity of Boulton, Watt settled at Birmingham, and constructed and brought into use engines, by which immense savings in fuel were effected wherever they were applied. By 1778, he had many of his engines at work; and, after their economy and superior efficacy became known, they were universally used wherever new engines were required, and were frequently substituted for the old ones, even where these were still in fair working condition. Watt was continually introducing important improvements, so that his later constructed engines were greatly superior. In 1778, he introduced the expansion steam-engine (299-300); and, in 1782, he took out a patent for the last great change he effected

on the engine—giving it the double-acting power. Many other improvements were introduced from time to time, but this was the greatest, as it adapted the engine for the important object of impelling machinery.

309. At the expiry of his parliamentary patent in 1800, Mr. Watt withdrew from business, and passed the remainder of his life in retirement. He was a man of great general information, and of a cultivated mind. He did not confine his attention to mechanics, but took considerable interest in the study of general literature and philosophy. He was always deeply interested in antiquarian researches; and the fine arts also received much of his attention. In private life he was much esteemed and beloved. In 1808, he was chosen a member of the National Institute of France.

310. Mr. Watt died in 1819, at his seat at Heathfield, near Birmingham, at the advanced age of eighty-three. After his death, public meetings were held in almost every considerable city in the kingdom, at which the leading men of the place of all parties, vied with each in the eloquence and warmth of their eulogiums on the truly illustrious deceased; and all united in an anxious wish to pay to his memory the tribute of a nation's gratitude and respect.

311. If we judge of Watt by the talent displayed in the construction of his steam-engine, he must be placed in the foremost rank of inventors. When we consider the perfect state to which he brought the engine, the many beautiful contrivances he introduced to economise the power and extend its applications, the rude materials and limited knowledge there then were to work upon, and that seventy years, at a time when science and art have been making rapid advances, have added little to the engine as he produced it, Watt must be allowed to hold a very high place among those distinguished for mechanical genius.

312. If we estimate him by the effects which have flowed from his invention, he stands second only to the inventor of printing. This may not be a proper ground on which to form an opinion of his genius; but it should not, or at least will not, be forgot, in paying a tribute of gratitude to his memory. The steam-engine has done and will do more to improve the condition of mankind, than any other discovery since that of printing. In considering the steam-engine, we cannot confine ourselves to a mere description of its construction and principles of action. We cannot look upon it merely as a beautiful piece of mechanism, only the action of which interests us. It is something more than the best contrivance for producing motion. It has a deeper and broader interest for mankind. By its extensive and important applications, it may be said to be a great moral power. It will lead to important changes in the moral structure of society.

313. The steam-engine furnishes abundantly, and on easy terms, that article which is required in almost every trade—namely POWER or FORCE. Having rendered this cheap and plenty, it has had the same effect on almost every commodity in the procuring of which *moving power* is required. It has thus rendered cheaper, and brought within the reach of thousands, articles which, in the times of our forefathers, were luxuries enjoyed only by the rich. If we cast our eyes on any one, even the most trifling, of the many conveniences we enjoy (and which we seldom, perhaps, reflect on, from our familiarity with them), trace it from the raw material furnished by nature, through its various stages of changes by art, we shall find that the steam-engine will meet us at every turn. It is draining the mines; and, but for it, our supplies of coal would now have been nearly exhausted—or it would have

become so dear as to have contracted greatly the sphere of its utility. The steam-engine is at work in our blast-furnaces, forcing in thousands of gallons of air every minute, to extract the tough iron from the brittle ore; and by the same powerful machine, the cast-iron is formed into bar iron, possessed of strength and tenacity to fit it for suspension-bridges, chain-cables, and other purposes, where it has to bear great strains. If the steam-engine did nothing else but thus aid in the procuring of coal, cast-iron, and bar-iron, it would still be one of the greatest gifts presented by genius to man; but it is hardly necessary to mention that these are but a fraction of the multitude of arts and manufactures which could not now be carried on without the aid of this all-powerful machine.

314. The steam-engine is now beginning to be applied to the diffusion of knowledge, by aiding the printer in his operations. Many of the cheap periodicals, which have no small influence in extending the knowledge, cultivating the understanding, refining the taste, and improving the habits of all classes of society, could not be published at the very low rate charged for them, and which is essential to their efficiency, without the co-operation of the steam-engine. It is thus lending a powerful aid in the advance of improvement—in working out a reformation which, though proceeding by slow and almost imperceptible steps, creeping insensibly, like Time himself, will advance no less surely, and rival that great innovator in the magnitude of the change it will produce on the whole frame of society.

315. The advantages to our manufactures and trade, in facilitating the transmission of goods and intelligence, cheapening the cost of the interchange of commodities and quickening the rate, bringing distant places near, and rendering the treasures of remote

countries more accessible—are obvious enough, and can be easily appreciated. But there are higher considerations than the mere commercial advantages growing out of increased facilities for intercourse between nations. Free intercourse between different countries is eminently calculated to remove those national prejudices and animosities without which war could not flourish. The friendships and connections, and commercial relations, which would be formed between two nations which had been some time at peace, and had easy access to each other, and throughout each country, by steam navigation and railways, would be a powerful barrier against the ambitious or selfish projects of those political or military adventurers, whose ends lead them to plunge two nations into the horrors of war. That community of feeling which would be generated by a knowledge of the true interests of nations, would be strengthened by the associations of those who had stood in the sacred relation of host and guest—who had experienced each other's courtesy and hospitality—shared the same pleasures—sat at the same board. Facility of intercourse would greatly multiply and increase those kindly sympathies, and foster those feelings of brotherhood among nations. The steam-engine is—and, when each country is intersected with railroads, will be much more—a powerful means of increasing those ties of friendship and commercial interest; and assuredly, along with other causes, will hasten the happy period which one may now hope for without being deemed a visionary, when it shall be felt that the human race are indeed of "one brotherhood"—when "swords shall be turned into ploughshares, and spears into pruning-hooks"—"when nation shall not lift up sword against nation, neither shall they learn war any more."

SECTION VI.

STEAM NAVIGATION.

316. The application of the power of steam to navigation, whereby voyages might be made in a dead calm, or even when the wind is adverse, was sufficiently obvious; and, accordingly, we find that every projector of machines for applying steam as a power, contemplated its introduction as a means of impelling vessels along their liquid path. We have already noticed the project of Blasco de Garay in the 16th century. Of that nothing further is known, than that such a design was by him put in execution, and then abandoned. Savery projected the application of his engine to navigation, but seems to have gone no further than throwing out the idea that a paddle-wheel attached to a vessel might be turned, and thus give motion to the vessel, by water to be raised by the engine.

317. The first feasible-looking project for a steamboat, was that of Jonathan Hulls, who took out a patent for it in 1736, and, in 1737, published a description of it, with a drawing, entitled—"A Description and Draught of a new-invented Machine, for carrying Vessels or Ships out or in of any Harbour, Port, or River, against Wind or Tide, or in a Calm." His power was procured by the pressure of the atmosphere against a vacuum, just as in Newcomen's engine; and, by very ingeniously devised machinery, he transmitted the motion to a paddle-wheel, and provided for the continued rotation of the wheel during the ascent of the piston. Mr. Tredgold remarks, "that it was certainly a beautiful contrivance for rendering so irregular a first mover equable;" and also "the pamphlet

of Hulls bears evidence of being the work of an ingenious and well-informed mind."

318. In 1775, a small steam-boat was built in France, by a M. Perier, and is said to have been successful. It was tried on the river Seine; but the scheme was abandoned. A larger vessel, to be propelled by the same power, was constructed at Lyons, by the Marquis of Jouffray, in 1782; but his schemes were overturned by the Revolution. The steam-boat he constructed was 140 feet long, fifteen feet wide, and is said to have plied on the river Soane, at Lyons, for a considerable time. In 1788, an engine for propelling a boat by the power of steam was built by Mr. Symington, under the patronage (some say under the directions) of Mr. Miller of Dalswinton. A canal boat, impelled by a steam-engine, built by Mr. Symington, plied with success on the Forth and Clyde Canal in 1789; but the scheme was abandoned, the agitation of the water by the paddles being found to injure the canal banks; and was not prosecuted elsewhere. In 1790, Fitch of Philadelphia is said to have constructed a steam-boat which plied successfully on the Delaware. In 1795, the ingenious Lord Stanhope constructed a machine for propelling vessels, which was tried in London but did not prove successful. In 1801, Mr. Symington, at the instigation of Lord Dundas, constructed a steam-boat for towing vessels on the Forth and Clyde Canal. The project seems to have been tolerably successful, but was again strangely abandoned. Mr. Symington certainly possesses considerable claims to being regarded as the inventor of steam navigation. He not only constructed efficient steam-vessels, but his plans are said to have aided those who followed, and were more successful in establishing them. His claims are asserted in a pamphlet which the author of this work has not had

an opportunity of seeing, entitled, "A Brief Narrative, proving the right of the late William Symington, civil engineer, of Falkirk, to be considered the inventor of steam land carriage, locomotion, and also the inventor and introducer of steam-navigation. By Robert Bowie." In a letter in No. 795 of the Mechanics' Magazine, Mr. Bowie states, "Mr. Symington fitted and propelled four boats with the steam-engine: the first in 1788, on Dalswinton Lake; the second in 1789, the third in 1801, and the fourth in 1803, on the Forth and Clyde Canal." Mr. Fulton, the American engineer, Mr. Bowie states, went a voyage of eight miles in an hour and twenty minutes, in Mr. Symington's third boat, in 1801.

319. The first really efficient steam-boat was built at New York, and launched in 1807. It was constructed under the superintendence of Mr. FULTON, an American, who had long been labouring to introduce steam-power in ships. The engine was built for him by Boulton and Watt, and sent out to America. Fulton had been experimenting in France, and had proposed to Bonaparte to employ steam-vessels in his intended invasion of Great Britain. Receiving little encouragement in Europe, he returned to America, and there completed his plan. The first steam voyage was successfully performed by his vessel, between New York and Albany (a distance of 160 miles, performed in about thirty hours); and this public demonstration of the practicability of steam navigation gave the impulse which has set steam in action on the waters in every quarter of the globe. Fulton's project was a good deal laughed at; and he deserves great credit for his perseverance, notwithstanding the ridicule and apathy he met with. Such was the temper of some of his own friends on the subject, that, after he had even conducted them safely to

Albany, in the first trip which his steam-vessel made, he was told *he could not do it again, and, supposing he could, what would be the use of it!* As a tribute for his services to society, the American Government have awarded a handsome grant to Fulton's heirs. Is not this country under similar obligations to SYMINGTON and HENRY BELL?—The sensation produced by the appearance of Fulton's vessel making its way over the waters, was thus described in an American paper:—

"She had the most terrific appearance from other vessels which were navigating the river. The first steamers, as others yet do, used dry pine wood for fuel, which sent forth a column of ignited vapour, many feet above the flue, and, whenever the fire is stirred, a galaxy of sparks fly off, and, in the night, have a very brilliant and beautiful appearance. Notwithstanding the wind and tide were adverse to its approach, they saw, with astonishment, that it was rapidly coming towards them; and, when it came so near that the noise of the machinery and paddles was heard, the crews, in some instances, shrunk beneath their decks from the terrific sight, and left their vessels to go on shore, while others prostrated themselves, and besought Providence to protect them from the approach of the horrible monster which was marching on the tides, and lighting its path by the fires which it vomited."

320. Fulton thus demonstrated the capability of steam to be applied as a moving power for ships. A few days after his successful steam-trip to Albany, another American, STEVENS, who had been long engaged in experiments in steam navigation, effected a successful steam voyage in a boat he had constructed; and, in the course of a few years, steam-boats were to be seen plying on the shores, and along the rivers, in all the populous districts of the United States.

321. In 1812, a steam-boat, called the COMET, began to ply on the Clyde, between Glasgow and Greenock. It was of three-horse power, and moved at the rate of five miles an hour, against a head wind. This was the first successful steam-boat in Europe, and was the result of the skill and ingenuity of Mr. HENRY BELL. A monument has lately been erected to his memory, on the banks of the Clyde. Since that time, steam navigation has made rapid progress, as may be seen from the following table, from the *Western Almanac* for 1838, shewing the number and tonnage of steam-vessels sailing on the Clyde in 1837.

	Vessels.	Tonnage.
Out-sea-boats (to England and Ireland) .	15	3187
Boats for passengers along the coast, some as far as to Inverness	35	2704
Luggage boats, between Glasgow and Greenock	9	534
Towing boats	4	219
Total	63	6644

In 1814, there were (exclusive of government vessels), eleven steam-vessels, manned by sixty-five men, and of 542 tons burden in all, in Great Britain and Ireland. In 1828 (fourteen years later), 344 steam vessels, manned by 2,708 men, and of 30,912 tons burden; and now (1838) 760 vessels, of 78,664 registered tonnage, 56,490 horse power. Of these, about 480 are river steamers and small coasters, 280 large coasters and sea-going vessels.

THE MARINE ENGINE.

322. In the steam-boat engine, the power is applied to turn a stout rod or shaft, to which a wheel is attached. To the rim of this wheel a number of flat boards are fixed, at regular intervals. When the

wheel revolves, these *paddle boards* act upon the water in the same manner as the oars of a boat, the resistance of the water propelling the vessel in a direction opposite to that in which the paddle acts upon the water. The lower paddles are always under the surface, and, by the revolution of the wheel, a continued impulse is given to the vessel. In this country, condensing engines are generally used for steam-vessels. They are in all respects on the same general plan as the double-acting engine of Watt, differing slightly in the construction and relative position of the parts.

323. In most steam vessels two engines are used, acting upon a common axis, and with the cranks so arranged that when the crank of one is at its critical points, that of the other is in full action; and thus the continuity and tolerable uniformity of the motion is insured, without the encumbrance of a fly-wheel. In other steamboats, only one cylinder is used. The manner in which the parts are arranged in steamboat engines, will be readily understood from the following outlines—*figures* 29, 30, 31, and 32. *Fig.* 29 is a view looking across the vessel; *fig.* 30 along it.

Fig. 29.

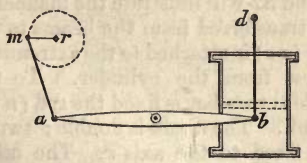
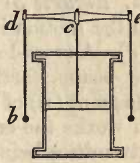


Fig. 30.



The beam is below the cylinder, not above it, as in land-engines; aud there are TWO BEAMS, one at each side of the cylinder. The piston-rod has a cross-bar (or cross-head), (*d e*, *fig.* 30,) attached to its upper extremity, and passing over the cylinder in a transverse direction in relation to the boat. From the ends of this cross-head *d e*, rods hang down, attached to the ends of the beams at their lower extremities, and playing on pivots at both their connection with the cross-head and the beams. One of these is marked *d b* in *fig.* 30, which represents a view of the piston, with its rod, cross-head, and side-rods, as seen looking along the boat. *Fig.* 29 is a side view, shewing the piston, one side-rod, one beam, and the situation of the crank, and axis or shaft, marked *r*, which turns the wheels. The beam is in the horizontal position, and the piston, as shewn by the dotted line, in the middle of the cylinder.

Fig. 31

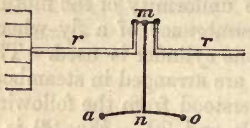
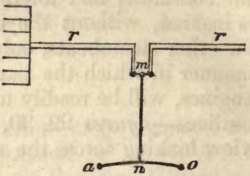


Fig 32.



324. *Figures* 31 and 32 will illustrate the manner in which the motion is transferred from the beams to the axis (*r*). A cross-bar (*a o*) is attached to the extremities of the beams farthest from the cylinder. To the middle point (*n*) of this cross-bar is fixed the rod (*n m*) which works the crank. The crank is double; two of its extremities being fixed to the axis *r*. The other two ends of the crank are connected by a short transverse bar, to the middle of which (*m*) the rod *n m* is fixed. The paddle wheels are firmly fixed to the rod *r*, which communicates the motion to them.

325. The action will be readily understood, with the aid of the preceding figures. The piston-rod raises

and depresses the cross-head (*d e*, *fig.* 30), with which the side rods rise and fall; and these elevate and depress the extremities of the beams to which they are attached. The other ends of the beams, alternately rising and falling, carry the cross-bar (*a o*) along with them, which, communicating its motion to the crank, by the rod *n m*, gives a continued circular motion to the axis, the extremity *m* of *n m* describing the circle shewn by the dotted line in *fig.* 29. *Figures* 31 and 32 shew two different positions of the crank.

326. In all other respects, this engine is very similar to the condensing engine of Watt, already described. The parallel motion, eccentric rod, air-pump, condenser, &c., are the same, and require no description.

327. Some steamboat-engines are now coming into use, in which the beam is dispensed with, and thereby much room is saved; and the engine is also rendered much lighter. The engine projects considerably above the deck, from which it is quaintly termed the *Steeple Engine.* The following figures will illustrate one of the plans by which this is effected. See also *figures* 35, 36, page 176.

Fig. 33.

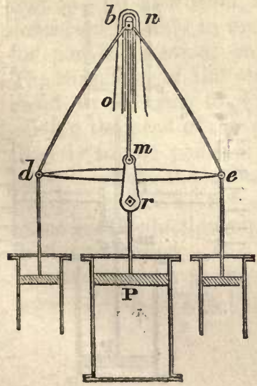
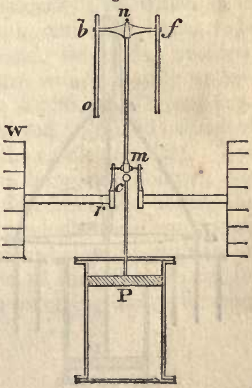


Fig. 34.



In the above figures, P is the piston, whose rod (*P c*, *fig.* 34) terminates in a cross-head (*d e*, *fig.* 33). From the ends (*d e*) of the cross-head, two bent bars proceed upwards, meeting at a point (*n*) in the middle of a short horizontal rod (*b f*, *fig.* 34, 36.) The piston rod carries up and down the triangular frame *n d e*; and to the point *n* is fixed the rod *n m*, which turns the crank *m r* in the usual manner. The extremity *n* of the rod *n m* is kept moving vertically, by the ends (*b f*) of the short rod, to the middle of which *n* is fixed, moving in grooves or slides (*bo*), so that the piston rod, notwithstanding the inclined motion of the rod *n m*, is always preserved perfectly vertical. Thus, through the medium of the triangular frame, the motion of the piston is transmitted almost directly to the rod *n m*, which turns the crank, while, by the simple contrivance of the slides, the vertical motion of the piston rod is accommodated to the circular motion of the crank. There are two air-pumps worked by the rods from *d*, *e*, the ends of the cross-head; and two condensers; and the valves and other pumps are worked by eccentric rods attached to the axis.

Fig. 35.

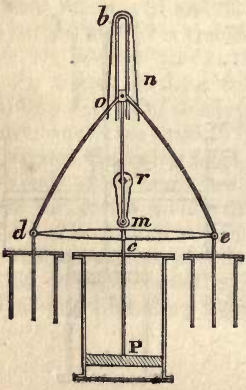
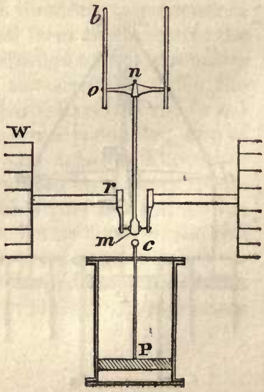


Fig. 36.



328. In *figures* 33, 34, the piston is at the top of the cylinder, and its rod above the level of the axis, and between the bars of the double crank: the rod *bf* is at the top of the slides, and the crank at its highest point. In revolving, the crank has free play from the triangular form of the bars *d e n*, and from the sinking of the cross-head *d e*. In *figures* 35, 36, the piston is at the bottom of the cylinder, the cross-bar *d e* below the crank and axis, the crank in its lowest position, and the horizontal bar *b f* at the bottom of the slide; W represents the paddles, turned by the axis *r*.

329. Vibrating Engine.—This is another contrivance, by which the beam, and rods connected with it, are dispensed with, and there is a considerable saving in room, weight, and expense. To adapt the rectilinear motion of the piston-rod to the circular motion required in the shaft or axis of the engine, the cylinder, instead of being fixed, is hung on an axis at its middle part, on which it has motion backwards and forwards, assuming alternately the positions of the two strokes of an X, and vibrating about as much as a beam on its axis. Thus, the piston-rod has a double motion—up and down, and laterally; by which it is connected directly to the crank, and thus beam, rods for parallel motion, cross-head, side-rods, avoided. The simplicity of the structure will be readily understood, by referring to *figures* 29, 30, p. 173, and conceiving the head of the piston-rod (*c*, *fig.* 30) attached directly to the point *m* of the crank (*fig.* 29). The axes on which the cylinder is hung, are hollow; one conveys steam to the cylinder from the boiler, the other is the eduction-pipe, by which the steam passes to the condenser. The cylinder hangs upon them, in a manner similar to the globe of the Æolipile on its axes, (*fig.* 8, p. 74), but not revolving, only vibrating

a little alternately to each side. This engine is the invention of Mr. Witty. It has been improved by Maudslay.

330. In the boilers of land engines, the earthy and saline matters contained in the water, and which are not evaporated along with the pure watery part, are deposited, falling down and forming a crust at the bottom, which requires occasionally to be cleaned out. But the quantity of such sediment is not great. In the case of marine-engines, however, it is very different. The sea-water, with which the boiler is supplied, contains a very large proportion of saline matters (about 3 per cent.), and this, deposited at the bottom, would very soon produce a serious impediment to the action of the engine, as well as cause some danger of explosion (158, 162.) From sea-water there is deposited, not only common salt, but sulphate of lime, which forms an extremely hard crust, difficult to be removed, and giving a slow passage to heat; so that, from the heat not being rapidly withdrawn by the water, the boiler (if the encrustation be thick) may be rendered red-hot. Also, much fuel is wasted.

331. It has been customary hitherto to retard the deposition of solid matter by an operation termed *blowing out.* This consists in allowing hot water to escape frequently from the boiler. The hot water contains, besides the salt it had when it first entered the boiler, the salt of a great quantity of the rest of the water. For, 100 parts of sea-water contain three of salt; but that quantity of water *can hold in solution thirty-six parts of salt;* hence, 100 parts of water run out, will contain the salt of eleven other hundred parts of water, besides its own. Thus, the salt will be carried out, and little deposit will take place. Of course, a waste of fuel will attend the removal of water which has been heated, but has not been formed into

steam to exercise any moving power. This loss has been estimated by Mr. Tredgold at 1-54th part. This is not a great proportion; but the plan does not entirely prevent deposit. Hence, a number of schemes have been proposed for remedying this great defect in marine engines. The most notable of these are *Howard's Vapour Engine*, and *Hall's Condenser*.

332. Howard's Vapour Engine.—This engine is not designed for vessels alone, but, as the advantages it aims at are the saving of room, weight, and fuel, and therefore its most important application must be to navigation, it may be described here. The plan of Howard's vapour engine is to dispense altogether with the bulky and heavy boiler for containing a large quantity of water, by forming the necessary quantity of steam only at each stroke of the engine. This is contrived in the following manner.

333. This engine is a condensing engine like Watt's, differing in the mode of forming the steam. A shallow pan of wrought iron is placed over a coke fire. The pan contains a quantity of mercury, above which, and in close contact with it, there is a thin covering of iron, so constructed as to present a surface four times that of the pan exposed to the fire. This apparatus is placed below the cylinder. The steam is procured by injecting the necessary quantity of water on the iron resting upon the mercury at the proper intervals. The power with which the engine works depends on the quantity of liquid thus injected, which is regulated by a valve moved by a governor, or by the engineer. The vapour thus formed passes into a chamber immediately surrounding the cylinder, in which it is heated to about 400°, and thus has additional elastic force communicated to it. The air which supplies the fire enters through a valve, by which the quantity is regulated; and, before entering the chimney, the heated

air passes into a casing, enclosing the vapour-chamber which surrounds the cylinder, and communicating part of the heat it contains to the vapour before it enters the cylinder. The steam is worked expansively, in order still further to save fuel, the supply being cut off at one-fourth of the stroke. It has thus a pressure, taking the average of the whole stroke, of 12 lbs. per inch, if it was 20 lbs. during the first fourth. This engine also presents a very ingenious plan of condensation, by which all deposit in the boiler is avoided, and a small air-pump is sufficient to work the condenser. The condenser is a copper vessel set in a cistern, continually supplied with cold water. The same condensing water is used over and over again. Two pumps withdraw the warm water from the condenser, and pass it into a pipe, which winds with many turns through the cistern, and thus the injection water is cooled. This pipe terminates in the condenser, into which its water, now sufficiently cooled, is again injected; and so on. Distilled water is used for the condensation, and for the formation of the vapour, and thus, no air being contained in either the vapour or condensing water, a small air-pump is sufficient to exhaust the condenser. The distilled water contains no earthy matters in solution, and there is, therefore, no encrustation or deposit on the iron plate, at the surface of which the water is vaporised.

334. Hall's Patent Engine.—The leading peculiarity in Hall's engine, is the condenser. By its construction, the same water is used over and over again for forming the steam (as in Howard's engine), and water free from earthy matter being employed at first, there is no deposit nor encrustation in the boiler. The vapour is condensed without any injection water. This is managed by forming the condenser of a number of slender tubes, which are placed in a cistern of

cold water, and, presenting a large surface to the water, are continually kept at a very low temperature, by which the steam in the interior is quickly and effectually condensed. Indeed, there is, in the condenser of Hall's engines, a vacuum so nearly perfect, that the mercury in the condenser-guage stands at times at about 29 inches, or even 29½, which is as perfect a vacuum as can be hoped for. In the SIRIUS, which is upon this plan, the condenser barometer is said, during her voyage to New York, to have been generally at 27½ inches. From the cylinder, the steam passes into a shallow chamber, from the lower part of which the tubes proceed. They are open above and below. The steam enters them, is there condensed, falls out below as water, and is pumped out by an air-pump, and conveyed back to the boiler in the usual manner. The waste from leakage is supplied by distilling sea-water, for which an apparatus is provided. By an ingenious form of the safety-valve, the steam which, in the usual form of marine engines, escapes into the atmosphere when the engine is stopped or works at a slower rate —is conveyed to the condenser, so that there is no loss of the pure water used, from this source.

335. The advantages of this engine in saving fuel, forming a good vacuum in the condenser, preserving the boiler from being destroyed, either by corrosion of the salt, or action of the high temperature caused by encrustation, and several other improvements which it presents, have brought it much into notice. It has been employed both on land and water, and, it is probable, will be the means of facilitating the use of steam-conveyance for long voyages.

DR. LARDNER'S SELF-RECORDING STEAM JOURNAL FOR STEAM-VESSELS.

336. This is a very interesting, very beautiful, and very useful invention. It is a perfect spy and tell-tale upon every circumstance connected with the machinery of a steam-vessel. It will be best explained by the following extract from DR. LARDNER's speech at the Newcastle meeting of the British Scientific Association (1838), in which it is described.

"To give an idea of what it would be necessary to have registered, in order to understand the behaviour of a vessel, he would just mention the things which filled the columns of a log, which was proposed by a captain in the navy to the Admiralty should be kept in the navy. The rate of the vessel, her course, the direction and force of the wind—and there were 12 marks by which the degrees of the winds' force were to be expressed—the height of the waves—the immersion of the vessel abaft and forward—the state of the throttle valve—the number of revolutions in the paddle wheel per minute—the consumption of coal per hour—the height of the steam-guage—the height of the barometer—the height of the thermometer—and lastly, the state of the boilers; and these were required to be entered in the log hourly. This plan, as he said, had been submitted to the Admiralty, and was considered impracticable; but a modified log, taken from this, had been introduced, and even it had not been found to work successfully. He mentioned these things to show that in the construction of his self-acting log, he had not gone beyond, nor indeed so far, as the objects required to be registered in the logs of the Admiralty steam-vessels. The result of his investigations were now before them. Here the Rev. Doctor proceeded to explain a very beautiful piece of mechanism in the room, which he called a self-recording steam-journal. His great object had been to have the state of the steam and machinery of the vessel accurately kept on paper. For this purpose, two cylinders were placed vertically in the inside of the engine, round one of which, a sheet of paper, 60 feet in length, was coiled up, the one end of it being passed round the other cylinder, and held fast by screws or pins. The two cylinders, with the sheet of paper round one of them, pressed closely but gently on each other, thus preventing all ruffling of the paper, and keeping it always in a smooth surface. When the engine was put in motion, the paper unrolled itself from the one cylinder, and was coiled up on the other, precisely like the chain in the machinery of a watch ; but in its passage from the one to the other, it was rubbed against a series of pencils in different positions of the paper, which were intended to express the state of the machinery."

* * * * * * *

"He then described the usual mode in which this pressure is ascertained in an ordinary engine, and stated that to an iron rod that rose or fell with the pressure of steam in the boiler, he connected a pencil which constantly, as before explained, communicated with the paper. If the steam were always maintained at an equal pressure, the consequence of this would be that the pencil would mark a perfectly straight and undeviating line along the surface of the paper as long as it was in operation. But as this could not be the case, as the steam would necessarily be of unequal pressure at different times, the effect of this would be to mark a waving line, consisting of a series of curves along the paper, rising or falling with the steam ; and the elevation or depression of these curves would give an accurate register of the average of diminution of the pressure of steam in the boiler. The time when these changes took place were also marked off in the same way on another part of the paper immediately opposite, by another ingenious process. A common clock was fixed in the engine, and the machinery of the clock set in motion a wheel, consisting of twelve teeth, the twelfth being differently formed from the others. A pencil was fixed in communication with this teethed wheel, which curved gradually on the paper, marking of course as it went until it reached the culminating point of the tooth, when it fell suddenly and straight down to a certain point. Each fall of this kind marked an hour on the paper until it came to the twelfth, when a different mark was made. Supposing, therefore, the machine to be set in motion, from this twelfth tooth, at noon of the day when the vessel leaves her port, an accurate register of time might be kept so long as the machine is kept going; and by conjoining any hour there expressed with the other characters expressing the steam-guage, it may be seen at a glance what was the time of any given state of pressure on the steam boilers. The other registers which it was intended to keep were the pressure of steam in the cylinder—the state of the barometer or the vacuum guage in the condenser—the time when the steam is cut off from the cylinder if the vessel is worked on the principle of expansion—the revolutions of the paddle wheels per minute—the depth of the water in the boiler and its saltness,—all these were expressed by means similar to those above described on portions of the sheet of paper, by means of mechanism which, coming from the different parts of the machinery, acted upon their respective pencils, and produced the effects described. These were all the guages he had thought of attempting in the first instance; and even if it should happen that one or two of them might fail, the guages being independent of each other, the remaining ones would not be interfered with. On consulting the steam companies as to the advantages of such a register, the answer he received was, that even if he should succeed only in registering the state of the steam and the barometer in reference to time, he would be doing a great service to steam and navigation; for it would be useful not only in determining the efficiency of the vessel, but also as constituting a check on the good conduct and diligence of every one on board connected with the machinery. He ought also to state that he proposed to have another pencil, not as a guage of any thing, but merely expressing what the average height of the steam ought to be. The impression of this pencil would, of course, be straight and unbending, so that any one, though he knew nothing of machinery, would see at a glance whether the impression made by the steam-guage was above or below this line, and by that means would ascertain whether the steam was higher or lower than it ought to be."

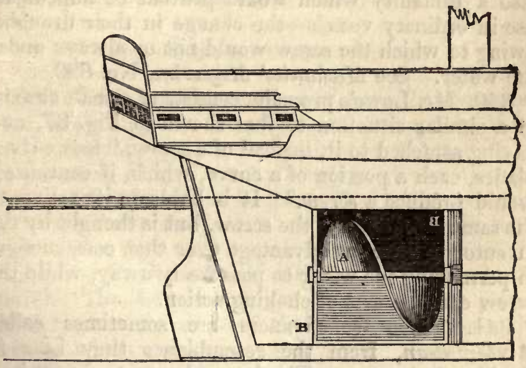
SCREW PROPELLER.

337. The swell and surf occasioned by the action of paddle wheels, which render them unfit for canals—the impediment which they offer to sailing—and their

being so exposed that they would be very certain to be destroyed by a few shot, as well as other inconveniences—have rendered it desirable to have means of propelling vessels by steam, that would be free from the above disadvantages. Of the leading schemes for this purpose, the most interesting is the screw propeller. Many different plans have been offered for propelling vessels by means of the screw. Those of Mr. Smith and Mr. Lowe have been tried, and are in actual operation—the former in the "Archimedes" Steamer, the latter in the "Wizard," both plying on the Thames. Having been tested by actual practice, these are the most deserving of notice.

338. The following figure and description (from the Mechanic's Magazine, No. 830) will convey some idea of the nature of Mr. Smith's screw-propeller

Fig. 37.



"A A is the blade of the propeller, being one turn of a screw, forming an angle of about 40 degrees with the shaft or axis; it is made of iron plates, strengthened by wrought iron arms. B B is the frame fixed in the deadwood of the vessel to support the propeller. The shaft or axis passes through a stuffing box in the after part of the frame, and stern of the vessel, and onwards to the engine, by which it is made to revolve. For every revolution of the crank-shaft of the engine, the screw turns about $5\frac{1}{3}$ times. The screws are made movable, and fixed on to the shaft with keys, so that different sizes may be used under different circumstances. The diameters of the screws which have been used are 5 feet and 7 feet, and their lengths $7\frac{1}{2}$ and 8 feet."

339. That the screw-propeller may come into use for war-vessels, where the chief object is to have all the parts connected with the motion of the vessel out of the reach of shot, is probable; but there are many obstacles to its introduction into general use. There is a great waste of power from the high velocity of the blade of the screw, the friction or adhesion of the water being very great; and the machinery for producing this high velocity being complex. There is also a difficulty which would prevent or impede its use in ordinary vessels—the change in their draught, owing to which the screw would not be always under the water. See *Mechanics' Magazine*, No. 830.

340. Mr. Lowe's propeller consists of a shaft or axis, in a similar situation to that shewn in Fig. 37, and having attached to it, instead of a screw, "four curved blades, each a portion of a curve, which, if continued, would produce a *screw*." It is liable in its action to the same objections as the screw, but is thought by the inventor to have an advantage over that construction, in permitting the water to pass freely away, while the screw causes a sort of choking action.

341. These contrivances are sometimes called *Archimedean*, from the resemblance they bear to Archimedes' screw. The latter, however, was a hollow tube in a spiral form, and set in an inclined position, the lower extremity being immersed in water, the raising of which, by turning the screw, was the object of this celebrated machine.

342. Another propeller, devised by Captain Ericsson,

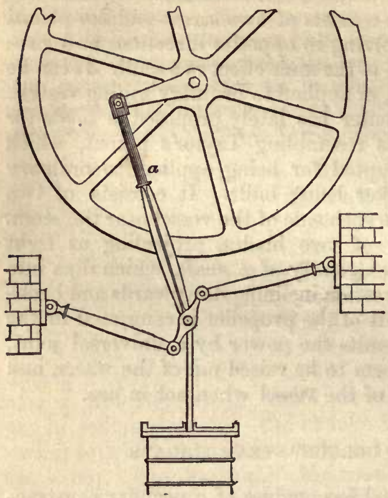
has been much talked of, and attended with considerable success. It consists of two screw-paddles placed at the stern, revolving in opposite directions and producing somewhat of the same effect as a scull. It can be easily unshipped, or applied to ordinary sailing vessels.

Captain Carpenter has lately proposed a mode for propelling vessels resembling Taylor's patent, which seems better adapted for being applied to ordinary sailing vessels after being built. It consists of two propellers, one on each side of the vessel near the stern. Each is formed of two blades, projecting at right angles from the extremity of a shaft, which dips into the water in a direction inclining downwards and backwards. The shaft of the propeller is connected to the axis, which transmits the power by a universal joint, which permits them to be raised out of the water, and hung at the side of the vessel when not in use.

THE "GORGON" STEAM FRIGATE.

343. This vessel has engines of a peculiar construction, possessing the advantages of being very light, and occupying comparatively little room; and being at the same time of great strength. It has two engines, and four copper boilers. The latter are quite detached from each other, so that they can be used together or separately; and though one or two be under repair, there would still be two to work the vessel. The shafts which turn the paddles are placed directly over the centre of the cylinders, crossing the line in which the piston rods move. There are no side beams, side rods, or cross heads: the piston is connected almost directly to the crank, a short rod only intervening, and is kept vertical by a simple contrivance, a sort of parallel motion, which will be understood from the following figure. This figure represents

Fig. 38.



Crowther's parallel motion for fixed engines. A somewhat similar construction, with a shorter crank rod, *a*, preserves the piston rod vertical in the engines of the Gorgon; and at the same time works the air-pump, feed-pump, and bilge pump. It is reckoned that there is a saving of weight to the amount of sixty tons—the side beams that would have been required alone weighing forty-five tons. Owing to the absence of side beams, there is less of that tremulous motion, so remarkable and disagreeable in other steam-vessels. The engines are of 320 horse-power, and there is plenty of room in every part of the machinery. They were built by Messrs. Seaward & Co., at Limehouse, London. The diameter of the cylinder is 64 inches; length of stroke, $5\frac{1}{2}$ feet; diameter of paddle wheel, 27 feet. The vessel is about 183 feet long on deck, 37 feet 6 inches between the paddle wheels. In an experimental trial, she went at the rate of about $11\frac{1}{4}$ miles hourly, the engine making $19\frac{1}{2}$ strokes every minute, and the consumption of the fuel being about 7 lbs. of Welsh coal per horse power, hourly. The motion was observed to be remarkably steady, quite free from vibration.

From the saving of weight and room, and the prevention of the vibratory motion, which is injurious to the vessel and machinery, as well as unpleasant, the Gorgon is one of the most interesting and important experiments yet tried in steam-navigation. A little time will shew if there is reason for the favorable anticipations formed of her. Hitherto, she has not disappointed these expectations. Another steam-frigate, the Cyclops, has lately been launched, about 200 tons larger, and with engines of the same construction as the Gorgon. And others, to have engines on the same principle, are on the stocks.

AMERICAN STEAM-BOATS.

344. Some account of the state of steam-navigation in the country where steam was first introduced as a moving power for propelling vessels, may be interesting. The following extracts from a very excellent work on *Engineering in America*, by Mr. Stevenson, will convey some notion of the system on which steam-navigation is conducted in the United States.

"With the exception of the vessels navigating the lakes, and one or two of those which ply on the eastern coast, there is not a steamer in the country which has either masts or sails, or is commanded by a professional seaman."

There are three classes of boats, the

Eastern Water Boats,

Characterized by "small draught of water, great speed, and the use of condensing engines of large dimensions, having a great length of stroke." The steam is used of a much higher pressure than in condensing engines in this country. The voyage on the Hudson river, between New York and Albany, Mr. S. states, is now performed in about ten hours, that is at the rate of 15 miles an hour.

The Western Water Boats

Have "greater draught, less speed, high pressure engines of small size, worked by steam of great elasticity."

The two preceding classes of boats ply on the rivers, and the frequent shoals render it necessary that their draught should be small.

The Lake Boats

are like sea-going steamers. Plying on the large lakes at the north of the States, they are exposed to tempests, and heavy swells, and surf on the waters, and require to be of a firmer make, and adapted for sailing.

"By far the greater number of the American steam-boats ply on the smooth surfaces of rivers, sheltered bays, or arms of the sea, exposed neither to waves nor to wind; whereas most of the steam-boats in this country go out to sea, where they encounter as bad weather, and as heavy waves as ordinary sailing vessels. The consequence is, that in America a much more slender build, and a more delicate mould give the requisite strength to their vessels, and thus a much greater speed, which essentially depends upon these two qalities, is generally obtained. In America the position of the machinery and the cabins, which are raised above the deck of the vessels, admits of powerful engines, with an enormous length of stroke, being employed to propel them; but this arrangement would be wholly inapplicable to the vessels navigating our coasts, at least to the extent to which it has been carried in America."

The following statements regarding the *Rochester*, a river boat, plying at the average rate of 15 miles an hour, are interesting.

Rochester.—209 feet length on deck and keel; 24 feet breadth of beam; breadth outside of paddles, 47 feet; depth of hold, 8 feet 6 inches; average draught of water, 4 feet; diameter of paddle wheels, 24 feet;

float-boards, 24; length, 10 feet; dip of float-boards, 2 feet, 6 inches. One engine; cylinder, 43 inches diameter, length of stroke, 10 feet.

"When the Rochester is 'pitched' against another vessel, and at her full speed, the steam is often carried as high as 45 lbs. on the square inch of the boiler; and the piston makes 27 double strokes, or, in other words, moves through a space of 540 feet per minute, or 6·13 miles per hour. In this case the circumference of the paddle wheels moves at the rate of 23·13 miles per hour. In ordinary circumstances, however, the engine is worked by steam of from 25 to 30 lbs. pressure on the square inch: and in this case the piston makes about 25 double strokes per minute, moving through a space of 500 feet per minute, or 5·68 miles per hour; and the circumference of the paddle-wheel moves at the rate of 21·42 miles per hour. The rate at which the pistons of marine engines in this country move, seldom exceeds 210 feet per minute. The pistons of locomotive engines generally move at the rate of about 300 feet per minute; but both of their speeds are very far short of the velocity of the 'Rochester's' piston.

"The diameter of the Rochester's piston is 43 inches, and its area 1452·2 square inches. The pressure of the steam in the boiler is 45 lbs. on the square inch; and the engine works expansively, and cuts off the steam at half-stroke. The half of that pressure, or 22·5 lbs. is assumed as the pressure acting on the square inch of the piston. To this 10 lbs. is added as the pressure of the atmosphere, obtained by the use of the condenser, making the whole effective pressure on every square inch of the piston's area, 32·5 lbs. The length of the stroke is 10 feet, and when going at full speed, the piston makes 27 double strokes, or, in other words, moves through the space of 540 feet every minute. Estimating the power of a horse as equal to that exerted in raising 33,000 lb. one foot per minute, the power of the engine is obtained by the following expression

$$\frac{1452{\cdot}2 \times 32{\cdot}5 \times 540}{33000} = \frac{25486110}{33000} = 772{\cdot}3$$

From this it appears that a force is exerted upon the engine equal to that of 772·2 horses; but one-third of this power is supposed to be expended in working the pumps, and overcoming the friction of the machinery, and a power of 514·8 horses remains as the true force exerted in propelling the vessel.

"If the calculation generally adopted in this country were applied to those engines, and only one-fourth of the power deducted, which appears to be an ample allowance for engines of that construction, the power of the 'Rochester' would be equal to 748 horses.

In the western water boats, "when only one engine is used, which is more generally the case, a large fly-wheel, from 10 to 15 feet in diameter, is fixed on the paddle-wheel shaft, and serves to regulate the motion of the engine, and enable it to turn its centres. The cylinders are invariably placed horizontally, and the engines are always constructed on the high pressure principle."

Steam of great elasticity is employed in the "Rufus Putman:" it is 138 lbs. on the square inch, under ordinary circumstances; 150 lbs. occasionally; that is never exceeded except on extraordinary occasions. In the "St. Louis," the pressure is 100 lbs. on the square inch. It is not surprising that explosions are frequent in American steam-vessels.

STEAMERS ON THE MISSISSIPPI.

"The paddle wheel axle is so constructed, that the portions of it projecting over the hull of the vessel to which the wheels are fixed can be thrown out of gear at pleasure, by means of a clutch at each side of the vessel, which slides on the intermediate part of the axle, and is acted on by a lever. When the vessel is stopped, the paddle-wheels are simply thrown out of gear, and the engine continues to work. The necessary supply of water is then pumped into the boiler during the whole time that the vessel may be at rest.

"The fly-wheel, formerly noticed, is useful in regulating the motion of the engine, which might otherwise be apt to suffer damage from the increase and diminution of the resistance offered to the motion of the pistons by suddenly throwing the paddle wheels out of gear. The water for the supply of the engine is first pumped into a heater, in which its temperature is raised, and is then injected into the boiler."

Mr. Stevenson considers that the explosions, so frequent and so fatal in America, are caused sometimes simply by the very high pressure—often, by a deficient supply of water, causing the boiler to become red hot; and water being then pumped in, is suddenly evaporated in larger quantities than can escape by the valve—the most common cause in steam-boats in this country.

The boilers rest on the paddle-wheel gaurds, one on each side of the vessel. The furnace is so placed that the ashes and charcoal fall into the water. The glare from the furnaces forms a very striking feature on the rivers at night. Pine timber, bituminous coal, and blind coal or anthracite, are the sorts of fuel used in the American steamers.

PROSPECTS OF STEAM NAVIGATION.

345. The greatest feats yet performed by steam on the deep are the voyages of the Great Western and British Queen across the Atlantic, of the steamers that ply from Leith and Dundee to London, and of those very fine vessels that run between Glasgow and Liverpool.

346. The Sirius led the way across the Atlantic, starting from Cork early in April 1838, on its first trip to New York, and arriving there in nineteen days: it made the return voyage in eighteen days. The Great Western, constructed expressly for the

Atlantic navigation, left Bristol a few days after the SIRIUS, arrived in New York in fifteen days, and made the home voyage in fourteen days.* On one occasion the *Great Western* came from New York to Bristol in $12\frac{1}{2}$ days—a distance of 3500 English miles—being at the rate of 280 miles a day, or $11\frac{2}{3}$ miles per hour. The time occupied by this fine vessel in both voyages is from 27 to 29 days. The average time of the sailing-packets for both voyages, is fifty-four days; so that the steam-ship *Great Western* crosses the Atlantic twice in about half the average time required by the packets. The average time of the voyage from Liverpool to New York is thirty-four days; from New York to Liverpool, twenty days. There is reason to believe that, by the usual course of improvement, the steam voyage to New York will be reduced to an average of from twelve to thirteen days. The *Great Western*, during some of her late voyages from New York to Bristol, encountered head winds nine days out of the fourteen; and, on one occasion, made $7\frac{1}{2}$ knots ($8\frac{3}{4}$ English miles), with a brisk gale directly in her teeth. The results that may be expected to follow this great demonstration of the capability of steam for long voyages, can hardly be too highly estimated. The superior safety and regularity of steam-vessels—independent of their greater speed—have been fully shewn by the steamers between London and Edinburgh, London and Aberdeen, England and the Mediterranean; and, when steam communication has thus been established between England and the United States, it may be said to be now proved to be applicable for the whole world. India (by the Cape of Good Hope), the Canadas, the

* See in the Appendix the Table giving the dimensions, &c., of five great steam-vessels already plying in, or intended for the Atlantic navigation.

West Indies, and South America, will be soon brought nearer Europe by the same powerful agent, and thus greatly increased facilities be given for friendly intercourse, commerce, and the mutual exchange of the higher benefits of knowledge and civilization *between all the nations of the earth.*

347. It is proper to mention that the first voyage of a steam-boat across the Atlantic, was made in 1819, by an American vessel, called the SAVANNAH, built at New York. This vessel, commanded by Captain Rogers, sailed from Savannah on May 25th, 1819, and anchored at Liverpool on June 20th; and, after visiting Russia, Denmark, and Norway, returned to Savannah on the 30th of November, in the same year. It is not certain that this vessel steamed the whole way. The CURACOA, a steamer, with two 50 horse-power engines, went from Holland to Surinam in 1828; sailing, however, a great part of the way. Nothing further seems to have been done by any parties in prosecution of the scheme till the GREAT WESTERN was laid on the stocks in 1837.

348. The following table shews the result of trials made by the GREAT WESTERN of her speed, consumption of fuel, &c.

Power of steam to square inch.	Revolutions of paddles per minute.	Miles per hour.	Cwt. of coals per hour.
3½ lbs. or full.	15½	12¾	28
8-10ths of 3½	15	12½	27
7-10ths of 3½	14	12¼	26
5-10ths of 3½	13	11	23

Reducing these cwts. to pounds, and dividing by 450, the number of horse power, the result will be for each horse power hourly,

12¾ miles	7 pounds of Coal.
12½	6¾
12¼	6⅗
11	5¾

349. In many of her voyages, the average daily consumpt of fuel was 27 tons; that is, if out 16 days, 432 tons of coal required by a vessel of 1321 tons burden, and 450 horse power, for a voyage of 3500 English miles; or 100 tons of fuel for 800 miles. But this vessel could carry 300 tons more fuel. Of that, allowing one-third for the power required for extra weight, adverse weather, &c., 200 tons might be available for extending the voyage. That will carry her 1600 miles, which added to 3500, gives 5100 miles as the distance the GREAT WESTERN could undertake. This renders steam applicable for almost every voyage. But processes such as that of Messrs. Ivison and Bell will effect some saving in fuel in marine engines, so that there is every probability of steam-vessels being soon able to undertake easily and safely voyages of upwards of 5500 miles.

350. Steam is about to be applied to navigation in a new way. Vessels on long voyages often lie a long time becalmed, and in certain latitudes, a vessel has often a chance of finding a favourable wind, if she can get into it, a little distance being sometimes sufficient to bring her from a dead calm or an adverse wind into a favourable breeze. And for the want of means to sail that comparative trifle, vessels often lie becalmed for many days, or even weeks. A small steam-power would effect this, and could be applied so as not to interfere materially with the construction best adapted for a sailing vessel. In a work lately published, Mr. Henry Wise states that, on an average, in a passage from England to Bombay, there are—

Hours.	
868	calm, or light airs.
1518	fair wind.
306	foul wind.
2692	

A small engine, propelling the vessel only three miles an hour, would thus quicken the voyage by 2604 miles, reckoning only the saving by steaming during the calm. The VERNON has lately sailed for India, fitted up with a small engine to be used in this way, which, there is little doubt, will enable her to shorten considerably this long and tedious voyage. The Vernon is so constructed that the paddle wheels can be unshipped and taken on board; or, what acts in the same way, though less effectual, the floats can be taken off; either of these will facilitate very much the sailing of the vessel.

351. It has been suggested that it might be very useful upon some occasions, as a storm, when the machinery has got out of order, were the paddle-floats movable, or even could the wheel be separated from its connection with the engine (thrown out of gear), so that it would revolve when the vessel is moving through the water. There would then be a better chance of working the vessel with a sail—the paddle-wheel and floats when fixed offering a serious resistance to the motion of the vessel, and causing it to be very much at the mercy of the winds and waves should the machinery fail.

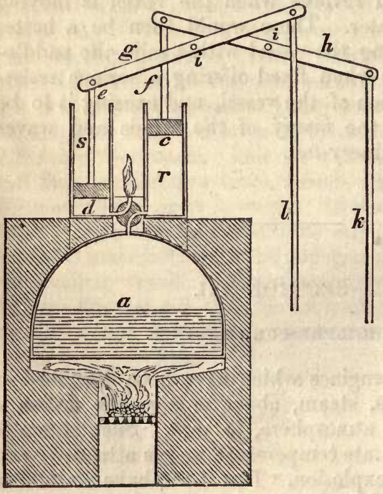
SECTION VII.

HIGH-PRESSURE ENGINES.

352. In the engines which have been described in the last sections, steam, about or near the ordinary pressure of the atmosphere, is used. Such steam is raised at a moderate temperature, and is attended with little risk of an explosion. But it can have no motive power, if resisted by the atmospheric pressure: to give

such steam an impelling force, the space into which it acts (pushes the piston) must be a vacuum, or nearly so. Hence the necessity for a condensing apparatus, embracing condenser, air-pump, cold-water-pump, &c. These are termed CONDENSING or LOW-PRESSURE Engines. They are both costly and cumbrous; and, if it is desired to have an engine as cheap, simple, and light as possible, this is effected by dispensing with the condensing apparatus. The steam, in such a case, will be resisted by the atmospheric pressure; and, therefore, to do any work, must have a pressure much higher than steam acting against a vacuum. Simply to balance the air's pressure, it must have an equal force; and it will exert no impelling power until it exceeds it considerably. Such engines are termed HIGH-PRESSURE, or NON-CONDENSING.

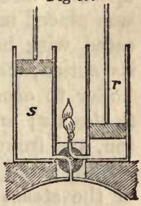
FIG. 39.



353. Savery's engine was (in the second part of its action) a high-pressure engine. One of the simplest was that devised by Leopold, a German, author of the *Theatrum Machinarum.* This engine, invented about 1720, is represented in the adjoining figure:—

Two cylinders with pistons were placed above a boiler, each having an aperture at its lower part, communicating with the boiler, or with the open air, according to the position of a valve, called a four-way cock, interposed between the boiler and cylinders. The cylinders are open above, and the piston rods are attached to levers or beams, which they work. In *Fig.* 39, steam is entering the cylinder *r*, and pushing up the piston, the force of the steam being sufficient to overcome the pressure of the air, the weight and friction of the piston, and the resistance at the other end of the beam *h*. In the cylinder *s* the piston is descending by its own weight, (the steam, which, by the position of the four-way cock, has free access to the air, rushing out,) and thus pulling down the extremity of the beam *g*, to which it is attached. When the piston in *r* has reached the top of its cylinder, and that in *s* is at the bottom, the four-way cock is turned to the position shewn in *Fig.* 40. Thus, steam is again admitted to *s* to push up its piston, and the steam in *r* has access to the air—it rushes out, its elasticity is greatly weakened, and the piston in *r* descends. The four-way cock was contrived by Papin. The engine was proposed by Leopold for raising water, pump-rods being attached to the extremities of the beams *g* and *h*. This was the first high-pressure engine in which the motion was transmitted by a cylinder, piston, and beam; and the steam, after having performed its work, was made to escape into the air—the method now employed in all high-pressure engines.

Fig 40.



354. The next high-pressure engine, the first that came into use, was that of Messrs. Trevithick and Vivian, a very simple and beautiful contrivance, and

which, while it is applicable to the usual purposes for which condensing engines were used, was the first engine applied to locomotion, in drawing waggons on railways. Their engine was constructed about 1802, and, two years after, was in use upon a railway at Merthyr Tydvil in South Wales.

355. In the engine of Trevithick and Vivian, the boiler was of a peculiar construction. It was of a cylindrical form, with flat ends. The flue carrying off the heated air from the grate, made a bend like a U through the boiler, from one end of it to the other, where it terminated in the chimney. The flame and heated air thus winding through the boiler, communicate a considerable quantity of heat to the water. The cylinder was in a great part immersed in the boiler, by which its temperature and the elasticity of the steam were maintained; and it was closed above, and the *steam* was made to produce the downwards as well as the upwards stroke. The four-way cock was used. It was placed near the top of the cylinder, and communicated with both ends of the cylinders by tubes. By its action, steam was alternately admitted from the boiler to *above* the piston, and from *below* the piston to the air; and next, from the boiler to *below* the piston, and from *above* the piston to the air. Thus the engine acted with a force proportioned to the excess of the steam pressure above the air's pressure. The steam, upon leaving the cylinder, passed into a tube, which led through a vessel of water, which, being thus heated, was supplied to the boiler by a force-pump. It then entered the chimney, assisted in creating a draught, and escaped into the air. The end of the piston rod was attached to a cross-bar, whose motion was preserved vertical by slides, as *b f* in *Fig.* 34, p. 175. At its extremities were two side-rods, as in *Fig.* 30, p. 173, which worked the cranks in the usual manner.

By a fly-wheel the motion was equalized; and, if necessary, could be regulated by a governor, as already described.

356. As the steam in this engine had a high elastic force, about 70 lbs. to the square inch, and was, therefore, more liable to burst the boiler, besides the usual safety-valve, another was provided, not under the control of the engineer; and in case of the water falling too low, and the boiler thereby becoming too hot, and forming steam too rapidly, or corroding, a small part of the side of the boiler, just below the lowest level at which the water should be, was formed of a fusible metal, as lead, or some metallic composition which melted at that temperature when danger might ensue, and gave exit to the steam. The steam guage would also act as a valve, the mercury being expelled by the force of the steam when too high in the limb exposed to the air, and of course too low (or altogether out) of the other.

357. High-pressure engines, being cheap in the first cost, occupying little room, and being easily moved, are now coming much into use. The piston rod is preserved vertical by a cross bar working in slides (or guides as they are sometimes called): to the ends of this cross bar, rods are attached, which work the cranks. The boiler is usually constructed of the form shewn in *Fig*. 18, p. 127. High-pressure engines are sometimes constructed with a beam and parallel motion according to the condensing engine structure. The steam is used from about 25 to 40 lbs. on the square inch.

SECTION VIII.

LOCOMOTIVE ENGINES ON RAILROADS.

358. In an engine which is to be transferred from place to place, it is evident that lightness and compactness are two principal objects. Hence the condensing engine of Watt, with its bulky and cumbrous beam, condenser, air-pump, &c., however well adapted for a stationary engine, is totally inapplicable for the purposes of locomotion. The object of the condensing apparatus is to produce a vacuum, that steam, of little or the ordinary elastic force, may act with considerable power. In locomotive engines, all this apparatus is dispensed with; the steam acting on one side of a piston is resisted by air pressing on the other side; the steam must have an equal force simply to balance the air's pressure; it exerts no motive power until it exceeds that, and therefore, to do any work, must have a pressure very much higher than steam acting against a vacuum. Hence, for locomotive engines HIGH-PRESSURE STEAM is always employed, the steam, after performing its office, being allowed to escape into the air.

359. The first locomotive engine on a railway, was that of Trevithick and Vivian in 1804. Their engine for this purpose, was on the same principle as that described in 355, differing a little in the arrangement. The cylinder was horizontal, the piston moving parallel to the road, and turning cranks by which the motion was transformed from rectilinear to circular motion, and transmitted to the wheels. This locomotive engine seems to have been very successful; and yet, for nearly thirty years afterwards, little was done

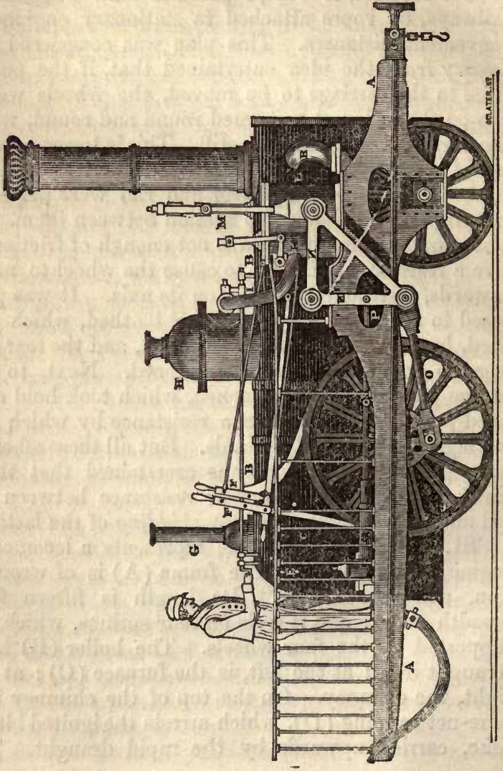
to extend the use of steam as a locomotive power. Indeed, until the opening of the Manchester and Liverpool Railway in 1830, it could not be said that the public were at all aware of the practicability and advantages of locomotive steam-engines on railways.

360. At first, it was proposed to draw waggons on railways, by ropes attached to stationary engines at convenient distances. This plan was considered necessary from the idea entertained that, if the power were in the carriage to be moved, the wheels would slip on the rail, and be turned round and round, while the carriage would remain still. This is termed *skidding* of the wheels. This would no doubt take place, if the surfaces of the wheel and rail were perfectly smooth, and there were no friction between them. It was supposed that there was not enough of friction to give a resistance sufficient to cause the wheel to move onwards, instead of turning on its axis. It was proposed to make the wheel and rail toothed, which was tried, but the motion found so rough, and the tear and wear so great, that it was abandoned. Next, to the engine propellers were attached, which took hold of a fixed point, and thus gave a resistance by which the carriage was impelled onwards. But all these schemes were given up when it was ascertained that there really is sufficient friction or resistance between the rail and wheel, to prevent any *skidding* of the latter.

361. The following figure represents a locomotive engine for a railway. The frame (A) is of wrought iron, and very strong. Its length is fifteen feet, breadth seven; and it rests on four springs, which are supported by the four wheels. The boiler (B) is of wrought iron; at the left, is the furnace (C); at the right, the chimney. On the top of the chimney is a wire-net capping (D), which arrests the ignited bits of coke, carried upwards by the rapid draught. The

boiler is a long, somewhat cylindrical vessel, with a number of tubes of thin sheet copper or brass within it, traversing the lower half. The tubes are surrounded by the water, and through them the hot air from the furnace passes; so that, besides the direct

Fig. 41.



heat of the furnace, considerable heating effect is procured from the hot air, as it passes through the tubes on its way to the chimney. The tubes are about ninety in number, and one and a-half inch in diameter. The boiler has two safety-valves (G and H); the first is under the control of the engineer; and he can load it to any extent up to a certain limit, and thus regulate the power of the engine. The other is not under his control, and is always loaded so that it does not permit the steam to acquire strength beyond a certain point, a little beyond what is required to work the engine. The tubes (I) convey the steam from the boiler to the cylinder. These tubes are provided with throttle-valves, under the control of the engineer; so that he can, as necessary, shut altogether or contract the connection between the cylinder and boiler, so as to stop the engine, or adjust the quantity of steam admitted, and thus produce any desired rate of motion. In these engines, the engineers perform the part of the governor in engines for impelling machinery. E, E, are guage cocks, by which the height of water in the boiler may be learned in the usual manner.

362. The steam from the boilers enters the valve box (K), from which it is admitted alternately above and below the piston. From the cylinder the steam passes by the pipe R to the chimney, after it has produced its action on the piston, rushing there with great force, and producing a powerful draught through the furnace.

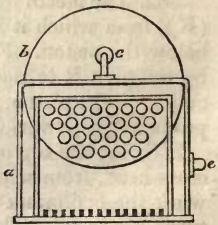
363. At the top of the piston-rod is a cross-bar or cross-head, from which two side rods (M), descend to work the bell crank (N N); the triangular frame N′ N turns above N′. The rods M act on one lever of this bell crank, while to the other extremity is attached the rod O, which by the usual crank turns the wheel like a common spinning-wheel. The cranks on each wheel are at right angles to each other, so that they

are not both at the dead points at the same time. To the perpendicular lever of the bell crank is attached a rod (P), which it works. This is the rod of the force-pump by which the boiler is supplied. The water is contained in a carriage called a tender, behind the engine. The pipe which conveys the water to the force-pump is seen at the left, below the engineer. The bell crank movement requires no parallel motion; the lever to which the side-rod M is attached is long, so that the segment it describes is nearly a straight line—at least does not deviate materially from the vertical. By the levers F, F, the engine is directed by the engineer, these levers acting upon the valve, and directing the course of the steam, so that the engine may be moved backwards or forwards as required.

364. In many locomotive engines now constructed, the cylinders are not exposed to the air, by which a considerable saving of heat is effected. They are placed in a casing immediately under the chimney, which is kept warm, both by its being near to the end of the boiler, and by the heated air rushing to the chimney.

365. The following figure (42) will convey a better idea of the usual construction of the boilers of locomotive engines. The circle *b* represents a section of the boiler, which is cylindrical, about six feet long, and flat at both ends. The chimney ascends from the front end. At the other extremity there is a square box, *a e*, behind and below the level of the cylinder, composed of two castings, one within the other, with a space of about three inches between them. This box is about three feet in length. The

Fig. 42.



inner box is the fire box, containing the fuel, resting upon the grating, which is represented at the bottom. The space between the two boxes is filled with water, and communicates with the lower part of the boiler by the tube *e*, and with the upper part by the tube *c*. Thus, the water is at the same level in the casing and in the boiler. The boiler is usually kept about half filled with water, so that the casing is quite full. Any steam found in the casing, passes to the boiler by the tube *c*. The tubes represented at the lower part of the boiler, pass along its whole length, and communicate with the fire box at one end, and with the chimney at the other, so that the hot air from the furnace passes through them, and has a very considerable heating effect upon the water. The draught is increased by the waste steam being passed into the chimney. There have been many other forms of boilers for locomotive engines, but the above, or some modification of it, has been found the most economical and effective.

366. The speed attained on railways has been very great. The rate of forty miles an hour, even with a considerable load, has often been effected; and without a load, an engine has on some occasions gone with the uncommon velocity of about sixty miles an hour. An engine in good working condition, with five feet diameter wheels, will draw a load (reckoning its own weight, tender with water, &c.) of fifty tons at the average rate of thirty miles an hour. With rather frequent stoppages, as on most railway lines at present open, the average rate of an engine so loaded may be somewhat less—about 28 miles an hour.

367. Each stroke of the piston (a stroke meaning one motion up and one down) will cause one revolution of the driving wheel; so that if it be 5 feet in diameter, the carriage will be impelled a distance of

15.7 feet (the circumference of the wheel, a little less than $15\frac{3}{4}$ feet) for every stroke. Thirty miles an hour is at the rate of half a mile (2652 feet) every minute, for which distance, about 168 or 169 strokes of the piston will be required. This is a very high velocity in the piston, and the vibration and concussion produced in the whole machinery by such frequent alternations of the motion—such rapidly reciprocating motions—are not only found to be highly injurious, but form a serious obstacle to any considerable increase in the rate of speed on railways.

368. One method of attaining a higher speed for the carriage, without increasing the speed of the piston, is to enlarge the diameter of the impelling wheels which the piston rod turns round. By this, one stroke of the piston still causing one revolution of the wheel, while its circumference is larger, it moves over a greater distance; and thereby a higher velocity is attained, without the piston making more rapid strokes. Of course, the power of steam must be greater to impel the same load at a faster rate; but, in proportion as the piston moves slower, there is less tear and wear of the engine; and thus the large wheels may be the means of rendering a still higher velocity attainable than the present practice. Wheels of ten feet diameter are to be tried on the Great Western Railway.

369. The introduction of larger driving wheels renders it necessary that there should be six instead of four wheels to support the carriage. The carriage is kept from going off the rails by the *flange* or projection on the inner side of the tires of the wheels. As a large wheel passes more easily over any obstacle than a small one; so the carriage would more easily go off the rail (a common cause of railway accidents) in proportion as the wheels are large. Where there are only four wheels, it is evident that the flanges of both the

front and back pair are necessary to keep the carriage on the rail, so that neither can be made very large. If, however, there be three pair of wheels, the front and back pair will be sufficient to prevent the carriage from going off the rails, and they may be made small, by which they will be very effective for this end; while the middle pair may be very large, and not trusted to at all for keeping to the rails. Accordingly, locomotive engines are now generally made with six wheels, a large pair by which the carriage is impelled, in the middle, and two small pairs. This has other advantages:—the driving wheel was the most apt to go off the rail; but where there are three, the wheels which retain the carriage on the rails, are not subjected to the direct action of the piston rod, and are therefore less likely to be driven off. Also, if the axle or any part of the driving wheel be broken, and it is the most liable to this accident, the engine will still be fully supported by the four small wheels.

370. But, even with large driving wheels, the motions of the piston must be very rapid to give a high speed—so rapid as to impair the machinery materially, and not yield the most effective power. This has been regarded by Mr. Watt and others as best attained when the motion of the piston is about 240 feet in a minute; whereas, even with wheels of eight feet diameter, a velocity in the piston of 520 feet (18 inch stroke) would be required to give a rate of about 40 miles an hour. To remove this great difficulty, it has been proposed to convey the power from the piston to the wheels by tooth and pinion gear; which would enable a moderate velocity in the piston to give a high velocity to the wheel. Engines on this plan will soon be tried on the Great Western Railway.

371. Another obstacle in the way of a rapid rate of motion on railways, is, the resistance of the air. This

has been lately ascertained to be a more formidable obstacle than had been previously supposed. It had formerly been suggested (by writers in the *Mechanics' Magazine* and others) that the atmospheric resistance would be a more serious obstacle to very high rates of speed than was generally supposed; but there was no positive knowledge on the subject until the recent experiments of Dr. Lardner and Mr. Wood, instituted on the Great Western Railway under the authority of the directors of that undertaking. On this railway the engineer was constructing the guage (distance between the rails) much wider than in other railways—7 feet instead of 4 feet 8 inches—which led to some alarm on the part of the directors, particularly regarding the atmospheric resistance to the increased breadth of front which the carriages would present to the air. Messrs. Wood and Hawkshaw were appointed to investigate the subject and report: they called in the assistance of Dr. Lardner; and after numerous experiments, presented a report, condemning the increased breadth of guage. The directors, however, determined not to alter their engineer's plans, so that the matter will be tested by a more efficient trial than any experiment—by actual practice.

372. The following extracts from the report in the Athenæum of Dr Lardner's statement on this subject at the last meeting of the British Association, will present a sketch of the present state of this interesting question:—

"The resistance opposed by a railway train, to the power which draws it, arises from several causes:—1st, The friction or attrition of the axles of the wheels in their bearings. 2nd, The rolling friction of the tires of the wheels upon the rails. 3rd, The resistance of the air to the train moving through it." —— "independently of these, there are resistances peculiar to the engine, arising from the friction or attrition of the various parts of the machinery which are in motion, and which suffer a pressure or strain, depending on the resistance of the load drawn; also, the reaction of the steam, escaping from the blast pipe on the other side of the piston, and other similar causes. But to simplify the inquiry in the first instance, the resistance of the engine was put aside, and the investigation was directed exclusively to the resistance of the train."

The following conclusions have been drawn by Dr. Lardner from the experiments :—

"1. The resistance to a railway train, other things being the same, depends on the speed.

"2. At the same speed, the resistance will be in the ratio of the load, if the carriages remain unaltered.

"3. If the number of carriages be increased, the resistance is increased, but not in so great a ratio as the load.

"4. Therefore, the resistance does not, as has been hitherto supposed, bear an invariable ratio to the load, and *ought not to be expressed at so much a ton.*

"5. The amount of resistance of ordinary loads carried on railways at the ordinary speeds, more especially of passenger trains, is very much greater than engineers have hitherto supposed.

"6. A considerable, but not exactly ascertained, proportion of this resistance is due to the air.

"7. The shape of the front or hind part of the train has no observable effect on the resistance.

"8. The spaces between the carriages of the train have no observable effect on the resistance.

"9. The train, with the same width of front, suffers increased resistance with the increased bulk or volume of the coaches.

"10. Mathematical formulæ, deduced from the supposition that the resistance of the railway trains consists of two parts, one proportional to the load, but independent of the speed, and the other proportional to the square of the speed, have been applied to a limited number of experiments, and have given results in very near accordance.

"11. The amount of resistance being so much greater than has been hitherto supposed, and the resistance produced by curves of a mile radius, being inappreciable, railways laid down with gradients of from 15 to 20 feet a mile, have practically but little disadvantage compared with a dead level; and that curves may be safely made with radii less than a mile; but that further experiments must be made to determine a safe minor limit for the radii of such curves, this principle being understood to be limited in its application to railways intended chiefly for rapid traffic."

373. The consumption of fuel in railway locomotive engines is very small indeed, so much heat is saved by the peculiar construction of the boiler. Coke is the fuel used. Of this, when the load drawn is considerable, one pound per ton conveyed a mile, or even considerably less is the proportion consumed. The following table illustrates this. It refers to experiments on the Great Western Railway:—

	Load in tons.	Speed in miles per hour.	Coke per ton per mile.
Director's Experiments	43	38	.95 lb.
Mr Brunel's do.	40	40	.90 lb.
Mr Wood's do.	41.65	38.8	1.09 lb.

SECTION IX.

LOCOMOTIVE ENGINES FOR COMMON ROADS.

374. In 1831, a steam-carriage plied between Gloucester and Cheltenham regularly for four months, on the common turnpike-road. This carriage was constructed by Mr. GOLDSWORTHY GURNEY, whose invention it was. Dr. Robison, Mr. Watt, Oliver Evans in America, and Mr. Symington of Falkirk, had projected

the idea of using steam for carriages on common roads. Also, previously to Mr. Gurney, attempts to construct a steam-carriage for common roads had been made by Mr. Trevithick in 1802, Mr. Griffiths in 1821, Mr. Gordon in 1824, Messrs. J. and S. Seaward, Messrs. Hill & Burstall, and Mr. Hancock. The first sufficient trial of steam-propelled carriages on common roads was by Mr. Gurney, who, in 1829, travelled from London to Bath, and back, in his steam-carriage. To the disgrace of the individuals who had charge of the roads where Mr. Gurney's carriage was running in 1831, the difficulties encountered were so great, from heavy tolls imposed, and obstructions placed on the road, that, after running successfully for four months, it was abandoned. Mr. Gurney petitioned Parliament, and a committee was appointed to inquire and report upon the subject.

375. The following extracts from their report contain some interesting information on the subject:—

Mr. Gurney states, "that he has kept up steadily the rate of twelve miles an hour; that the extreme rate at which he has run is between twenty and thirty miles an hour."

Mr. Hancock "reckons that, with his carriage, he could keep up a speed of ten miles an hour, without injury to the machine."

Mr. Ogle states, "that his experimental carriage went from London to Southampton, in some places at a velocity of from thirty-two to thirty-five miles an hour. That they have ascended a hill, rising one in six, at sixteen and a half miles per hour; and four miles of the London road, at the rate of twenty-four and a half miles per hour, loaded with people."

Mr. James Stone states, "that thirty-six persons have been carried in one steam-carriage. That the engine drew five times its own weight, nearly at the rate of from five to six miles an hour, partly up an inclination."

Mr. Farey gives as his opinion, "that steam-coaches will very soon, after their first establishment, be run for one-third of the cost of the present stage-coaches."

"In steam-power, there is no danger of being run away with, and that of being overturned is greatly diminished. Mr. Farey considers that the danger of explosion is less than the danger attendant on the use of horses in draught.

"There is every reason to expect that, in the end, the rate of travelling by steam will be much quicker than the utmost speed of travelling by horses."

The committee stated in conclusion:—"Sufficient evidence has been adduced to convince your committee—

"1. That carriages can be propelled by steam on common roads at an average rate of ten miles per hour.

"2. That at this rate they have conveyed upwards of fourteen passengers.

"3. That their weight, including engines, fuel, water, and attendants, may be under three tons.

"4. That they can ascend and descend hills of considerable inclination, with facility and safety.

"5. That they are perfectly safe for passengers.

"6. That they are not (or need not be, if properly constructed) nuisances to the public.

"7. That they will become a speedier and cheaper mode of conveyance than carriages drawn by horses.

"8. That, as they admit of greater breadth of tire than other carriages, and as the roads are not acted on so injuriously as by the feet of horses in common draught, such carriages will cause less wear of roads than coaches drawn by horses."

376. As this report is founded on the evidence of men who are inferior to none in scientific knowledge, practical skill, and experience, there is reason to consider the hopes it holds out as well-founded; and that the time is not far distant when steam will be in constant use in propelling carriages on common roads.

377. Mr. Gurney's boiler consists, essentially, of a narrow perpendicular chamber, with tubes proceeding from the bottom. The tubes are nearly horizontal,

with a slight inclination upwards; they bend through the furnace, and return, inclining slightly upwards, to the chamber, entering it a little above the middle. The water is pumped in at the bottom of the chamber. There is thus a continual circulation of water through the whole boiler, passing from the part where it enters the boiler, through the tubes ,to the upper part of the chamber, where it passes off in steam. There is thus a very great extent of surface exposed to the fire, by which a powerful and rapid heating effect is produced: and, the tubes being always filled with water, are not soon injured by the fire. The waste steam, thrown by several small jets into the lower part of the chimney, increases the draught.

378. It will be observed that this differs materially from the railway engine boiler. In Mr. Gurney's boiler, the water is in the tubes, which are surrounded externally by the heated air: in the railway engines, the heated air passes through the tubes, which are surrounded externally by the water.

379. Mr. Hancock, who has been the most persevering prosecutor of the scheme of steam-carriages on turnpike roads, has constructed a very ingenious boiler, in which the steam is raised rapidly. It consists of a number of narrow perpendicular chambers containing the water, with spaces between, where the heated air circulates; 100 square feet of surface being exposed to the fire.

380. The steam in carriages for turnpike roads is used of a very high pressure, 70 to 100 lbs. on the square inch. The cylinders are small, about 7 to 10 inches diameter, and 16 inches stroke.

SECTION X.

ROTATORY ENGINES.

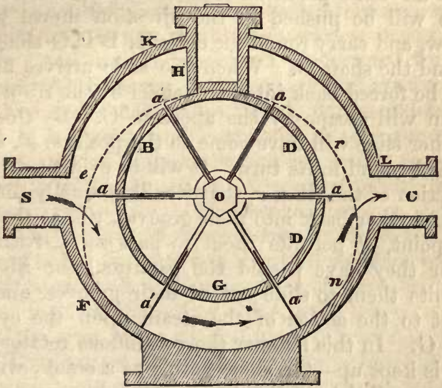
381. In all the engines hitherto described, applied to produce a rotatory or continued circular motion—as the steam-boat engine, the railroad engine, the engine for machinery—the steam produces at first an alternate rectilinear motion, which has to be converted into circular motion, by machinery interposed between the steam and the axis or shaft to be turned. The piston and cylinder, beam and crank, are all interposed betweeen the axis and the steam. These are cumbrous and costly; power, it is supposed, is lost by the crank; and many attempts have been made to dispense with them all, by applying the force of steam so as to produce a circular motion at once. Such an engine, in which the steam is made to act in a circular direction, is termed a ROTARY or ROTATORY Engine.

382. The first idea of such an application of steam seems to have been suggested by Watt in his patent of 1769, from which the following, describing his scheme for a rotary engine, is taken:—

"Fifthly, where motions round an axis are required, I make the steam-vessels in form of hollow rings or circular channels, with proper inlets and outlets for the steam, mounted on horizontal axles, like the wheels of a water-mill; within them are placed a number of valves that suffer any body to go round the channel in one direction only; in these steam-vessels are placed weights so fitted to them as entirely to fill up a part or portion of their channels, yet rendered capable of moving freely in them by the means herein after mentioned or specified. When the steam is admitted in these engines between these weights and the valves, it acts equally on both. so as tc raise the weight to one side of the wheel, and, by the reaction of the valves successively, to give a circular motion to the wheel, the valves opening in the direction in which the weights are pressed, but not in the contrary; as the steam-vessel moves round, it is supplied with steam from the boiler; and that which has performed its office may either be discharged by means of condensers, or in the open air."

Such was the scheme of the first rotary engine. Although not successful, it shews the fertility of Watt's mechanical genius, which had anticipated and thrown out some scheme for almost every variety of form in which steam could be used.

Fig. 43.



383. The above figure (43) is a representation of a rotary engine in use, the patent of Mr. Job Ryder, but only a slight modification of one devised by Messrs. Bramah and Dickenson in 1790. A vertical section is shewn. F K L and B D G are two cylinders, with a space between. The shaft (O) to be turned, is fixed to the inner of these cylinders, and revolves along with it. The outer cylinder is fixed. In the inner cylinder are deep grooves or slits, into which the slides or

plates *a a* fit, having free motion along the niche or slit. Each slide is connected to the opposite one by pins through the shaft. A fixed partition (H) separates the space between the two cylinders into two divisions. On each side of the partition, there is fixed a *rib*, or part of an eccentric ring, *e a a r*, shewn by the dotted line. The steam is admitted by the opening S, and passes out by the opening C, to the condenser, or to the air, if the engine be a high-pressure-one. When steam enters at S, it will press upon the partition H, and the slide *a'*. The partition is immovable; therefore the slide will be pushed in the direction shewn by the arrow, and carry round the cylinder B D G along with it, and the shaft O. When the slide arrives at *n*, it will be forced back into its channel by the rib *n r*, and steam will escape by the aperture C. By this time another slide will have come to the position *a'*, and be pushed round in its turn. It will be evident, from the direction of the rib *n r*, that it will gradually push the slides farther back into their grooves, till, at the highest point, it permits them to pass the partition H. After they have passed the partition, the rib again permits them to slide out of their grooves, and give effect to the action of the steam upon the cylinder B D G. In this manner the continuous rotatory motion is kept up—the slides acting as a crank, with the steam applied to it directly.

384. Most of the rotary engines have been somewhat similar to this in their general form.

385. A rotary engine of a different construction, used in America, has lately been much talked of. It is exactly on the principle of a Barker's mill, or of Hero's Æolipile, the first machine moved by steam. (164). The principle on which it is constructed will be readily understood, by referring to the figure of the Æolipile, page 74. An engine of this kind was pro-

posed by Kempel, and described in a German work published in 1794. The arms of the Æolipile, without the ball or globe, and lying horizontally, may convey an idea of this rotary engine. A vertical pipe from a steam-boiler terminated in a horizontal arm, which had free motion round the pipe. The arm was hollow, and had apertures at *the opposite sides* of its two extremities, by which the steam issued, and propelled the horizontal pipe in a direction opposite to that in which the steam escaped. This is an extremely simple piece of machinery. Perhaps no engine can be simpler in construction. It has been lately revived by an American, Avery, with much success in his own country; and several have been constructed by Mr. Ruthven, of Edinburgh. The arms are about five feet long, five and a-half inches broad, flattened like the sheath of a sword, and sharpened at both edges, so as to receive as little resistance as possible from the medium in which they move. The apertures by which the steam issues, are 1-4th inch in diameter, 1-20th area. The engine constructed by Mr. Ruthven, and in operation at his works, is about fifteen horse power. It may be worked with a pressure of from 30 to 70 lbs. per inch on the safety-valve, and, when, in full action, the arms make about fifty revolutions in a second. They are set vertically, and revolve in a cast-iron case, about eight inches wide, so that they are not seen.

386. An interesting and elaborate paper on rotary engines, by Mr. John Scott Russel, has appeared in the Transactions of the Scottish Society of Arts, in which the project for direct rotary motion by steam is entirely condemned. He endeavours to shew, that the

"*ordinary crank engine does not possess the defects attributed to it,* and which it is the sole object of the rotatory engine to remedy—that the use of the crank causes no loss of power.

"In a practical point of view the *rotatory engine is every* *way inferior* to the reciprocating engine;—in simplicity, and cheapness, and ease of construction,—in durability and economy in use,—in uniformity of action, and equable motion.

"The rotatory engine is *peculiarly inapplicable to the great purposes* of terrestrial locomotion and steam navigation,—objects to which it has been considered peculiarly suitable.

"The *present steam-engine is practically perfect* as a working machine, being within ten per cent. of mathematical perfection.

"The *crank* of the common steam-engine possesses certain *remarkable properties* of adaptation to the nature of matter, of motion, of steam, and the human mind, from which its supremacy as an elementary machine is derived,—properties which cannot possibly belong to any species of rotatory engine."

387. Mr. Russel divides Rotatory Engines into four classes.

1. *Rotatory Engines of simple emission*—as the Æolipile, page 73, Branca's engine, page 80, and Ruthven's, page 219. On these, Mr. Russel remarks:

"There is no possibility of obtaining, by simple emission, more than one half of the whole power of the steam, so as to make it available to useful mechanical effect. The other half is wasted in giving off its impulsion to the air, or is expended in a current equally unavailable."

388. II.—*Rotatory Engines of Medial Effect.* These "do not immediately give revolution to an axis by the action of steam upon the wheel, but have a medium of communication between the power and the effect, which medium is the direct agent in circular motion,"—as Watt's rotary engine, par. 382.

"In this class of engines," says Mr. Russel, "the loss of effect is manifest, for it is necessary that the steam, in order to produce circular motion, shall give out its force in setting the medium in motion, and, in overcoming the very great resistance of the liquid in all the pipes, passages, and valves, through which it is admitted to alternate sides of the wheel in every revolution; the whole of this force is subtracted from the useful effect, and becomes power lost.——

"In those which move weights from and towards the circumference, these are mere groups of reciprocating pistons without cranks, and share the evils to be explained in class V.

389. III.—*Rotatory Engines of Hydrostatic Reaction.*

"The principle of action is this: steam is admitted into a circular channel or chamber on the circumference of a wheel; this chamber is partially filled with some liquid, the pressure of the steam is expended in pushing the mercury in one direction, and the end of the chamber in the opposite way, so that while the liquid is thus forced out of the chamber, the chamber is by an equal force pushed away from the liquid; the wheel is turned round.

"It is apparent that a part of the force is employed in propelling the wheel, and the remainder is extended in overcoming the resistance of the liquid of reaction, and expelling it from the chambers, which remainder is a large portion of the power withdrawn from useful effect."

390. IV.—*Rotatory Engines of the Revolving Piston.* This is the best and most common form of rotary engines. In Mr. Russel's words,

"The steam is confined in a close and rigid chamber, and acts only on a solid and inflexible surface, and makes its escape by confined passages, so that its full effect may be obtained in useful work. Abstractedly considered, it is an engine capable of giving out the full power of the steam, and therefore may fairly be imagined to come into competition with the ordinary reciprocating crank engine. The objections to it are entirely of a practical nature, and regard the engine not in its abstract or mathematical form, but as a machine made of destructible matter, of matter imperfectly elastic, of surfaces opposing resistance to motion, of matter obeying the known laws of motion and rest."

391. Mr. Russel adds another class of engines, as

partaking of the same fallacy as the preceding, viz., those in which

"Revolving mechanism is substituted for the crank of the common steam-engine, for the purpose of obtaining from the reciprocating piston a rotatory effect otherwise than by the crank, and in a better manner than by the crank."

392. Mr. Russel considers that there is no loss of power by the crank, on the grounds that the motions of the piston and crank are so adjusted to each other, that at the times when there is an apparent loss of power by the crank (about the upper and lower segments of the circle in which it revolves), there is little or no power given out by the piston, so that the force given by the crank and piston are in direct proportion. During one revolution of the crank, the piston makes one stroke, that is, moves twice through the cylinder. When the piston has completed a half stroke, it is virtually at rest, and the steam then applied to set it in motion again does so by degrees, so that it moves slowly at first, and does not attain its full velocity till it reaches the middle of the cylinder. Then, says Mr. Russel:—

"The piston begins to be retarded, the steam expands more and more slowly, the final stoppage is gradually prepared for, and at last the rectilineal motion, having dwindled to nothing by insensible shades, altogether ceases."

Accordingly, the piston gives out little power when it is about the ends of the cylinder, and these are exactly the times when the crank is in and about the dead points.

393. Mr. Russel shews

"1. That the mean pressure on the crank during the whole revolution, is less than the pressure on the piston, just in the proportion in which the space moved over by the latter is less than the space described by the former, so that the total of all the power in the one is equal to the total of all the effects in the other;—2. That the steam is not at all expended at the neutral points, and that its expenditure is at every point exactly proportioned to the power it gives out in useful effect;—3. That the velocity of the motion of the piston is in the ratio of the force acting at each instant on the crank."

394. The effect is compounded of the force and the velocity; when the crank is at its neutral points, when power is supposed to be lost, the velocity of the piston is low, but that of the crank is large in proportion; and when the velocity of the piston is increased, that of the crank is less in proportion. This will be evident, in considering that the crank and piston are simultaneous in their motions, and that at the upper and lower parts of the course of the crank, it moves laterally, so that a small ascent or descent of the piston carries it through a greater distance there, than at other parts of its course.

395. After shewing that there is not in the crank that loss of power which is supposed, Mr. Russel proceeds to observe:

"Since there is no loss incurred by propagating the action of the steam on a reciprocating piston through the crank of a revolving axle; and since it is not in the power of machinery of any kind to augment the quantity of power given out by any mover, but merely to arrange, dispose, and multiply that power to suit any given purpose, it follows that the rotatory piston can have no purpose to accomplish, unless it excel the reciprocating one in simplicity and economy of construction, diminished bulk, durability, and economy in operation, facility of repair when deranged, diminished friction, or a peculiarity of adaptation to some individual purpose, such as steam-navigation or inland transport.

396. Mr. Russel then shews that the rotary engine has no advantage over the reciprocating engine in any

of these points; that it is inferior to the latter in some, particularly, durability, economy in operation, facility of repair when deranged, and the resistance from friction; and that the crank posseses peculiar advantages for a medium of moving power—at too great length to be entered upon here. See part II. Transactions of the Society of Arts for Scotland, or vol. XXIX. Mechanics' Magazine.

CATALOGUE OF WORKS TO BE CONSULTED ON THE STEAM-ENGINE, OR SUBJECTS CONNECTED WITH IT.

BARLOW, PETER, Treatise on the Manufactures and Machinery of Great Britain. From the *Encyclopædia Metropolitana.*

EDINBURGH ENCYCLOPÆDIA, Article, Steam-Engine.

ENCYCLOPÆDIA BRITTANNICA, Article, Steam-Engine.

FAREY on the Steam-Engine.

TREDGOLD on the Steam-Engine.

GALLOWAY *and* HEBERT on the Steam-Engine.

GREGORY, Mathematics for Practical men.

PAMBOUR, Theory of the Steam-Engine.

ROBERT STUART, Anecdotes of Steam-Engines.

WOOD, Practical Treatise on Railroads.

LECOUNT, Treatise on Railways.

ROBINSON, Mechanical Philosophy, by Brewster, vol. 2.

BRUNTON, Compendium of Mechanics.

WALLACE, Mechanic's Pocket Guide.

LONDON MECHANICS' MAGAZINE.

REPERTORY of ARTS.

REPORT of COMMITTEE of THE FRANKLIN INSTITUTE on Explosion of Steam-Boilers—published in America. To be found in various numbers of the *Mechanic's Magazine.*

GILBERT, Observations on the Steam-Engine.

JOURNAL of ELEMENTAL LOCOMOTION.

GORDON, Treatise on Locomotive Engines.

ARMSTRONG, Essay on Steam-Engine Boilers.

APPENDIX.

I. POWER OF STEAM-ENGINES.

397. In speaking of the power or force which an engine exerts, it is necessary to have some measure of force, or standard of reference. That used in this country is a *horse-power*, a force equal to that which the average strength of a horse was believed capable of exerting. This has been estimated at 33,000 avoirdupois pounds weight, raised one foot high in a minute. There have been different estimates as to the real power of horses, and it is now considered that, taking the most advantageous rate for using horse-power, the medium power of that animal is equal to about 22,000 lbs. raised one foot high per minute. However, the other, 33,000 lbs., is taken as the standard, and is what is meant when a horse power is spoken of. In comparing the power of a steam-engine with that of horses applied to do the same work, it must be remembered that the engine horse-power is 33,000 lbs. raised one foot per minute, the real horse-power only 22,000 lbs.; and that the engine will work unceasingly for twenty-four hours, while the horse works at that rate only eight hours. The engine works *three* times as long as the horse—hence, to do the same work in a day as an engine of one horse power, 4·5 horses would be required—($33,000 \times 3 = 99,000$:—$99,000 \div 22,000 = 4{\cdot}5$). The power of a man may be estimated at 1-5th of the real power of a horse, or, 4,400 lbs. raised one foot per minute.

398. The following table from Tredgold, will convey

some idea of the power procured from steam in Watt's double-acting engine.

Let the force of the steam in the boiler be		1·000
The following deductions must be made,		
Force impelling the steam into the cylinder	·007	
Cooling in the cylinder	·016	
Friction of piston, and loss	.125	
Force impelling the steam through the passages.	·007	
Force to work valves, raise injection water, and overcome friction of axis	·063	
Loss from steam cut off before end of stroke .	·100	
Force required to work the air-pump . .	·050	
	·368	·368
		·632

399. Thus, about 4-10ths are lost from friction, working of the pumps, &c. The pressure in the boiler may generally be estimated at that of a column of thirty-five inches of mercury. The steam in the boiler is always kept a little stronger than the air—2½ to 4 lbs. on square inch, or, about 5 inches column of mercury.

400. If this be multiplied by ·632, the proportion of the above force which remains after making the necessary deductions, as per the above table, it gives 22·12 inches as the force of the steam on the piston represented in inches of a column of mercury: *i. e.*, 10·83 pounds to the square inch. But the uncondensed vapour in the cylinder resists this force. It also must be deducted from the above. If the temperature in the condenser be 120°, this vapour will have a force of about 3·7 inches of mercury, or 1·81 lbs. to the square inch; 3·7 inches deducted from 22·12 inches, gives 18·42 inches of mercury—or, 1·81 lbs. deducted from 10·83 lbs., gives 9·02 lbs. per square inch, as the effective pressure on the piston. Calculated in circular inches, as is sometimes done, we have 7·1 lbs. to the inch.

401. The following extract from the author above quoted, will shew the method of computing the power of an engine, the above data being assumed.

"*Rule.*—Multiply the mean effective pressure on the piston, by the square of its diameter in inches, and that product by the velocity, in feet per minute; the result will be, the effective power in pounds raised one foot high per minute.

"To find the horses' power, divide the result by 33,000. Example. The diameter of a cylinder of a double engine being twenty-four inches, the length of the stroke five feet,* the number of strokes per minute, twenty-one and a-half, and the force of the steam in the boiler, thirty-five inches of mercury, or 5 inches above the pressure of the atmosphere—required, its power.

"The velocity is $2 \times 5 \times 21\frac{1}{2} = 215$ feet per minute, and the mean effective pressure on the piston will be 7·1 lbs. per circular inch; therefore, $7{\cdot}1 \times 24^2$ (the square of the piston's diameter, or 576) $\times\ 215 = 879{,}264$ lbs. raised one foot high per minute;

$$\frac{879{,}264}{33{,}000}$$

gives 26·64 horses' power. The nominal power of this engine would be only twenty horses power, by Boulton and Watt's mode of calculation; but it will be found that the nominal and real power nearly agree, when the steam acts expansively." Such an engine would require for steam, half a cubic foot of water per minute, or, thirty cubic feet hourly; and allowing 8·22 lbs. of caking coal for every cubic foot of water, 246·6 lbs. of such coal would be consumed hourly; or dividing 246·6 by 26.64, 9·2 lbs. of coal per hour for each horse power. It is said by some that the fuel consumed is about one-half more than this—fourteen or fifteen lbs. per horse power hourly; this is the more general estimate.

402. In an engine working expansively, the steam being cut off at about one-half ($\frac{1}{2}$) of the stroke, the mean force would be 4·8 lbs. on circular inch. This multiplied as above, would give 594,432 lbs. raised one foot per minute, or, dividing by 33,000, eighteen horses' power. The fuel required,

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* A *stroke* means a motion of the piston, from the top of the cylinder to the bottom, and back again. When the *length* of a stroke is spoken of, only half the stroke is meant. Thus, if the length of stroke be five feet, the stroke will be ten feet.

would be about one-half ($\frac{1}{2\cdot1}$), 117 lbs. per hour,or, 6·5 lbs. per horse power, hourly, about 2·7 lbs. per horse power being saved every hour.

403. In a double-acting engine, of about twenty horse power, the diameter of the piston is about twenty-four inches, its area being 452 square inches, or 22·6 inches, for each horse power. The effective pressure on the piston may be about 7·3 lbs. per square inch. The length of stroke will be five feet, it will make twenty strokes per minute, and its velocity be 200 feet per minute. Such an engine would raise 660,000 lbs. one foot high per minute; and consume hourly 166 lbs. of coals, or, 8·3 lbs. per horse power. In smaller engines, the pressure on the piston is less, and the consumption of fuel greater. In large engines, the reverse. In an engine of 200 horse power, the effective pressure on the piston may be about 8·9 lbs. per square inch, and, the coal consumed hourly is, per horse power, only 5·5 lbs. These proportions are from a large table in the "*Encyclopædia Metropolitana.*"

404. Mr. Tredgold estimates the deductions to be made from the force of the steam in the boiler in high-pressure engines, at about 0·4, the whole force being 1·0. The effective pressure thus, is 0·6. To find the power of a high-pressure engine, multiply the excess of the force of the steam in the boiler over the atmospheric pressure by 0·6; subtract from the product 4-10th's of the pressure of the air in pounds on a circular inch; multiply this product by the square of the diameter of the cylinder, and this, multiplied by the velocity of the piston, gives the number of pounds raised one foot high per minute.

405. By the construction of the boilers of marine engines, they consume less fuel than land engines in ordinary vessels, 7 to 10½ lbs. of coal per hour for every horse power.

406. The following table shews the relative heating powers of the chief sorts of fuel in use for steam-engines:

Kind of Fuel.	Pounds of water converted into steam of 222° (from 52°) by one pound of fuel.	Pounds of fuel required to form a cubic foot of water into steam.
Caking coal	8·4 lbs.	7·45 lbs.
Splint coal	6·75	9·25
Coke	7·7	8·1
Dry pine	3·1	20·02
Dry oak	5·13	12·2
Dry compact peat	3·35	18·7
Charred peat	4·85	12·9
Culm (Glasgow)	2·85	22·0
Culm (Welsh)	3·56	17·5

407. In estimating the quantity in practice, Mr. Tredgold, from whom the above table is taken, adds 1-10th (10 per cent.); thus making 8·22 lbs. of caking coal the quantity necessary to vaporize a cubic foot of water. A cubic foot of water weighs 62 pounds avoirdupois. Equal heating power is obtained from 1 of Newcastle coal, 1⅓ of Glasgow coal, 3 of wood, and about twice as much culm as coal. See page 134.

II. ON THE EXPLOSION OF STEAM BOILERS.

408. The first edition of this work contained a few observations on the causes and means of preventing the explosion of steam-boilers, which the author afterwards extended into an essay, and read in March and April last, before the PHILOSOPHICAL SOCIETY of Glasgow. This paper, condensed into a tabular view, which at once gives a sketch of the causes and means of preventing accidents in steam-boilers, is here added. It may be useful to many who ought to be intimately acquainted with the subject, but, from whatever cause, have not paid much attention to it. Almost every body travels now and then in a steam-boat; it may not be amiss for even

general readers to know something of a subject in which they are certainly interested.

409. The casualties to which steam-boilers are liable, are interesting in a scientific point of view, and demand some attention from all. The extent to which the steam-engine has come into use—in manufactories—for navigation—for inland conveyance; the number of lives, and amount of property entrusted to its care; its frightful power of destruction, when the pent up vapour is allowed to acquire undue strength;—all combine to render this one of the most important subjects which can engage the public attention. It has acquired great additional interest within these few years, for explosions of steam-boilers have within that period become very frequent; and are likely to become more so. The use of steam was attended with few mishaps at first, because there were few engines; these were new and in good condition; and at first the engineers were naturally much more careful. But the danger is vastly increased now, because steam-engines have multiplied; because many old ones are now in use; because long familiarity with this new power is begetting its usual effects, carelessness, and indifference to those precautions necessary to ensure safety.—Yet, with proper management, explosions of steam-boilers might be altogether prevented. Such an occurrence must arise from neglect or rashness in some quarter. Steam is well known to be a good servant, but a bad master; but it need never be master. It is not like a wild untrained animal, with an independent and capricious will of its own, and whose motions cannot be calculated. Steam is far more manageable than the best trained and most naturally docile animal. It is called into existence by the will of man; there is no mystery about its action; it is perfectly under his control; it can be increased or diminished in its strength at a moment's warning; and there is a perfect knowledge of all the circumstances from which variation in its power can arise. Any one who has attended to the subject knows, that a few simple contrivances would render explosions impossible; and it is disgraceful that such an occurrence as the explosion of a steam-boiler should ever take place.

410. That these casualties are on the increase is too evident. From 1817 to 1836, inclusive, a period of twenty years, there were 14 explosions of steam-vessel boilers, by

which 33 lives were lost:—and from 1837 to the present time, a period of less than three years, there have been no less than 10 explosions of boilers in steam-vessels, by which 45 persons have been killed. Besides these 10 cases of explosions, the KILLARNEY, (Jan. 1838), FORFARSHIRE, (Sept. 1838), and NORTHERN YACHT, (Oct. 1838), were lost, and 114 lives sacrificed—from, there is every reason to believe, the defective state of the steam-machinery. The explosions since the commencement of 1837 have been *five times* that of the average of a similar period in the preceding twenty years; whereas the number of steam-vessels since 1837, is *less than three times* that of the average of three years, from 1817 to 1836 inclusive. The three years 1837—9, being not yet complete, renders the increase in explosions, still larger in proportion. This proportion—of explosions to the number of steam-vessels—may be said to have been, since 1837, nearly double what it was previously.

411. Explosions of steam-boilers are of two kinds—EXPLOSION OUTWARDS, or EXPLOSION, properly so called, when, from the elastic force of gaseous matter within the boiler being greater than it can support, it is burst, and its sides forced outwards — and COLLAPSE, when the sides of the boiler are forced inwards by the atmospheric pressure, from want of support, arising from diminution of the resistance within. When the flues pass through the boiler, *explosion* of the latter is at the same time *collapse* of the flue, which must be distinguished from the true collapse just mentioned. It is a collapse as regards the flue, an explosion as regards the boiler.

412. Although the causes of explosions are stated separately, according to their nature, it is not meant to be implied that explosions often or usually arise from the action of any *one* of these causes alone:—several may be concerned, and in general there are more than one of the following causes in action. But to obtain a clear view of them, it is best to consider them individually.

The large letters at the end of each line refer to a subsequent note, where any necessary explanation or commentary on that subject is given. There is not room, consistent with the plan of the present work for the full discussion of each —that would require a volume.

CAUSES OF STEAM BOILER EXPLOSIONS.

EXPLOSION OUTWARDS

arises from

I. Too High Pressure of Steam, caused by

1. *Inefficiency of the Safety Valve,* from being

   (1.) Overloaded, A

   (2.) Fastened by oil drying,

   (3.) Corroded, (oxidated, rusted), B

   (4.) Gagged, C

   a. From expansion of plug, D.

   b. From cohesion.

   c. From action of blast from aperture, E

   (5.) Being too small.

2. *The sudden formation of more steam than can escape in time by the safety valve,*

caused by

Water brought suddenly in contact with too hot metal.

Boiler too hot from

(1.) Water falling too low, F.

from

a. Fire increased, evaporation increased, and supply the same.

b. Supply stopped, G.

a.a. From engine not being started.

b.b. From engine stopping.

c.c. From feed-pipe out of order.

d.d. From supply cut off by engine-man.

(2.) Water driven out of narrow water spaces.

(3.) Fire suddenly increased.

(4.) Sediment in boiler.

Water come suddenly on boiler,

from

(1.) Supply pump set on.

(2.) Lurch in a steam-vessel.

(3.) Inertia of liquid, when steam-vessel starts.

(4.) Foaming (water boiling up on sides) from

a. Water low, and valve suddenly opened. } H.

b. Water low, and engine started, } H.

(5.) Crack in sediment.

3. *By the boiler being at too high a temperature.*

II. Weakness of the Boiler,
from

1. *Boiler too weak at first,* I.
2. *Boiler of a bad form.*
3. *Boiler yield at the seams.*
4. *Form of boiler altered by unequal heating.*
5. *Tenacity diminished from being too hot,* K.
6. *Metal rendered brittle.*
    (1.) From action of heat upon it.
    (2.) By sudden application of cold water when highly expanded by heat.
    (3.) Carbonised ?
    (4.) Sulphuretted ?
    (5.) Cells of air in cast iron.
7. *Metal corroded, (oxidated.)*
    (1.) By fire outside.
    (2.) By the sediment.
    (3.) By water inside (when red-hot) . . ?
8. *Pressure of high column of water in certain Boilers,* L.

413. A. *Safety-valve overloaded.*

This is a frequent cause of the explosion of steam-boilers, particularly those of marine and locomotive engines. The Parliamentary Committee which reported on this subject in 1816, gave it as their opinion that the overloading of the safety-valve was one cause of the explosion which had led to the inquiry (at Norwich), and from the evidence led as to the causes of explosions, and the opinions of many engineers and engine-makers who were examined, they recommended, "That every boiler should be provided with two sufficient safety-valves, *one of which should be inaccessible to the engine-man,* and the other accessible both to him and to the persons on board the packet."—This is quoted to shew that it was the opinion of the committee, and of many of the witnesses, that the valve is frequently overloaded by the engineman, as it is imagined by some that the valve is so constructed, and such weights applied, that the engineer has only a safe and limited control over it.

414. It is well known that when there is much competition among the steamers on any line, it is very customary, in the haste on calling at any port, not to relieve the valve

—trusting not to be detained a moment—to permit the steam to accummulate to get a good start—accidents cause a longer delay than was anticipated, and explosion ensues.

415. Mr. David Napier, in his evidence before the jury at the inquest on the last explosion of the VICTORIA, admits that there were extra weights on the safety valve. He says, "The engineer ought to have removed the extra weight on the lever at Blackwall, going and coming, and the accident could not have happened."

416. In the evidence at the inquest after the explosion of the PATENTEE locomotive engine last autumn, it came out that the "Engineers were in the practice of weighting the valve, or keeping it shut by holding down a lever by the hand"—when ascending an inclined plane, or wishing a strong power of steam, and thus raising the elastic power of the steam far above the pressure allowed by the directors.

417. Another cause why the safety-valve is sometimes inefficient is, that while it is too heavily weighted to relieve itself, it is of a form not adapted for being easily opened, or in a situation where the engineman has not ready access to it.

418. In many of the smaller boats the weights consist of flat pieces of metal with a hole in the middle which are slipped down a rod, and require a considerable time to be taken off. In some boats, where this is the manner of loading the valve, there is a lever, by which, if necessary, the whole can be raised in an instant. But in other boats, this cheap, simple, and effectual device is wanting; and the valve when over-weighted can only be relieved by the tedious process of removing the weights, raising them one by one to the top of the rod.

419. With regard to the situation, in few of the small boats is the valve at hand for the engineer who is regulating the engine. On one occasion I noticed the engineman of a steam-vessel calling hastily and impatiently for some one to raise the weights off the valve; no one answered for a little: he could not leave the engine; at last a boy appeared, who had some difficulty in reaching the uppermost weights to take them off. And others have assured me that they have often observed similar occurrences in steam-boats.

420. In every steam-boat there is an engineer stationed at one particular spot, to regulate the motions of the engine.

It is singular that the very simple contrivance of a lever within his reach, by which he could control the valve has not been universally adopted—so essential where there is only one valve, and that one in the practice of being overloaded. At the inquest on the second explosion of the VICTORIA, the jury gave it in their verdict that, "The engineer having no immediate control over the safety-valve, in the engine-room, is highly reprehensible."

421. From these and similar circumstances, there can be very little doubt that overloading the safety valve is a common practice with the engineers in marine and locomotive engines, and that they are kept overloaded at a time when the safety valve is most likely to be required. No one can foresee those sudden emergencies at which the action of the safety valve is essential to give vent to an accumulation of steam; and it cannot be looked upon as a security at all, unless it be *always* in such a state as to rise instantaneously whenever the steam tends to acquire undue force.

422. B. *Safety-valve failing, from the surfaces being corroded.*—This is not a frequent cause of inefficiency of the valve, but it has happened, and the valve should be frequently inspected to ascertain that the opposed surfaces of metal are not in any degree rusted or corroded. Corrosion may either cause the plug of the valve to adhere altogether to its seat, or produce such a degree of friction as to interfere seriously with the easy motion of the valve, and add a resistance, equal to a weight of many pounds per square inch, to the exit of the steam.

423. C. *Safety-valve gagged.*—It seems to be pretty well ascertained that the safety-valve sometimes fails, in cases where it could not be attributed to overloading, nor to corrosion.

424. D. *Safety-valve gagged from Expansion of the Plug.*—The plug is usually made of brass, while the ring, or cylinder, or cone in which it works, is of iron. The latter is less expanded by heat than brass, so that if the plug be made to fit close at ordinary temperatures, it will, when they are both expanded by heat, be rather too large for the

tube in which it works. Hence, if this tube be cylindrical —unless it be of a conical form with a large angle at the apex—the effect of this expansion will be to tighten the plug in its seat, fix it there with great force, and thus completely counteract the object of the safety-valve. This is a possible —a probable, cause of adhesion of the safety-valve—but I am not aware that it has yet been ascertained. It was suggested to me by Mr. Edington of the Phœnix Foundry, Glasgow, who, I believe, intends to investigate the subject experimentally.

425. E. *Safety valve gagged from action of blast from aperture.*—It is well known that in certain circumstances, a blast from an aperture has the effect of drawing the lid or disc of the aperture towards it instead of driving it away. It has been shown that this is determined in a great measure by the proportion between the aperture and the disc covering it. See the recommendation of the American committee, page 243.

426. F. *Water falling too low in the boiler.*—This is the most frequent cause of the over-heating of the sides of the boiler. When a part exposed to the action of the fire, however fierce, is covered interiorly by water, the liquid removes the heat from the metal as fast as it is supplied to it, and it can never become very hot, if the steam formed has free exit. But if the water have fallen low in the boiler, and a part exposed to the action of the fire be bare internally, the heat will accumulate in the part left uncovered by water, and it will become red hot (as has often happened) if it be long in this state, or the fire be very strong.

427. G. *Water falling low in the boiler from the supply being stopped.*—The supply of water by the feed-pipe being altogether cut off, while the action of the fire is still continued, is a common cause of the water sinking too low. The feed-pipe is supplied by a pump worked by the engine, so that the supply ceases when the engine stops:—and, before the engine is started, or whenever its action is suspended, there is no fresh water supplied, and if the fire be continued long, the water must necessarily fall low. Hence it happens, that most explosions, both in stationary and in marine

engines have occurred, either when the engine is just about to be started, immediately after it has been started, or when it stops, as in steam-vessels when calling at a port in the course of the voyage. The Americans are well aware of the danger of cutting off the supply when a steam-boat stops. See p. 192.

428. H. *Foaming of the water in a boiler.*—When the supply pipe is stopped, and perhaps the steam not escaping freely, so that there is considerable pressure, and the water, therefore, not boiling freely; and the water has sunk low so that the sides are hot; any cause that diminishes suddenly the pressure of the steam, will enable the liquid to boil more vigorously, so that it will be thrown up upon the hot sides, and suddenly a large volume of steam be produced.

429. Now, the engine starting and consuming the steam—or the safety-valve being opened, will, either of them, relieve the pent up steam in the interior of its force, diminish the pressure on the surface of the water, and cause the water to boil up briskly upon the sides—just as the well known experiment devised by Bishop Watson, in which, by pouring cold water on a flask containing only tepid water and watery vapour, the water enters into very brisk ebullition.

430. I. *Boiler too weak at first.*—The strength of a boiler is tested by a gradually applied pressure, whereas, in explosions, the power is applied suddenly; and a boiler may bear a very great strain, gradually increased up to a certain point, which it could not stand if thrown upon it rapidly. Is this considered in the estimation of the strength and testing of boilers?

431. K. *Tenacity of boiler diminished from being too hot.*—This is a very important consideration. Malleable iron reaches its maximum strength at a temperature a little above that at which condensing engines are commonly worked. *Above this, the decrease in tenacity is rapid, so as to be, at a red-heat, only about one-sixth of its tenacity at ordinary temperatures.*

432. Hence another cause of danger, when the boiler is permitted to become too hot, a most reprehensible practice in every point of view.

433. L. *Boiler weakened by pressure of high column of water*

in certain boilers. In the Victoria, which exploded twice, and in which the boilers were very large and deep, it was calculated that the water exerted a pressure upon the bottom, equal to 3½ lbs. on the square inch.

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434. In considering the means that may be adopted to prevent or lessen the chances of steam-boilers exploding, the same plan will be followed as in describing the causes. First, a tabular view will be presented, and this will be followed by such observatious as seem requisite on each point. On these we can only remark very briefly, referring to the proper sources for detailed plans.

MEANS OF PREVENTING THE EXPLOSION OF STEAM-BOILERS

I. Have the Safety-valve efficient.

1. Additional safety-valve, not under the control of the engine-man. M

2. Working valve so that it cannot be loaded above a certain point.

3. Working valve stamped, so as to shew the pressure at any time. N

4. Working valve within reach of the usual place of the engineman. O

5. Working valve so that it can be completely relieved in a moment. O

6. Safety-valve in motion, constantly, or at short intervals. P

7. Disc valve to be used—the diameter of disc not to be more than 1½ that of the valve-seat. Q

8. Lever of valve to be bent up at the end, so as to relieve it of part of its weight in rising. R

9. Valve to be large. S

10. Plug same metal as valve seat.

II. Know the Height of the water in the Boiler.

1. Gauge cocks. See plate II., Parliamentary Report; and p. 102, ditto.

2. Glass-tube gauge.

III. Keep the Boiler always supplied with water.

1. Throw paddles out of gear and keep engine going in marine engines.

2. Evan's Plan, Parliamentary report, p. 177.

3. Russel's, do., p. 55. see p. 245 of this work.

IV. Know the Force of the Steam.

1. Mercurial Gauge.

2. Gauge by bulk of confined air.

3. Thermometer immersed in Steam.

V. Know temperature of Water and of Boiler.

1. Thermometer in water and in metal at side of boiler.

2. Fusible plug. See Plan of Professor Bache, Report of American Committee; also, Plan of M. Cazalat, Parliamentary Report on Steam-vessels, 1839, p. 198.

VI. Prevent Sediment.

1. Hall's Patent Condenser.

2. Blowing out.

VII. Precautions in managing the Engine.

1. Boilers examined at short regular intervals.

2. Boiler supplied with water by hand when Engine stopped.

3. Safety-valve quite or nearly open when Engine stopped.

4. Fires lowered when boiler too hot.

5. Water introduced slowly (or not at all) when boiler too hot.

6. The safety-valve opened very slowly, or steam let into engine very slowly, when water low and boiler hot, to prevent boiling up.

435. M There is a very obvious remedy for overloading of the safety valve—namely, to have two safety valves—one to be used by the engineer for working the engine—the other to be inaccessible to him, and, therefore, to act as a check upon him.

436. This was recommended by most of the witnesses (17 out of 23) who were examined by the Parliamentary committee, which investigated and reported on this subject. It was recommended by the committee themselves; and also by the American committee, which has been already referred

to—and has been adopted in locomotive engines: and in some steam-vessels.

437. As this has been almost universally recommended and adopted, and is in constant use in many vessels, there does not appear to be any feasible objection to it, while it presents other advantages to which I shall presently allude, besides being a check upon the engineer. I cannot help thinking it strange that it has not been generally adopted.

438. There is in every boiler, a limit beyond which it is confessedly *not safe* to strain its powers. Ignorance, carelessness, recklessness, accident—may occasion the working safety valve, the only means of safety—to be overloaded at some critical period. Why should there not be another means of outlet for the steam—a safe and sure one, not liable to be interfered with or deranged by carelessness, ignorance, or accident? Why should there not be a valve—always loaded to the same extent—and that load adjusted so as to confine the steam for all necessary purposes, and only permit it an outlet by yielding when the steam is acquiring what is allowed to be an unsafe pressure.

439. The words of the report of the Parliamentary committee are:—

"That every such boiler should be provided with two sufficient safety valves, one of which should be inaccessible to the engineman, and the other accessible both to him and to the persons on board the packet."

The American committee recommend—

"That every boiler be provided with two safety valves, each of which shall be competent to discharge the steam, made in the ordinary working of the engine." "The second valve to have a weight immovably fixed upon it, the pressure of which upon the seat, together with that of the atmosphere upon the valve, is equal to the working pressure of the engine. This valve should be so arranged as to admit of raising, but not of placing additional weight upon it. To this end it should be enclosed." "The rise allowed by the enclosure should rather exceed half the radius of the valve seat."

440. Besides acting as a check on the engineer, the additional safety valve would present other advantages.

1. The valve is apt to go out of order or get gagged. There would be a very small chance of both failing at the same moment.

2. In case of the sudden formation of a large volume of steam, where one valve is insufficient to give it quick escape, an additional one might make up the defficiency and prevent an explosion.

441. N As every valve is apt occasionally to fail, the lock-up valve should not be entirely trusted to. The free valve also should be arranged in such a manner that it cannot be loaded beyond a certain extent. The American committee recommend that the free valve

"Should be graduated by the maker of the engine, and have stamped upon the lever by which it is weighted, the bursting pressure at which it will open, by calculation, when the movable weight is placed at the several notches. The pressure corresponding to the last notch to be equal to the bursting pressure, under which the engine is to work."

442. Whether the free or working valve should be open to passengers, so that they may at any time know the pressure of the steam, and how far it is from the extreme pressure allowed, may admit of some question. It might be certainly attended by some inconveniences, interference with and annoyance of the engineer in the discharge of his duty. Some, however, consider this necessary, as a still farther check on the engineer. I should almost be disposed to consider, however, that the state of the lock-up valve being always open to the inspection of passengers (it being stamped so that they can easily know its condition) would be a sufficient check, and that it would not be necessary that they should at all times have the power of knowing how much pressure the engineer is applying.

443. But it is absolutely essential that *he himself* should know exactly what he is about; what weight he is laying on the valve under his control; to what pressure he is bringing up the steam. It is evident that unless the engineer knows this accurately, he is working in the dark; in a random

sort of way, that may be very apt to lead to dangerous consequences. We, therefore, consider that it is essential that, whatever be the form of the valve, it should be graduated, stamped, or, in short, be of such a construction, that, in all his operations with it, he may know, and see clearly and easily, what will be the precise effect of each step on the force of the steam in the boiler.

444. O That the engineer may have complete control over the valve, two other things are required, which can be so easily arranged, and are so obviously necessary, that it will be quite enough here, simply to mention them.

The first is, that the

Safety Valve be within reach of the engineman when in the usual place for working the engine, the valve either being placed there, or brought within his reach by a lever.

Second, that the

Safety Valve be of such a construction that it can be completely eased in a moment; that a lever be connected to it, which, by one simple motion, will at once raise all the weights.

These precautions I have seen adopted in some boats, but there are many in which the S. V. is not at hand for the engineman, and where it can only be eased completely by lifting off successive weights, an operation which requires considerable time.

It is at once obvious that the engineman should have the safety valve at hand, and not need to send for or wait for others to ease it, and that it should be capable of being completely relieved at once, by one simple action. In short, THAT THE MAN WHO GUIDES THE ENGINE BE ABLE TO EASE THE VALVE COMPLETELY IN A MOMENT.

445. P To guard against the safety valve failing from oil-drying, rusting, or cohesion, it might be made to keep itself in order, or be preserved in proper working condition by the action of the engine. In short, *self-preserving*.

446. This might be attained by giving the plug of the safety valve a motion along with the engine, so as to keep it constantly in action; and thus provide the best possible security against adhesion, from whatever cause; and render the

efficacy of the great security against explosion, quite independent of any care or attention on the part of the individuals in charge of the engine, whom a thousand causes may interfere to prevent being always on the alert.

The details of mechanism requisite to bring about the motion of the valve plug, would not offer any material difficulty to those who are familiar with practical mechanics.

The plug might be kept constantly in motion, or it might be made to rise at regular intervals, and let off a little steam, thereby notifying that it is in good working condition. There are many ways in which this might be done so as to secure the constant or frequent assurance that the valve is in efficient condition.

It might also be so arranged that when the engine stops, it should always be open to *a certain height*, leaving it low enough to permit the accumulation of sufficient steam to start with.

447. As long as the present safety valve is in use, the safety valve in which two smooth surfaces are kept in close contact, there appears no way so effectual for providing against failure from friction arising from oil-drying, rusting, or even accidental particles slipping in, as keeping it constantly, or, at least, very frequently in motion, so as either to prevent these adhesions altogether, or give notice, by the stoppage of the motion, when the action of the valve is in any way deranged.

448. Q As there is a less surface of metal in contact in the disc valve than in the conical valve, were the former to be adopted there would be less danger from cohesion, or adhering particles, from its construction ; while, as to the tendency of discs to approach an aperture from which an aerial body is issuing forcibly, this seems to be very much modified by the proportion between the area of the disc and that of the aperture.

449. The American committee recommend the Disc Valve, which they consider very safe, when the *diam.* of the disc is made not more than one and a half times that of the valve seat.

They state that " a less ratio than $1\frac{1}{2}$ to 1 will leave sufficient margin, and any sensible tendency to close from the effect of the issuing current, will be certainly avoided."

450. R There is another recommendation of the American committee with regard to the safety valve which appears to be of value, namely, that there be some method of relieving the valve of part of the weight in rising. This has been proposed to be effected by having the weight on the lever to roll towards the fulcrum when the valve opens. But the committee, on the grounds that this construction might lose its power of action by disuse, preferred the plan of having the lever bent at the end; the weight being fixed there, and rising when the valve is pressed upon, would diminish further the power exerted by the weight, and thus aid in giving freer exit to the steam.

451. S The last circumstance requiring attention with regard to the valve is its SIZE. This is evidently a matter of very great importance. If the steam always accumulated very slowly and gradually, a small aperture would be sufficient for the safety valve, but as it is so apt to be suddenly formed in large quantities, the safety valve, to meet such cases, should have an aperture of a considerable size; as large as is convenient, or would not permit the escape of too much steam when it is open under ordinary circumstances.

452. There is reason to believe that many safety-valves, though sufficient for the case in which the steam acquires its increased strength slowly, are far too small to meet the other emergency. They might easily be made larger, and would, if the probability of the rapid vaporization of a large quantity of water were kept in mind. Some engineers consider that they should have at least one square inch area, for every two and a half horse power; others, for each horse power.

453. From what has been shewn, it will be pretty clear that with the present form of safety-valve, it is essential that all, or at least some, of the above-mentioned measures should be adopted. Many of them have the authority of the British and American committees who examined the subject—and these at least are entitled to some consideration, as founded either on the opinion of the most experienced engineers in either continent, or on the experiments instituted by the

transatlantic committee. When steam navigation is liable to such dreadful occurrences as have lately taken place in this country, the owners and makers of marine engines are not altogether justified in neglecting to provide precautions easily adopted—recommended by the authority of bodies whose opinions carry such weight—and evidently doing something towards providing security, and diminishing the probability of explosions occurring.

454. After what has happened lately, however, we think most persons will feel that, to ensure adequate security, there must be a vigilant control by some public body. There is a Dean of Guild to inspect building in towns, and enforce proper repairs, or even cause houses to be pulled down, if regarded as unsafe. There is need of a Dean of Guild for the waters, more especially when so dangerous an element as steam is to be guarded against.

455. A few years ago, shortly after the explosion of the Earl Grey at Greenock, the Town Council of Glasgow offered a premium for the best plans for preventing these fatal occurrences. A number of plans were given in, but no report on the subject has yet appeared from the Council. As a number of very excellent schemes, there is reason to believe, were given in, the public are deprived of valuable hints by these plans being locked up, which might perhaps have prevented some of the fatal explosions which have occurred since; and the individuals who suggested them are deprived of the benefit of their ingenuity and labours. Surely that body will not long delay fulfilling the pledge which they gave to both the public and the competitors.

The remaining parts of the Appendix, Nos. III. to XII. inclusive, are extracted from the Report of Messrs. Parkes and Pringle, on Accidents on Steam-boats, published last summer. They exhibit the opinions of eminent engineers on the subject of explosions; and some interesting tables regarding accidents to steam-boats, and the number and size, &c., of Steamers in Great Britain.

III.—Mr J. Scott Russel's *plan for supplying boilers with water during the stoppage of the Engine.*

"*A safety reservoir.*—It has already been stated, that the great Hull accident arose from want of water in the boilers before starting. This is a very common cause of danger, and arises from the circumstance that it is the motion of the engine which usually feeds the boiler with water; so that if by any accident there shall be too little water in the boiler when the fires are lighted, or the fire shall burn more briskly than was expected, or some unforeseen delay shall arise, there will remain no remedy, unless, indeed, the crew shall be set to work the force-pump, which is tedious and laborious, and is not only an unwilling task to them, but exposes the improvidence or neglect of the engineer, which he is of course desirous to conceal. Having experienced the advantage which would occur from such an arrangement as should afford such a supply of water to the boiler, I constructed for a steam-boat of sixty horse power the following safety reservoir, by which the boiler can always be filled, even when the steam is strong, without manual labour or the motion of the engine. It is on the principle adopted by Savary in his engine, and is so simple that it has, in all probability, been applied to a similar purpose.

"A reservoir of a few cubic feet in capacity is placed on the top of the boiler, connected by pipes (furnished with cocks or valves), firstly, with the steam-chest; secondly, with the lower part of the body of water in the boiler; and thirdly, with the external water in which the vessel floats. When the engineer wishes to supply his boiler with water, he opens the first cock, and the reservoir is filled with steam; he shuts it, and the steam is condensed. A vacuum is formed; the water rises on opening the second cock and fills the reservoir. The second cock is then closed, and the two others being opened, a free communication is established between the steam-chest, the reservoir and the water contents of the boiler. The water from the reservoir then passes into the boiler by its pressure from greater height. This may be repeated until the whole supply is obtained. The whole apparatus might be rendered self-acting, but is simpler without it." —*Report, p.* 59.

IV.—*Statement by Messrs.* TOD *and* MACGREGOR, *Engineers, Glasgow.*

"The sea-going steamers in general on our coast are kept in good repair, both in machinery and hull; but small river boats are often run till they are unsafe.

"We know of little improvement, either in the safety valves, feed or blow-off cocks, but being well manufactured and well attended to. We always put two safety-valves, one of which is inaccessible to the engineer; we also always put in water-guages, and should further recommend the general use of mercurial guages."—*Report, p.* 79.

V.—*Statement by Messrs.* MAUDSLAY, SONS, *and* FIELD, *Engineers, London.*

"The safety-valves should be large enough to admit of the escape of the whole of the steam, when the engine is suddenly stopped, without its rising more than half a pound on the inch beyond the usual pressure. Two valves, having an area of one square inch for every horse-power, are sufficient for this purpose. Those valves should be so constructed that no increase of weight can possibly be put on, even by the engineer; and there should be provided an apparatus by which they may be conveniently lifted from the engine-room, when it is requisite to ease off the steam. In many ports, especially in the North of England, the safety-valves are too small to relieve the pressure fast enough, and require a portion of the weight to be taken off whenever the engine is stopped. Many such valves have an indefinite number of weights, which the attendants put on at pleasure, and being on the deck, they are open to the chance of being overloaded, either by accident or design. This practice is highly dangerous, and has, no doubt, been the cause of many accidents. Its never having prevailed in the passenger vessels of the river Thames, may account for so few accidents having happened among them. The feed-pumps should be in duplicate, each of ample size for the supply of the boiler, well constructed, with valves, so contrived that they may be taken out, examined, cleaned or repaired while the vessel is on her voyage, the other pumps supplying the boiler the while; and besides this, the hand-pump should be capable of forcing water into the boiler."—*Report, p.* 118.

VI.—*Messrs. John Seaward and Co., Engineers, London.*

"1. Of the very numerous accidents occasioning direct loss of life or personal injury, which within the last few years have occurred in steam vessels, and to be ascribed to the machinery, ninety-nine cases out of a hundred have been occasioned by some imperfection of the boiler, either by a collapse, or by bursting, or rending; the casualties which have occurred through imperfection of other parts of the machinery have been so few and inconsiderable as hardly to be of any importance. We do not include the loss of life occasioned by wreck arising from the machinery being incapable of continuing to work, as this class of accident comes under the head of general unseaworthiness.

"2. That of the many accidents so occurring in steam-vessels through imperfection of the boilers, it will, we believe, invariably be found that they have happened in vessels where steam of high pressure has been used, and in no instance with steam of low pressure. By the term low-pressure steam, we mean steam of a pressure not exceeding 5 lbs. to the square inch. In the vessels fitted by Messrs. Boulton and Watt and the London engineers, the pressure is generally under four or four and a half pounds per square inch.

"3. Of the numerous accidents so occurring to steam-boat boilers employing high pressure steam, or steam of a dangerous pressure, it will be found that a large proportion, probably half, have occurred through the collapsing of large internal cylindrical chambers or flues employed in such boilers; the remaining accidents being occasioned through the bursting or rending of the external casings of boilers.

"4. Of the various causes which have been suggested by different persons to account for the explosions of steam boat boilers, such as the sticking of the safety valves, the igniting of explosive gases, the loss of feed and heating of the metal plates, the sudden immission of a large quantity of feed and consequent generating of an unusual volume of steam, and other pretended causes of similar character, not one, in our opinion, is deserving the smallest attention; they should be all scouted as merely calculated to mislead the inquirer from the only true cause of these accidents, which is simply, that the materials of the boiler are not sufficiently strong to withstand the force of the steam. It is however true, that a boiler may lose its water so far as to allow some of the internal parts to become red hot, and thereby assist in producing a collapse when high pressure steam, or steam of a dangerous pressure, is used; but the circumstance of some internal part of a boiler becoming red hot, ought not to be considered as the true immediate cause of the accident, because the losing of feed in a boiler, and the consequent heating of a flue red hot, is a mishap of very frequent occurrence in low pressure boilers; but no accident has ever occurred on such occasions calculated to occasion loss of life or personal injury: the fact is, that the parts of a boiler liable to become red hot should even in that state be sufficiently strong to resist the force of the steam, so that no dangerous collapse shall take place; and all good low pressure boilers are so made."—*Report, p.* 125.

No. VII.—*Extract from Report by Messrs.* Parker *and* Pringle, *Parliamentary Commissioners on Accidents in Steam-boats.*

"That the surveyor shall ascertain that the safety-valves be sufficient to pass all the steam which the boilers can generate in their ordinary state of work, at the pressure determined by the weight on the valves; the maximum of which pressure shall be fixed by the maker of the engines, or boilers, and the valves be loaded accordingly.

"That, after an assigned period, no passenger license be granted to any vessel having safety-valves whose spindles or levers are exposed on deck, or capable of being loaded externally, unless satisfactorily protected. Penalty on engineers, masters, or others, for loading valves beyond the weight ascertained by the surveyor, and regulated as above.

"That, in all new steamers; and, after an assigned period, in all steamers, now afloat, glass water-guages, and mercurial pressure-guages shall be required to be fitted to the boilers, to entitle the vessels to a license to ply with passengers.

"No perfect mechanical substitute can be found for *care,* in the management of the steam-engine at sea, or on land; nor do we think that the use of the fusible discs enforced by the French laws, would be productive of additional security; nor, indeed, that any complexity of apparatus, attached to boilers, would contribute to the attainment of that object.

"Apparatus, however, for indicating the level of water, and pressure of steam in boilers, is essential to their safe and economical management, and is of far greater import to the boilers of marine, than of land engines; accidents to the former, or failure in their supply of steam, being attended with peculiar dangers and disasters at sea, from which land boilers are exempt."—*Report. p.* 25.

No. VIII.—Steam Whistle, *recommended by Parliamentary Commissioners.*

"A distinguishing sound should be provided on board steam vessels, as an alarm, to notify their proximity to other vessels at night, on occasion, but more particularly during fogs or thick weather, when lights can only be seen on a very near approach. The want of such regulation is alluded to by several of our correspondents, and a means is also suggested for accomplishing the end. Sailing-vessels are generally provided with some instrument for making a noise, to which resort is had when circumstances require it; viz. bells, horns, gongs, &c. A steam vessel carries with it an agent more powerful, than any of those contrivances, and one which could not fail in notifying its approach, distinctively from every class of vessel, and from a much greater distance than bells, &c.; a circumstance of no slight consequence, when the greater velocity of a steamer is considered. The steam-whistle in common use, attached to locomotive engines, if applied to the boiler of a steam vessel, would completely fulfil the desired end. All that is required is a small pipe opening into the steam chest, and brought up on deck, with the whistle on the top of it, in a convenient position to be used when the commander may order it. By simply turning the handle of a cock, a prolonged sound is produced, or a succession of sounds, on opening and shutting the cock at short intervals. The sound from the whistle of a locomotive engine has frequently been heard more than two miles. We have made particular inquiries as to the degree of sound producible with low pressure, compared with high pressure steam, and learn that this whistle may be constructed so as to be equally as effective with the one, as with the other."—*Report, p.* 14.

IX.—PARTICULARS OF EXPLOSIONS, AND FORM OF BOILERS.

Date.	No. of Reference to the Schedule of Accidents.	No. of Accidents.	Names of Vessels.	Form of Boiler.	No. of Lives lost.	Personal and other Injuries.
1817	1	1	Norwich .	cylindric	9	many persons injured.
1824	4	2	Eagle . .	not known	1	not known.
1824	5	3	D. of Bridgewater	rectangular	2	many persons injured.
1825	6	4	James Ewing	ditto	1	not known.
1826	10	5	Graham . .	ditto	6	many persons injured.
1827	11	6	Fingal . .	ditto	2	not known.
1828	14	7	Corsair . .	ditto	1	ditto.
1828	17	8	Magdalene .	ditto	—	40 pigs scalded to death in the hold.
1829	20	9	Dumbarton Castle	ditto	—	one person injured.
1830	24	10	Hercules .	ditto	—	ditto.
1831	33	11	Royal William	ditto	—	no harm done except to the boiler.
1834	45	12	Herald . .	cylindric	—	ditto, ditto.
1835	48	13	Earl Grey .	rectangular	10	many persons injured.
1836	57	14	Freedom .	cylindric	1	the vessel was sunk.
1837	63	15	Union . .	rectangular	24	many persons injured.
1838	73	16	Victoria .	cylindric	5	others injured.
1838	74	17	Victoria .	ditto	9	ditto.
1838	75	18	James Gallocher	rectangular	2	many persons injured.
1838	76	19	William Stanley	ditto	—	ditto.
1838	77	20	Antelope .	ditto	—	18 cattle destroyed in the hold.
1838	79	21	Vivid . .	cylindric	2	boiler worn very thin in the ruptured part.
1839	91	22	Urgent . .	rectangular	—	eight or nine persons severely scalded.
1839	92	23	Morning Star	cylindric	2	boiler worn very thin.
				TOTAL	77	

It thus appears that 7 explosions have occurred in cylindric boilers.
,, ,, 15 ditto in rectangular boilers.
,, ,, 1 ditto, the "Eagle"—form of boiler not ascertained.

TOTAL 23

19 Explosions happened whilst the vessels were stopping, or on the instant of setting the engines in motion.
3 Ditto, whilst steaming.
1 Ditto, the "Antelope," not ascertained

23

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X.—Summary of Causes of Accidents.

The primary causes of nearly all the accidents which occur to life and property on board Steam-Vessels may be classed as follows:

	Causes.	Instances.
Of Wrecks foundering, or imminent peril of the same.	Defectiveness of hull; intoxication of captain and mate	"Rothsay Castle."
	" hull, boilers and engine	"Northern Yacht."
	" boiler, cables, and anchors	"Forfarshire."
	" boilers, cables and sails	"Ardincaple."
	" boilers, and crankness	"Aurora."
	" boilers, engine, or vessel	"Erin."
	" boiler or engine, and sails	"Killarney."
	" hull, cables, engine, and boiler	"Abbey."
Of Explosions.	Ignorance, carelessness, recklessness, and drunkenness of engine-men.	
	Bad construction, or insufficiency of safety-valves.	
	Inattention to, or want of proper apps. to denote level of water and pressure of steam in boilers.	
	Malformation of boilers to sustain pressure.	
	Working old boilers too long, and at too great pressure.	
	Bad materials, and bad workmanship of boilers.	
Of Fires.	Carelessness and want of cleanliness.	
	Bad construction of coal receptacles.	
	Stowing coals on the boilers, and against the undefended sides of the vessel.	
	Placing boilers too near the decks and sides of the vessel.	
	Defective state of the boilers.	
	Want of fire-extinguishing apparatus.	
Of Collisions.	Want of an universal code of night signals.	
	Want of a defined and compulsory "rule of the road."	
	Racing.	
	Carelessness, or neglect of look-out.	

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XI.—STATEMENT OF THE APPROXIMATE NUMBER, TONNAGE, AND POWER OF VESSELS BELONGING TO THE MERCANTILE STEAM-MARINE OF THE UNITED KINGDOM AND ITS DEPENDENCIES.—END OF YEAR, 1838.

	Number of vessels per Custom-house Return, 1838.	Size of Vessels per Custom-house Return.	Registered Tonnage.	Tonnage of Engine-Room, &c., not registered at the Custom-house.	Total computed Tonnage.	Computed Amount of Horse-power.	Computed Power per Vessel.	Total computed Tonnage per Vessel.
	No.	*Tons.*	*Tons.*	*Tons.*	*Tons.*	*Horse-Power.*	*Horse-Power.*	*Tons.*
	256	below 50	6,106	10,816	16,922	6,400	25	66
	145	50 to 100	10,267	7,458	17,725	6,866	47	122
	84	100 to 150	10,034	7,761	17,795	7,483	90	211
	63	150 to 200	10,982	7,147	18,129	7,560	120	287
	76	200 to 300	16,654	10,839	27,493	11,188	147	361
	41	300 to 400	14,247	7,580	21,827	10,914	266	532
	10	400 to 600	4,488	3,506	7,994	3,000	300	769
	1	679	679	661	1,340	450	450	1,340
	1	10,53	1,053	810	1,855	500	500	1,855
No. registered, 1838.	*677	- -	74,510	56,578	131,080	54,361	—	—
Unregistered.	83	- -	4,154	5,484	9,638	2,129	50	116
Total, Great Britain and Ireland, 1838,	760	- -	78,664	62,062	140,718	56,490	—	—
Guernsey, and Jersey, &c. 1837,	† 6	- -	832	618	1,450	600	100	241
Plantations, 1837,	†44	- -	8,411	7,253	15,664	6,160	140	356
Grand total,	810	- -	87,907	69,933	157,840	63,250	—	—

* The Custom-house Return enumerates 678 steam-vessels; but the tonnage of one—burnt—is omitted.

† These are extracted from Mr. Porter's Returns, as we have not received them for 1838.

XII.—DIMENSIONS OF GREAT WESTERN, &c.

DIMENSIONS.		Great Western.	Liverpool.	British Queen.	President.	United Kingdom.
Extreme length . . .	*feet*	236	223	275	265	—
Ditto, under deck . .	,,	212	216	245	238	206
Ditto, keel . . .	,,	205	209 5 in.	225	220	198
Breadth within the paddle-boxes	,,	35 4 in.	30 10 in.	40	41	36 6 in.
Ditto including ditto . .	,,	59 8 in.	56 3 in.	64	64	—
Depth of hold at midships . .	,,	23 2 in.	19 8 in.	27 6 in.	23 6 in.	22
Tons of space	,,	679½	559½	1,053	—	—
Tonnage of engine-room . .	,,	641½	581	963	—	—
Total tonnage	*tons*	1,321	1,140½	2,016	1,840	1,400
Power of engines . .	*horses power*	450	468	500	540	450
Diameter of cylinders . .	*inches*	73	75	77½	80	73
Length of stroke . . .	*feet*	7	7	7	7½	7
Diameter of paddle-wheels .	,,	28 9 in.	28 5 in.	30 6 in.	31	28
Total weight of engines, boilers, and water . . .	*tons*	480	450	500	500	450
Total weight of coals, 20 day's consumption . . .	,,	600	600	750	750	—
Total weight of cargo . .	,,	250	200	500	750	—
Draught of water with the above weight of stores . .	*feet*	16 8 in.	16 6 in.	16 6 in.	17	—