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Augustine W. Wright

PRINCIPLES AND CONSTRUCTION

OF

MACHINERY:

A PRACTICAL TREATISE

ON

THE LAWS OF THE TRANSMISSION OF POWER, AND OF
THE STRENGTH AND PROPORTIONS OF THE VARIOUS
ELEMENTS OF PRIME MOVERS, MILL-WORK,
AND MACHINERY GENERALLY;

ARRANGED FOR THE USE OF

Students, Engineers, and Practical Mechanics.

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TO THE

REV. JOHN FREDERICK HARDY, M.A.,

This Work

IS RESPECTFULLY DEDICATED,

AS A MARK OF ESTEEM, AND IN GRATEFUL REMEMBRANCE,

BY

HIS FORMER PUPIL,

The Author.

wright tile

PREFACE.

In issuing the present Treatise, a few words explaining the motives of its production, addressed to those classes for whose use it is designed, seem not only appropriate but necessary, in order to account for the arrangement which has been adopted.

The contents of the work are in substance a carefully-revised digest of the author's oral instructions, which for some years past he has found successful in training pupils to a knowledge of that portion of Civil Engineering which takes cognizance of Machinery and Mill-work. The great bulk of treatises on Mechanics are cumbrous to the last degree, loaded with varieties of rules and overwhelming numbers of examples of their application, to determine the modification of forces and ratio velocities of gearing; but in none of them has the Author found the laws of construction in reference to strength of parts set forth at all fully; hence the Lectures given by him were specially arranged to show, not only the principles by which forces and velocities are modified, but also the mode of determining the least dimensions of all descriptions of mill-work and machinery, so that the reader may understand not only why a given machine produces a certain effect, but also *how to make it practically.* Sufficient examples are given in the first portions of the book to show the method of using symbolical formulæ, wherefore in the latter parts the formulæ are not all illustrated by arithmetical examples, as to have followed such a course would have inconveniently extended the bulk of the volume.

The Author's aim throughout has been, in the first place, to explain the Fundamental Theories of Mechanism in the clearest and briefest manner, so as to impress upon the mind *general principles*, not special cases, and then to show the practical development of such theories, care being taken so to arrange the matter as to try the faculties of the mind as little as possible.

FRANCIS CAMPIN.

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PRINCIPLES
AND
CONSTRUCTION OF MACHINERY.

INTRODUCTION.

In the majority of treatises on Mechanics, and perhaps more especially in those which are professedly of an elementary character, a great number of unnecessary divisions and classifications have been introduced, tending to complicate rather than elucidate the questions discussed, and taxing the memory of the student by imposing upon it the duty of retaining a number of purely arbitrary systems of formulæ or rules, instead of impressing upon the mind of the learner the main principles upon which all such formulæ are based.

Every kind of machine or structure met with in engineering practice is of necessity based upon some fundamental principle or principles which should be thoroughly comprehended by those who undertake to construct, modify, or improve upon, these machines or structures. It is very insufficient merely, as it were, to learn the action of one particular machine, without ascertaining the principle of such action and the extent of its application, for without this latter knowledge a thorough comprehension of the machine cannot be attained. Similarly in regard to structures, say lattice bridges, the student who merely learns by rote the rules for calculating the trussing of all (at present) known descriptions of lattice girders will find himself at a loss and incompetent to fulfil the duties he assumes should a new method of trussing be invented, according to which he may be called upon to design a bridge; whereas had he mastered the principles which rule the arrangement of trussed girders, the matter would be one of no difficulty whatever.

The intention of this work is to instil into the minds of engineering students and mechanics, in the simplest way, what may be termed the *alphabet of engineering practice*, and in order to render it available to as large a class of readers as possible, everything approaching to high mathematics will be carefully avoided, and *all calculations restricted to the simplest language.*

It is, however, impossible to deal with the subject before us in a sufficiently lucid manner without employing simple equations, upon which, therefore, a few words in this place may be appropriate. Suppose x to represent the quantity proposed to be found from an ordinary "proportion" or "rule of three" statement, such as the subjoined:—

$$12 : 45 : : 13 : x,$$

then, according to the rule,

$$x = \frac{45 \times 13}{12}$$

This is simply the same thing, but stated as an equation. It is, however, convenient to have a general formula, for there may be many similar cases where the values of the first three terms are not as above; hence replace 12, 45, and 13 respectively by the letters a, b, and c, then the general equation becomes

$$x = \frac{b \times c}{a} \quad . \quad . \quad (1)$$

The value of an equation, or rather its equality, is not altered by either multiplying or dividing both its sides by the same multiplier or dividend, for "things which are double of the same are equal to one another," and "things which are halves of the same are equal to one another." (Euc., Axioms vi. and vii.) Hence

$$2x = 2 \times \frac{b \times c}{a}$$

Let the general equation (1) be multiplied by a,

$$b \times c = x \times a$$

but usually the multiplication symbol × is substituted by a period, thus

$$a \,.\, x = b \,.\, c$$

The object of such an equation as this is evidently that three terms out of four being known, we may be able to find the *unknown quantity:* according to the terms represented by the letters, any one of the latter may present the unknown quantity; therefore let an equation be found for each:—

Divide by x, then $a = \dfrac{b\ c}{x}$

Divide by c, then $b = \dfrac{a\ x}{c}$

Divide by b, then $c = \dfrac{a\ x}{b}$

Divide by a, then $x = \dfrac{b\ c}{a}$

In this case there are only multiplications and divisions to be performed; but very commonly, as well as these, additions and subtractions will be found to occur, as in the equation following:—

$$x + y = 3\,a\,b + \frac{2v}{6} - m \quad . \quad . \quad . \quad (2)$$

We can, without vitiating the truth of the equation, subtract from or add a like quantity to both sides, for "if equals be added to equals the wholes are equal," and "if equals be taken from equals the remainders are equal."—(Euc., Axioms ii. and iii.)

In equation (2) add m to both sides of the equation,

$$x + y + m = 3\,a\,b + \frac{2v}{6} - m + m = 3\,a\,b + \frac{2v}{6} \quad (3)$$

Or subtract y,

$$x + y - y = x = 3\,a\,b + \frac{2v}{6} - m - y \quad . \quad (4)$$

Both are true equations.

From observation of the above process the following rule is drawn :—*If it is required to change a quantity from one side of an equation to the other, in so doing alter the sign of the quantity moved.*

Thus $-\,m$ in eq. (2) on the *right* becomes $+\,m$ in eq. (3) on the *left*, and $+\,y$ in eq. (2) on the *left* becomes $-\,y$ in eq. (4) on the *right*.

These few brief remarks will probably be sufficient to explain the nature of a simple equation, so far as may be requisite to the comprehension of the formulæ and analyses with which we shall subsequently have to deal.

In concluding this Introduction it seems desirable to point out the general object of every machine or structure. This object, then, is to render some natural law or set of natural laws subservient to human purposes, to subjugate and guide the energies of the physical forces, either in motion or at rest, so that they may be expended at the places convenient and in manner suitable to our requirements. Thus, from coal dug out of the earth energy is developed to propel vessels on the ocean; and by a skilful arrangement of materials vast loads are supported over chasms, and their weight transmitted to the piers or abutments on either side.

The main distinction in principle between a machine and a structure may be thus stated:—A machine is used to apply physical force *in motion;* a structure depends upon the laws of physical force *at rest.* The former is termed dynamic, the latter static force (from the Greek δυναμι, I move, and ιστημι, I stand).

CHAPTER I.

FORCE OR PRESSURE.

FORCE or pressure acting upon any body indicates that such body is under some control which for the time being regulates the circumstances of its existence and condition; but of forces there are several which, although capable of reproducing each other mutually, nevertheless may be regarded as of different characters from the different phenomena to which they give rise. The natures of these forces will now receive our attention.

According to the most generally received theory all matter is composed of minute bodies called atoms (from the Greek α privative, and τεμνῶ, I cut), which are indivisible, and by the building up of which molecules of matter are formed, by the aggregation of which again masses of matter are formed. The character of a molecule is that it consists of a number of atoms either similar or dissimilar *chemically* attracted towards each other; but a mass of matter consists of molecules mechanically attracting each other: thus the mass of matter may be broken or crushed by mechanical means, but the molecules can only be disintegrated by chemical action.

The atoms of matter, which Newton describes as being hard, impenetrable, and incapable of wear, forming a mass, are not in actual contact, as is evident from the compressibility of matter; hence they must be balanced in certain positions, allowing greater or less intervals between them according to the nature of the body of which they are the component parts; and to occupy such a position, two forces must be acting upon them, the one tending to bring them together, the other exerting a repelling force which unopposed would drive them asunder.

The force tending to bring the molecules together is called the attraction of cohesion, and that which repels them is heat, and the molecules occupy positions dependent on the relative intensities of these two opposing forces. The intensity of the attractive force remains constant amongst the molecules of any given body, but that of the heat may be varied by external agencies; thus we can add heat to a mass of matter or deprive it of a portion of that which it already possesses. In the former case the additional heat further opposing the cohesive force drives the molecules further apart, and the body *expands;* but in the latter case the repulsive force being diminished, the molecules are drawn by the predominant cohesive attraction into closer contiguity, and the body *contracts.* It would be foreign to the purpose of the present treatise to dilate more fully upon these forces, as by so doing we should be trenching too much upon the sphere of physics.

The next force to which we must allude is the attraction of gravitation, by virtue of which all heavy bodies tend to approach one another. It is this force which holds the planets in their orbits, and to it is due the *weight* of matter. By gravitation ponderable substances fall to the earth, and by gravitation ships and balloons are supported in the aqueous and aërial oceans; but in the last two instances the vessels are floated upwards because they are displaced by the superior gravitative force of the media by which they are sustained: they are forced up as a light weight is drawn up by a heavier one.

Gravitation furnishes the measure for force, work, and power, as all forces, in whatever direction they may act, are always stated according to the weight of a mass which by reason of its tendency to fall to the earth would produce the same effect in a vertical direction. Thus, if a man push a carriage, exerting on it with his hand the same energy he would have to exhibit to support a weight of thirty pounds, he is said to be pressing the carriage with a force of thirty pounds.

The actual weight of a body does not affect the intensity of the earth's attraction for its parts, as a mass weighing ten pounds will fall no quicker to the earth than one weighing five pounds, nor any slower than twenty pounds' weight, as the effect of gravitation is manifest on each molecule of the mass independently of the neighbouring molecules, and were they all separate they would fall with the same velocity as they have when aggregated together in a solid mass. Not only do bodies gravitate towards the centre of the earth, however, but also towards irregularities on its surface and towards each other. The pendulum which in level country points when hanging freely to the centre of the earth, will when placed in the neighbourhood of mountains deviate from that position, being attracted in some degree by the masses of earth in its vicinity.

Matter in general possesses a property termed *inertia*, by reason of which it will, if unacted upon by external agencies, continue in any state in which it may happen to be left by the last force that acted upon it; that is to say, if a body is at rest it will remain so until some exterior force moves it, and if it be in motion it will continue to move until some external resistance stops it.

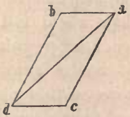
A body acted on by one force alone cannot be in a state of rest; there must be at least two in operation, and these two must be equal in intensity and opposite in direction: in the language of statics these forces are termed action and re-action, hence the law of equilibrium of forces.

To satisfy the conditions of equilibrium, the action and re-action must be EQUAL *and* OPPOSITE.

If two forces only are acting, as a matter of course they must act in one and the same straight line, but in opposite directions.

It not unfrequently happens that two forces act at a point so as to produce a combined effect; it is necessary in that case to find what single force would produce the same effect as these two forces, which latter are supposed to be inclined at an angle to each other.

Fig. 1.



Let two forces act at the point *a*, Fig. 1, respectively in the directions of the lines *a b*, *a c*, and let their intensities be represented by the lengths of the lines *a b* and *a c;* complete the parallelogram, *a b c d*, and join *a d*, then will the diagonal *a d* represent in direction and intensity the force equivalent to the two forces *a b* and *a c*. This is obvious at sight, for if we suppose the two forces acting to move a body from *a*, and each acts singly, first—the body will be drawn to *c;* and then *c d*, being equal and parallel to *a c*, will represent it and draw the body to *d;* but if both forces, maintaining parallelism to their initial directions, act continuously and at the same time, the body would really be moved along the diagonal *a d*.

If there be more than two forces acting at a given point, they may be solved by pairs by the "Theory of the Parallelogram of Forces," until at last one force is found equivalent in intensity and direction to all of them together.

All solid bodies are to some greater or less degree elastic, although in some, such as lead for instance, the elasticity is not easily perceptible; elasticity being that property by which bodies when compressed, extended, or otherwise altered in form by external force, endeavour to recover their former shape and size. If a weight be placed upon a spring balance, the spring is shortened in proportion to the weight placed upon it, and similarly if a weight is placed upon a solid mass there is induced a compression of the solid, and its tendency to expand to its original bulk produces the force sustaining the weight; in short, the weight is the action, and the elasticity of the material supplies the re-action. Hence, when force is brought into action upon a fixed body, compression (or extension, as the case may be) takes place until the elastic resistance of the material supplies a re-action equal to the external force which has called it into operation; provided always that the external force has not sufficient intensity to overcome the molecular attraction, and so rupture the body upon which it is acting.

The reaction to every action which occurs on the earth might be reasoned out; but to do so would be merely occupying a large quantity of space for no useful purpose, and the argument would be merely a series of repetitions of the example just given.

Force may be transmitted from the first point of its application through either a solid, liquid, or gas, to operate at some distant point; but if through a solid—

no mechanical appliance intervening—the force can only ultimately act in the same direction as that in which it is first applied, or in one parallel to it.

If, however, the force be transmitted through a liquid or gaseous medium confined in a vessel, the force may be received from such medium in any direction, regardless of that in which the force was applied in the first instance. This difference is due to the distinctive characteristics of solids and fluids, which are as follows:—

The weight of a *solid* body presses vertically towards the centre of the earth, but

The weight of a *fluid* body presses equally in all directions.

We must now pass on to describe "*potential*," or stored force. Perhaps as good an illustration as can be cited on this point is that supplied by a clock-spring when wound up; a certain amount of force is communicated to the spring, and there remains stored up ready for use at pleasure; while the spring is at rest this force is regarded as potential force, because although its presence is not evidenced by any phenomena, yet it exists and is capable of being brought into action at any time. The same may be said of any weight raised and suspended over a body on which it may subsequently be required to exert pressure, or of steam or gas compressed in a close vessel, whether it be by actual forcing into the vessel more than it normally holds, or by increasing the tension of its normal contents by the effects of externally applied heat. In conclusion, the forces which act upon all terrestrial matter may be arranged in two classes:—Internal forces and forces acting externally.

The *internal forces* are those upon which the form, properties, and constitution of various bodies depend in a normal state.

The *external forces* are those which, proceeding from without the body, tend to move it from its position, alter its shape or bulk, or to destroy the cohesion of its parts.

CHAPTER II.

WORK, POWER, AND MOTION.

IN the previous chapter forces at rest have been treated of principally, but now we have to consider the results which accrue from forces accompanied by motion, that is from dynamic forces.

When a force is exerted through a space, then WORK is said to be done; if a resistance is overcome throughout the space passed through by the force, then uniform work is being done; but if the resistance is all at the end of the space, then the work *accumulated* in passing through the space overcomes it. Work is usually expressed in pounds lifted through feet as foot-pounds; thus, if a resistance of 45 lbs. is overcome through a distance of 50 feet, then the amount of work done is

$$= 45 \text{ lbs.} \times 50 \text{ ft.} = 2250 \text{ ft.} : \text{lbs.}$$

It matters not what direction the force is exerted in, whether to push a truck or lift a weight.

By introducing a third element, time, comparative measurements of POWER are obtained. A horse, according to Watt, can lift 33,000 lbs. one foot per minute; hence, if a steam-engine be lifting 1,848,000 lbs. one foot per minute, its power is

$$= \frac{1{,}848{,}000}{33{,}000} = 56 \text{ horse-power.}$$

Hence, to find the horse-power exerted by any machine the following rule may be used :—

Multiply the weight or resistance by the speed per minute at which it is overcome, and divide the product by 33,000.

Example : Let the resistance be equal to 503,089 lbs.

Speed per minute . . . 100 ft.

$$\text{Horse-power} = \frac{503{,}089 \times 100}{33{,}000} = 1524{\cdot}5$$

If a body fall freely, then the work, not being expended as it falls, is accumulated in it; thus, if a weight of 15 lbs. drops 10 feet, the work accumulated in it will be

$$15 \times 10 = 150 \text{ ft.} : \text{lbs.}$$

But supposing such a mass as a railway train in motion, then the accumulated work must be ascertained from the velocity; it is equal to the weight of the train multiplied by the height through which it would have to fall to acquire a velocity equal to that at which it is moving; but in order to find a rule to determine what this would be, we must ascertain the laws which govern the motion of bodies falling freely.

From experiment it is found that a heavy body during the first second of its fall passes through 16·1 feet; hence its velocity at the end of the first second must be 32·2 feet per second, as at the commencement the velocity is 0 and

$$\frac{0 \times 32{\cdot}2}{2} = 16{\cdot}1 \text{ ft.}$$

the *average* velocity as found from the initial and final velocities. During the next second the body will pass through 32·2 feet, due to the velocity already acquired, and 16·1 feet, due to the continued attraction of gravitation, in all 48·3 feet; and in the two seconds 64·4 feet;

it will also acquire another 32·2 feet per second, making a final velocity of 64·4 per second. Following this up, the distances and velocities corresponding to different durations of time will be found as follows:—

Let $h =$ total distance fallen through, and v corresponding final velocity per second:

Duration of fall in seconds.	h	v
1	16·1	32·2
2	64·4	64·4
3	144·9	96·6
4	257·6	128·8
5	402·5	161·0

From this table it is evident that the distance fallen through varies as the square of the time occupied by the fall, and the velocity varies simply as the time.

Let $t =$ time of fall in seconds, and $g = 32{\cdot}2$ feet per second, then the following formulæ will serve to solve all cases relating to falling bodies:

$$h = \frac{g\ t^2}{2} = \frac{v^2}{2g} \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Let the time be 5 seconds,

$h = \frac{1}{2} \times 32{\cdot}2 \times 25 = 402{\cdot}5$ feet fall in 5 seconds.

Let the velocity per second be 100 feet, the fall to acquire such a velocity will be

$$h = \frac{10{,}000}{2 \times 32{\cdot}2} = 155{\cdot}3 \text{ feet nearly.}$$

Again, to find the velocity, we have, by transposing the above equations,

$$v = g\ t = \frac{2\ h}{t} = \sqrt{2\ g\ h}$$

Let the time of fall be 5 seconds,

$$v = 32{\cdot}2 \times 5 = 161 \text{ feet per second.}$$

Let the height of fall be 100 feet,

$$v = \sqrt{2 \times 32{\cdot}2 \times 100} = 80{\cdot}25 \text{ feet per sec. nearly.}$$

The weight of a body being $= W$, the work accumulated in it in falling through a distance $= h$, will be $= Wh$, and, also, replacing h by its value in the foregoing formulæ equation (5).

$$\text{Accumulated work} = \frac{Wv^2}{2\,g}$$

Let a weight of 5 lbs. be moving at a velocity of 20 feet per second, the accumulated work is

$$= \frac{5 \times 400}{2 \times 32{\cdot}2} = 31 \text{ foot-pounds.}$$

Taking the example of a train weighing 80 tons (179,200lbs.), and moving at a speed of 20 miles per hour (29·3 per second), we find the accumulated work to be

$$= \frac{179{,}200 \times 858{,}49}{2 \times 32{\cdot}2} = 2{,}388{,}840 \text{ foot-pounds.}$$

Again, let a cannon ball weighing 60 lbs. leave the mouth of a gun at a velocity of 2,000 feet per second, the work accumulated in it will be

$$= \frac{60 \times 4{,}000{,}000}{2 \times 32{\cdot}2} = 3{,}726{,}708 \text{ foot-pounds.}$$

This well illustrates the immense destructive power which may be concentrated in comparatively small weights by causing them to move at high velocities; for whereas the accumulated work varies simply as the weight, it varies as the square of the velocity.

If the velocity of a moving body, such as a train, after attaining a certain point becomes constant, then the body is said to have a uniform motion, and the propelling power is just sufficient to overcome the frictional resistances opposed to the motion of the body at the velocity acquired. Let the propelling force cease to act, and the body will gradually come to rest, the work accumulated in it being expended in overcoming the frictional resistances to the gradually decreasing motion of the mass.

Any mass set in motion will, if unoperated upon by any fresh force, move continually in a right line having the direction in which the force imparting motion to the body originally acted, but through the intervention of another force the body may be caused to move in a curve instead of in a right line. Let a body in motion be compelled, by a cord of constant length attached to it at one end and to a fixed point at the other, to revolve about a centre describing a circle at each revolution. A rule is required to determine the tension on the cord, or the centrifugal force.

In order to state the amount of force necessary to draw a body through any given space, we must consider the case in comparison with the earth's attraction, which produces an effect of g, or 32·2 feet velocity, in one second of time. The attractive *force* varies as the bulk of the body, hence the *mass* of a body is expressed by

$$\frac{W}{g}$$

The normal direction of the moving body will be a tangent to a circle, and according to the laws of the circle (Cape's Mathematics, vol. ii., p. 233,) the distance which it will be drawn out of this direction by the tension of the cord will be expressed for one second by $\frac{v^2}{r}$; hence the centrifugal force will be,

if r = radius of gyration,

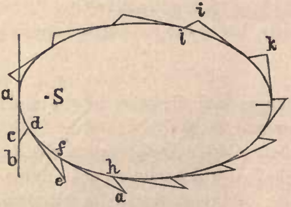
$$\frac{W v^2}{r g} = \text{force in pounds.}$$

In order to make more clear the mode of comparing centrifugal force with gravitative attraction, a special case may be taken. Let a force be capable of imparting a velocity of 64·4 feet to a mass of matter in one second, then will this force have twice the intensity of the attraction of gravitation, and a body requiring 5 lbs. pressure to sustain it against the latter will require 10 lbs. to sustain it against the former. Let it be required to determine the centrifugal force of a mass weighing 15 lbs., revolving in a circle 4 feet in diameter at a velocity of 20 feet per second, the centrifugal force will be

$$= \frac{15 \times 400}{4 \times 32{\cdot}2} = 46{\cdot}58 \text{ lbs.}$$

Bodies may be caused to move in a great variety of curves, dependent upon the composition of the forces acting upon them; thus the planets in their courses describe elliptical orbits, the path being determined by the initial velocity and direction of movement combined with the attraction of the sun.

Fig. 2.



Let the ellipse shown in Fig. 2 represent the path of a planet moving round the sun *S* placed in one of the foci of the ellipse. The *rationale* of its movement is as follows:—If the body first have a motion impressed upon it acting in the direction *a b*, by the time the body would have reached *c* the attraction of the sun has drawn it out of the right line as far as *c d*, when it may be considered as again moving in a tangent to the curve; and again, when it would have reached *e*, the sun's attraction has drawn it to *f*, and so forth. It will be observed that during the passage through this part of the orbit, the sun's attraction is *retarding* the moving body, until at *k* its course is turned round and it approaches the sun, the attraction of which is now accelerating its speed, as is evident from the direction in which it is acting, as shown at *i j;* thus the loss of velocity due to the sun's attraction in one half of the orbit is restored in the other half, so that when the body again arrives at the point *a* it is moving with its initial velocity.

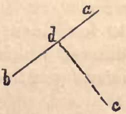
It would very rarely occur that a planet, moving under the influence of its initial velocity and the sun's attraction, would adopt a circular orbit, as, for such to be the case, the latter must first come into action when the planet is in such a position that a line drawn from the sun to it would be perpendicular to its motion, and in addition to this there would be required a certain definite relation between the velocity of the body and the attractive force of the sun.

CHAPTER III.

GENERAL LAW FOR ALL MACHINES MODIFYING FORCE.

When a force acts about a fixed point as a centre, the effort of this force reduced to the centre is termed the moment of the force. In Fig. 3 let *a b* show the direction in which a force *p* is acting; its moment about the point *c* is required

Fig. 3.



to be determined. From the point c let fall a perpendicular $c\ d$ upon $a\ b$, and let the length of this perpendicular be represented by l, then the moment of the force p about the point c will be

$$= p \times l$$

Thus, if the force have an intensity of 20 lbs., and its distance be 3·5 feet, the moment of the force about the point c will be

$$= 20 \times 3{\cdot}5 = 70 \text{ foot-pounds.}$$

In all appliances for increasing or diminishing the intensity of force there are two main points requiring primary attention—the point of application of the force and the point at which it is given off. In every case there is a tendency to produce motion, and whether it actually is produced or not, the proportions of the machine to secure equilibrium between force and resistance, whether at rest or in uniform motion, will be the same.

It is one of the fundamental laws of natural science that force can neither be created nor destroyed; hence, if a force is increased, as by means of a lever, something else is diminished, as the space through which the force acts. Let work be done on one end of a machine equal to 10 lbs. acting through 20 feet, that will equal 200 feet-pounds; and this may be given off at the other end of the machine in a variety of different ways, but *only the same amount of work* can be given off. (At present friction is disregarded.)

If the part of the machine at which the work is given off moves 2 feet while the point of application moves 10 feet, then dividing the work done by the space through which the force passes, it is found that the intensity of the force will be

$$\frac{200}{2} = 100 \text{ lbs. pressure}$$

thus the intensity of the force is increased by means of the machine five times, but the space through which it acts is diminished in like ratio.

Again, if two forces act about a centre so as to preserve equilibrium, acting, of course, in opposite directions, their moments must be equal. Let a force of 30 lbs. act about a centre at a distance of 3 feet from it, the moment of force will be

$$= 30 \times 3 = 90 \text{ ft.} : \text{lbs.}$$

at what distance from the same centre must a force of 12 lbs. act in the opposite direction to balance this moment? Let x equal the required distance, the moment of this last force will be

$$12 \times x = 12\,x$$

but to satisfy the conditions of equilibrium the moments must be equal; hence

$$12\,x = 90 \text{ ft.} : \text{lbs.}$$

wherefore,

$$x = \frac{90}{12} = 7{\cdot}5 \text{ feet.}$$

In this case, if the forces were rotating, the spaces passed through would be inversely as the forces acting, because the circumferences of circles vary as their radii, and the distances of the forces from the point about which they act are the radii of the circles of gyration of such forces, and from the above it is observed that these distances are inversely as the forces to which they refer; the force of which the intensity is 30 lbs., having a distance of 3 feet, and that of 12 lbs. a distance of 7·5 feet.

The general law for machines for modifying or increasing pressure (irrespective of friction) may now be stated:—

The pressure is to the resistance as the space through which the resistance is overcome in a given time is to the space through which the force acts in the same time.

By this law may be solved questions referring to every description of lever, pulley, toggle, train of wheels, hydrostatic press, or other similar contrivance.

Let p = pressure or force in pounds, R = resistance in pounds.

s = distance traversed by force in a given time.

S = ,, ,, by resistance in the same time.

From the following four equations any one of these quantities may be found, the other three being given:—

$$p = \frac{R\ .\ S}{s} \qquad R = \frac{p\ .\ s}{S}$$

$$s = \frac{R\ .\ S}{p} \qquad S = \frac{p\ .\ s}{R}$$

A few examples will serve to show the application of these formulæ :—

Fig. 4.

A b is a lever supported on a fulcrum at *c*, the points of resistance and force being respectively at *a* and *b*, the distance *a c* = 10 inches, and *b c* = 56 inches, *a c*, *b c* being radii of gyration of the points *a* and *b*, the spaces passed through in a given time would be *a*, 10 inches, and *b*, 56 inches; hence, if it is required to equal a resistance of 114 lbs., the force applied must be

$$p = \frac{114 \times 10}{56} = 20{\cdot}36 \text{ lbs. nearly.}$$

Let a weight of half a ton be required to be lifted by a force of 80 lbs., the distance *a c* being equal to 2 inches, then the distance *b c* will be

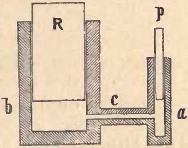
$$s = \frac{1120 \times 2}{80} = 28 \text{ inches.}$$

In these cases it must be understood that the distances *a c*, *b c*, are employed instead of the spaces actually passed through by *a* and *b*, because the ratios are the same, that is

$$\frac{s}{S} = \frac{bc}{ac}$$

The principle of the hydrostatic press is illustrated in the section shown in Fig. 5. *a* and *b* are small and large cylinders fitted with water-tight pistons or plungers, one (*p*) being the point of application of force, the other (*R*) that of resistance; the cylinders communicate with each other by means of the pipe *c*. The water flowing out of *a* into *b* evidently has to cover a much larger surface in the latter than in the former, and consequently the depth of a given quantity of water would be much greater in *a* than in *b;* or, in other words, if the piston in *a* be forced down, that in *b* will be raised to a height less than that through which *p* descended, in proportion as the area of *b* is greater than that of *a;* but the areas of circles vary as the squares of their diameters (Euc., Bk. xii., Prop. ii.); hence the distances (*s* and *S*) passed through in a given time by the points of force and resistance, in the present case, are inversely as the squares of the diameters of the respective cylinders to which they are applied. Let the diameter of the cylinder *a* be 1·5 inches, and that of the cylinder *b* 10 inches, then the spaces passed through by *p* and *R* respectively in a given time will be

Fig. 5.



$$s = \overline{10}^{2} = 100$$

$$S = \overline{1 \cdot 5}^{2} = 2 \cdot 25$$

hence a force being applied at $p = 25$ lbs., the resistance it will be capable of balancing is,

$$R = \frac{25 \times 100}{2{\cdot}25} = 1111\,.\,\dot{1}\text{ lbs.}$$

or nearly half a ton.

CHAPTER IV.

CENTRE OF GRAVITY.—MECHANICAL POWERS.

It has hitherto been customary, when treating on the attraction of gravitation, to explain the use of the term "centre of gravity;" but in this treatise its consideration has been advisedly postponed to this chapter, in order that the reader might first be made acquainted with the principle of moments of force, as by pursuing this course we are enabled the more clearly to deal with our subject now.

That point in any body at which the whole weight may be supposed to be aggregated together is called the "centre of gravity" of such body, and if suspended from this point it will remain at rest in any position in which it may be placed. A mass of matter may be regarded as an assemblage of small particles or molecules, each and all exerting moments of force about a certain point, about which all such moments are in equilibrio; this point will be the centre of gravity of the mass.

Fig. 6.

It is required to find the centre of gravity of two forces, p, p' Fig. 6, distant from each other $a\ b$. Let c be the centre of gravity of the forces, then the moments of the forces about c must be equal, or

$$p \times a\,c = p' \times c\,b;$$

hence,

$$\frac{p}{p'} = \frac{c\,b}{a\,c}$$

let $p = 24$ and $p' = 7$, then the ratio will be

$$\frac{p}{p'} = \frac{c\,b}{a\,c} = \frac{24}{7}$$

or $a\,c$ will be $\frac{7}{24}$ of $b\,c$; or as there are 24 parts in $b\,c$, and 7 parts in $a\,c$ $(24 + 7 = 31)\,\frac{7}{31}$ of $a\,b$

Let $a\,b = 27$ inches, then

$$a\,c = \frac{7}{31} \times 27 = 6{\cdot}09 \text{ inches,}$$

and

$$b\,c = \frac{24}{31} \times 27 = 20{\cdot}91 \text{ inches.}$$

The centre of gravity of any number of forces may be thus finally found by solving it first for one pair, then considering the two forces as acting at their centre of gravity, and determining the point for this and another of the forces, and so forth.

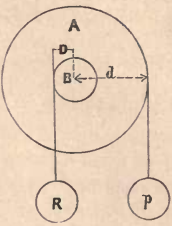
In all symmetrical bodies the centre of gravity is evidently coincident with the centre of figure or mass.

The simplest machine for modifying pressure or resistance is the lever, and after what has already been said the solution of all questions connected with it will be sufficiently easy.

Let $p =$ the force, $d =$ its distance perpendicularly from the fulcrum; $R =$ resistance, $D =$ its distance from the fulcrum, then

$$p = R \times \frac{D}{d},\ R = \frac{p\,d}{D},\ D = \frac{p\,d}{R},\ d = \frac{R\,D}{p}$$

Fig. 7.



These four equations will serve for any kind of lever; the wheel and axle shown in Fig. 7 is identical in principle with the lever. The radius of the wheel equals *d*, one arm of the lever, and the radius of the axle equals *D*, the other arm of the lever.

The circular movement of any point in the periphery of the wheel is called its angular velocity, of which the proper definition is as follows:—

The angular velocity of a wheel is equal to the velocity of any point in the periphery divided by the radius of the wheel.

The inclined plane, wedge, and screw are all but different forms of one and the same mechanical element.

Fig. 8.

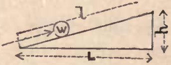


Fig. 9.

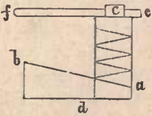


Fig. 8 is an inclined plane; it is required to determine what force will be necessary to support the weight W upon it. Let $p =$ this force, $l =$ length of the inclined plane, and $h =$ its height. It is evident that in order to raise the weight W vertically through the height h, it must be moved through the distance l, hence the force moves through the distance l, while the resistance of gravitation only acts through the distance h; hence

$$p = W \times \frac{h}{l}, \; W = p \times \frac{l}{h}, \; h = \frac{p\,l}{W}, \; l = W \times \frac{h}{p}$$

A wedge consists of two inclined planes placed base to base; the formulæ are the same as above, but replacing

l by L and h by $2h$, which would be the thickness of the back of the wedge, supposing it to consist of two equal and similar inclined planes.

If an inclined plane, *a b* (Fig. 9), be wrapped round a cylinder, *c d*, it will describe a screw about it, as shown by the dotted lines. At each revolution of the screw any body on which it acts will be moved through a space equal to the distance from centre to centre between two successive convolutions of the thread; this distance is called the *pitch* of the screw. The screw is usually turned by a bar or lever, *e f*. Let the distance from the axis of the screw at which the force acts $= L$, the pitch of the screw $= p$, the force $= P$, and resistance $= R$; in one revolution the force will describe a circle of which the radius $= L$, or will pass through a space equal to

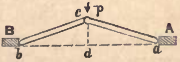
$$6{\cdot}2832\, L;$$

hence the formulæ for solving questions connected with the screw will be as follows:—

$$P = R \times \frac{p}{6{\cdot}2832\ L},\ R = P \times \frac{6{\cdot}2832\ L}{p}$$

$$p = P \times \frac{6{\cdot}2832\ L}{R},\ L = R \times \frac{p}{6{\cdot}2832\ P}$$

Fig. 10.



The toggle, Fig. 10, forms a very powerful mechanical element. *A B* are two blocks, one fixed, the other capable of sliding in the direction *a b*, but offering a resistance, *R*, to motion; *a c*, *c b* are two links jointed together at *c*, the force being applied in the direction of the arrow p, or at right angles to the direction of the resistance. While the force is moving through the space $c\ d$, the resistance will evidently be overcome through a distance equal to twice the difference between $a\ c$ and $a\ d$. But (Euc., Bk. i., Prop. 47),

$$a\,d = \sqrt{\overline{a\,c}^2 - \overline{c\,d}^2}$$

hence the space through which the resistance is overcome is

$$s = 2\left(a\,c - \sqrt{\overline{a\,c}^2 - \overline{c\,d}^2}\right)$$

Let l = length of one link ($a\ c$), d = distance traversed by force ($c\ d$), R = resistance, p = force, then

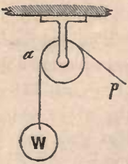
$$p = R \times \frac{d}{2(l - \sqrt{l^2 - d^2})}, \quad R = p \times \frac{2(l - \sqrt{l^2 - d^2})}{d}$$

This gives the relation of force to resistance when the former is acting in the position shown, but as the resisting block moves so the force becomes more and more intensified, until, just as the links $a\ c$, $b\ c$, fall into the same right line, the ratio becomes infinite.

We next have to consider the effects produced by arrangements of pulleys intervening between the weight or resistance and the force opposed to it. If but one pulley is used, and that one is fixed as at a, Fig. 11, it merely serves to change the direction of the force, and does not alter its intensity; hence, in this case,

$$p = W$$

Fig. 11.



When, however, moveable pulleys are used, the case is altered, and the force becomes intensified. In Fig. 12 it is evident that half the weight, W, is carried on each of the portions, a and b, of the cord; hence the tension on the cord is

$$\frac{W}{2}$$

Fig. 12.

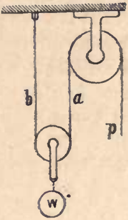
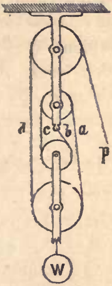


Fig. 13.



In Fig. 13 the weight is carried on the four parts, a, b, c, d, of the cord, hence the tension on it in this case is

$$\frac{W}{4}$$

So, in these two instances, the ratio of force to weight is,

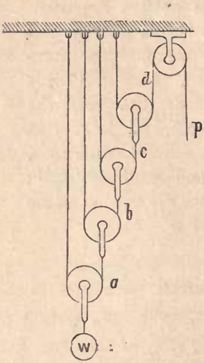
$$\text{Fig. 12}: p = \frac{W}{2} \qquad \text{Fig. 13}: p = \frac{W}{4}$$

The following formula will apply to all combinations of this class where only *one cord* runs through the whole system of pulleys:—

Let p = force, W = resistance, n = number of *moveable* pulleys,—

$$p = \frac{W}{2\,n}, \quad W = p \times 2\,n$$

Fig. 14.



In Fig. 14 are shown four moveable pulleys and four *separate cords*. It is a combination of systems of which each reduces the resistance by one half, hence the tensions are on $a, \frac{W}{2}, b, \frac{W}{4}, c, \frac{W}{8}, d, \frac{W}{16}.$ Hence the following formulæ will serve to solve cases of this sort. Let n = the number of times one system alone will reduce the weight or resistance, and x = the number of systems combined, then

$$p = \frac{W}{x^{n\text{th}}}$$

In the case illustrated, the number of times one system will reduce the resistance is 2, the number of systems combined 4, hence

$$p = \frac{W}{2^{4\text{th}}} = \frac{W}{16}$$

Of course in all cases of pulleys what is gained in intensity of force is lost in space passed through; thus, in Fig. 12, the parts *a* and *b* of the cord have both to be shortened as much as the weight is raised; hence the cord at *p* has to be drawn through a distance twice as great as that through which the weight is lifted or the resistance overcome.

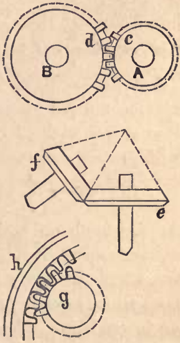
In machines which act by percussion, such as hammers, pile engines, &c., the effect is produced by expending work, accumulated through a certain distance, in a comparatively very short space. For instance, let the "monkey" of a pile-driving engine weigh 300 lbs., and have a fall of 10 feet, then in each fall the work accumulated in the monkey will be

$$300 \text{ lbs.} \times 10 \text{ ft.} = 3000 \text{ ft.-lbs.}$$

If this work be expended in driving the pile $\frac{1}{2}$ inch into the ground, then ($\frac{1}{2}$ inch $= \frac{1}{24}$ foot) the mean force exerted will be

$$\frac{3000}{\frac{1}{24}} = 72{,}000 \text{ lbs.}$$

Fig. 15.



In order to vary the speed obtained from a prime mover, wheels having teeth on their peripheries, called cog, toothed or spur wheels, are very commonly used; the general forms of some of these are shown in Fig. 15. *A* and *B* are two parallel shafts carrying the spur wheels *c* and *d*, which, by gearing together, ensure a certain ratio of velocity between the shafts; and also the hold afforded by the teeth allows of power being transmitted from one shaft to the other. The dotted circles show the effective size of the wheels, that is, the size they would be if the motion were transmitted by mere rubbing contact without teeth; they are called pitch circles, because the pitch, or distance from centre to centre of the teeth, is measured on them. When the shafts are inclined at an angle to each other, "bevil wheels," as shown at *e* and *f*, are used. In this case the periphery of each wheel is conical, the apices of the cones being where the inclined shafts would meet if produced, as shown by the dotted lines. In both these cases the wheels revolve in opposite directions. If, however, the large wheel has the teeth inside the rim, as shown at *h*, and the small spur-wheel or pinion *g* works within the large wheel, then both wheel and pinion revolve in the same direction.

The ratio of the angular velocities, or number of revolutions made by the shafts, will be dependent upon the radii of the wheels, as the peripheral velocity will of necessity be the same for both wheels. Let the radii of of A and B be *r* and R, and the number of revolutions made by them be respectively *n* and N, in a given time, then

$$n = N \times \frac{R}{r}, N = n \times \frac{r}{R} R = n \times \frac{r}{N} r = N \times \frac{R}{n}$$

Let the radius of $A = r = 4$ inches, its number of revolutions per minute $= n = 30$. The wheel B is required to make 7 revolutions per minute; its radius will be

$$R = 30 \times \frac{4}{7} = 17{\cdot}1 \text{ inches at the pitch circle.}$$

As the teeth on both wheels are pitched at the same distance apart, it follows that the number of teeth on the wheels will vary also as the radii of the wheels. If both wheels are required to move in the same direction, an intermediate wheel is sometimes interposed between the driving wheel and that driven; this, which is called an idle wheel, has no other effect beyond reversing the direction of the motion. The shape of the teeth of wheels will be treated of in a subsequent chapter.

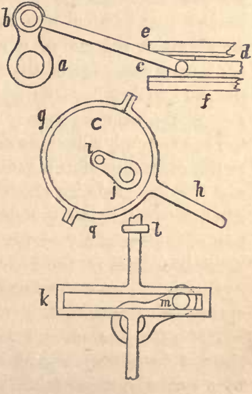
Very commonly, instead of using toothed gearing (especially where the shafts are far apart and noise is objectionable), pulleys or riggers, connected by belts or straps running round them, are employed; in this case the ratio of the angular velocities of the shafts is determined in the same manner as in the last, presuming, of course, that the belt does not slip.

For some especial purposes toothed gearing of unusual forms is applied, the wheels assuming the appearance of ellipses, squares and lobed figures; but it is unnecessary here to describe them, though it may be advisable to observe that in setting out such work care must be taken that in every position the sum of the radii of the pitch lines, at the point between the centres of the wheels, is equal to the distance between such centres.

CHAPTER V.

ELEMENTS FOR CHANGING THE NATURE OF MOVEMENTS.

Fig. 16.



The simplest modes of changing continuous rotary motion into reciprocal, or *vice versâ*, are shown in Fig. 16. *a* is a shaft carrying a crank *a b*, to which is jointed *a b*, a connecting rod, *b c; c*, the end of the connecting-rod, is jointed to a block sliding between guides, *e f*, so the revolution of the crank will impart the required motion to the rod *d*.

If we imagine the crank pin *b* enlarged until its periphery extends beyond the main shaft *a*, the principle of the crank is maintained; but in the altered form the element is termed an eccentric wheel, or, for brevity, an eccentric. One is shown at *C*. *C* is the eccentric, *j* the main-shaft, *i* the geometrical centre of the eccentric, *g* a band surrounding it, sufficiently free to allow the eccentric to revolve within it, *h* a connecting rod by which motion is transmitted from the eccentric.

Instead of the connecting-rod and guides a slotted link *k* may be used. This link is carried by two rods working in guides *l l;* to keep its motion rectilineal the lateral motion of the crank pin *m* is allowed for by the slot in the link. By making the slot sufficiently broad, an eccentric may also be used with this arrangement.

Fig. 17.

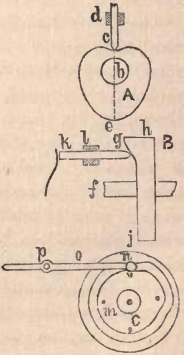


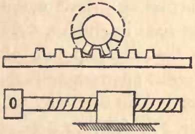
Fig. 17 exhibits types of three descriptions of cams in most general use. *A* is a heart-shaped cam carried on a revolving axis *b*, the end of a rod *c* rests upon the edge of the cam, the rod passing between guides *d*. As the cam revolves it lifts the rod through a distance equal to the difference of the radii *b c* and *b e*, the mode in which it is lifted depending on the formation of the periphery of the cam between *c* and *e;* the rod falls again by its own weight or by a spring or another cam.

B is a face-cam on an axis *f f*, the rod *k* working in guides *l* is pressed against its face by a spring or otherwise. The part *g* pushes the rod back as the cam revolves through a distance equal to the difference between *h g* and *i j*.

The third cam *C* has a groove in its face *m*, *m*, in which works a pin *n*, carried at the end of a bar *o*, capable of oscillating on a centre *p*. As the cam revolves the bar *o* will vibrate by reason of the irregularity of the groove *m m*.

Cams are very much used in machines where varying movements and those of an intermittent character are required. An intermittent movement is any movement of which whilst one part is always in motion the next has alternate intervals of motion and rest; such as would be the case if the cam A were circular all round except at one place, as then the rod *c* would be at rest except when the one irregular part of the cam was passing under it, when for a short space it would move. The cam *C* is an intermittent movement, as part of the groove in its face is circular, and therefore does not move the pin *n*.

Fig. 18.



In Fig. 18 is shown a spur pinion working into a rack; by the revolution of the pinion the rack is caused to travel in a rectilineal direction. A similar change of motion is effected by a screw which works in a block or nut. This nut is prevented from turning by a guide or other restraint; hence when the screw is turned the nut progresses in a straight line parallel to its axis.

In like manner a screw may be caused to act on the teeth of a segmental rack or on those of a wheel, thus converting rotatory motion in one direction into the same but at right angles to its original direction; this last combination is called a worm-wheel and tangent-screw.

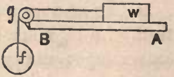
To enumerate one tithe of all the various cams and elements for changing motion would probably be impossible; nor does it seem desirable in a work such as the present to occupy space by enlarging further on the subject, as sufficient examples have already been shown to make clear the principles upon which such mechanical contrivances are based, and these once thoroughly understood the mechanician will have but little trouble in setting out details suitable for the attainment of any special object which he may have in view.

CHAPTER VI.

FRICTION.

Friction is that kind of resistance which is opposed to one body sliding upon another, or to a part of a machine moving when rubbing against another part, as the journal of a shaft against its bearings, a sliding block between its guides, &c. The law of the friction of solids is that the amount of friction varies simply as the weight or pressure acting upon the surfaces in contact; nor is it in any way whatever affected by the extent of the rubbing surfaces, so long as they are sufficiently large to withstand the crushing effect of the pressure acting upon them.

Fig. 19.



Let *A B* represent a slab having a horizontal top surface, upon which is a weight *W*, or body, which is pressed against *A B* by a force equal to *W*; from *W* let a cord be passed (parallel to *A B*) over a guide pulley, *g*, and at the loose end place a weight, *f*, of such intensity that if *W* be set in motion towards *g* it will continue to move, but, if stopped, it will remain at rest; then *f* will be the force equal to the friction between *W* and *A B*, and $\frac{f}{W}$ will be the relation of this force to the weight or pressure creating the friction. This is called the co-efficient of friction for the materials under consideration, and is useful to determine the friction of any other mass of the same material. The following table gives the co-efficients of friction for most of the substances met with in the construction of machinery :—

CO-EFFICIENTS OF FRICTION.

Timber on Stone	0·4
Iron ,, ,, ...	0·3 to 0·7
Iron on Metal	0·15 to 0·25
Timber	0·2 to 0·5
Timber on Metal	0·2 to 0·6
Lard and Oil	0·07 to 0·08
Wrought-iron on Brass . .	0·16
Cast-iron	0·144

CHAPTER VII.

ON THE CONSTRUCTION OF MACHINERY AND MILL-WORK.

HAVING in previous chapters set forth the various manners in which mechanical forces are altered in intensity, velocity, and direction, it now becomes necessary to show how the elements by which such effects are produced may be combined and applied practically as machines, each part being duly proportioned according to the stress to which it will be subjected when in use.

In designing machinery of all descriptions there are numerous details which are proportioned according to experience only, but these will generally be found to be such as from the circumstances of the case are necessarily made much stronger than is absolutely necessary to resist the strain; thus, for instance, if one part of a casting have a great strain upon it, and another part have scarcely any, the latter must not be made excessively thin in proportion, else from the unequal rapidity in cooling of the different parts of the casting it may be rendered weak and unreliable.

The principal elements, however, of machinery may be calculated in order to ascertain the proper dimensions to assign to them; but, before commencing to explain the processes by which this is done, a few general remarks on the action of strains on machinery are requisite.

In comparison with structures, such as bridges, mechanism requires to be made proportionately very much stronger, by reason of its having to undergo stress while in a state of more or less rapid movement, which induces a certain amount of vibration and concussion, whereas in the former the same fibres or portions of material are always subject to the same description of stress. The strains to which the parts of machines are liable are four in number: tension, compression, transverse strain, and shearing strain. Of these, transverse strain may be resolved into tension and compression; thus, if a bar be supported at both ends and loaded in the centre, then the fibres at the top of the bar will be in compression, and those on its lower side in tension, there being somewhere near the centre a layer of fibres having no strain upon them (this is called the *neutral axis* of the bar), on each side of which, upwards and downwards, the compressive and tensile strains gradually increase to their maximum intensities at the surfaces of the bar. Now, while the bar is at rest, it is certain that some fibres are always in tension, and others are always in compression; but if the bar be revolving, as the shafting of machinery, then will every fibre of which it is composed be subjected to tensile and compressive strain alternately, the rapidity of the changes from one to the other being regulated by the velocity of the moving part. This constant change in the nature of the strain produces vibration, which, in order that the apparatus may have a maximum durability, should be reduced to a minimum.

Also in those elements which reciprocate, or move to and fro, the strain very generally changes from tension to compression, or *vice versâ*, at each reciprocation also causing vibration in such elements.

The revolving parts, such as heavy wheels, cams, &c., are also liable to be ruptured by centrifugal force. For instance, it may occur that a fly-wheel is moving at so great a velocity that the strength of the rim and arms is overcome by the centrifugal force generated in the rim, in which case the wheel will come to pieces, the fragments being thrown considerable distances. Very serious accidents have arisen through the breakage of large grindstones from this cause; hence it is very necessary carefully to proportion revolving elements to resist the effects of centrifugal force.

As the vibration of a machine increases with the weight of its moving parts and with the velocity of their motion, it evidently is economical to reduce the speed of such parts as admit of it, and to make all the moving elements as light as is consistent with the possession of due strength. The framework, however, should be massive and rigid, and so designed as to resist without sensible yielding all the thrusts and pulls brought upon it by the various parts of the machinery, for if the framework be not strong enough the machine will soon be useless. The following table gives the ultimate strength of materials per square inch of sectional area :—

TENSION.

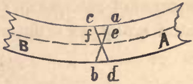
	lbs.
Swedish bar-iron	65,000
Russian ,,	59,470
English ,,	56,000
Cast-iron	17,628
,, brass	17,968
,, copper	19,072
Wrought-copper	33,892
Wire-rope	90,000

COMPRESSION.

	lbs.
Cast-iron	120,000
Wrought-iron	36,000
Brick	800
Portland stone	4,550
Craigleith stone	5,460
Bromley Fall stone	5,915
Purbeck stone	8,000
York paving	5,460
Granite.	9,000

Having made these general remarks, we can now proceed to consider the laws which rule the proportions of the different elements of machines. In the first place, it will be necessary to analyse the resistance of materials to transverse strain.

Fig. 20.



If two imaginary sections be taken infinitely close together in a rectangular beam when unloaded, and then a stress be put upon it, so as to bend it, as shown at A B, Fig. 20, then the sections may be considered to have crossed each other, as exhibited at a b, c d; all the fibres above the neutral axis, which is supposed to be in the centre of the depth of the beam, as shown by the dotted line, will be compressed, and those below extended.

It is evident that each fibre will be strained exactly in proportion to its distance from the neutral axis or point of intersection of the lines a b, and its reaction tending to resist the load will be equal to this strain. If $S =$ strain per square inch on the outer fibre a c, then that on any other fibre, e f, distant x from the neutral axis will be, if $D =$ depth of beam,—

$$= S \times \frac{2x}{D}$$

and if the width be unity, the sum of all the strains will be represented by the area of the triangle a g c,

$$= S \times \frac{D}{4}$$

But all these forces or reactions may be regarded as collected at the centre of gravity of the triangle a g c, and acting about the point g at a distance equal to that of the said centre of gravity, which is

$$= \frac{2\,D}{6}$$

hence the total moment of force for the *two* sets of fibres, a g c and d g b, will be

$$= 2\left\{S \times \frac{D}{4} \times \frac{2\,D}{6}\right\} = \frac{S\,D^2}{6}$$

but the resistance also varies as the breadth,—let the breadth equal b, then the general expression of moment of resistance for a rectangular beam the maximum stress per square inch of section on which $= S$ is

$$M = \frac{S\ D^2\ b}{6}$$

if the stress be in pounds and the dimensions in inches, the moment will be given in inch-pounds (instead of foot-pounds).

Action and reaction being equal and opposite when equilibrium is maintained, the moment of resistance will equal the moment of force.

If a bar is fixed at one end and loaded at the other with a weight, W, the length being l inches, the moment of strain will be

$$M = W\,l$$

hence,

$$W\,l = \frac{S\ D^2\ b}{6}$$

$$D = \sqrt{\frac{6\ W\,l}{S\ b}}$$

The safe working depth would therefore be,—

$$\text{For cast-iron } D = \sqrt{\frac{W\,l}{800\ b}}$$

$$\text{For wrought-iron } D = \sqrt{\frac{W\,l}{900\ b}}$$

the first being a tenth, and the second an eighth of the breaking strain. If the bar be uniformly loaded, the moment of strain will be one half of that due to the concentrated load; hence the formulæ for a bar fixed at one end and uniformly loaded with a weight, W, will be—

$$\text{For cast-iron } D = \sqrt{\frac{W\,l}{1600\ b}}$$

$$\text{For wrought-iron } D = \sqrt{\frac{W\,l}{1800\,b}}$$

If the bar be supported at both ends and loaded in the centre, the moment of stress will be—

$$M = \frac{W\,l}{4}$$

hence the formulæ in this case are—

$$\text{For cast-iron } D = \sqrt{\frac{W\,l}{3200\,b}}$$

$$\text{For wrought-iron } D = \sqrt{\frac{W\,l}{3600\,b}}$$

Or if the load be distributed uniformly—

$$\text{For cast-iron } D = \sqrt{\frac{W\,l}{6400\,b}}$$

$$\text{For wrought-iron } D = \sqrt{\frac{W\,l}{7200\,b}}$$

If a weight be placed upon the bar not centrally, then the length, l, must be substituted as follows :—

Let x and y respectively equal the distances of the points of support from the weight, then

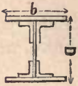
$$l = \frac{4\,x\,y}{x + y}$$

By a process similar to that pursued in reference to rectangular beams, the moment of resistance of a cylindrical bar may be found. The following formulæ give safe working results for a cylinder supported at each end and loaded in the centre (if not so loaded replace l as above): let l = length in feet, d = diameter in inches, W equal weight in pounds—

$$\text{For cast-iron } d = \sqrt[3]{\frac{W\,l}{120}}$$

$$\text{For wrought-iron } d = \sqrt[3]{\frac{W\,l}{150}}$$

Fig. 21.



Large girders and bearers may be calculated in a simpler way. Let Fig. 21 represent a wrought-iron flanged bearer supported at both ends. D = depth in feet, l = length in feet, a = area of one flange, plate and angle irons in square inches, s = safe strain per square inch, W = load in tons at centre, then for the resistance of both flanges

$$M = s \times a \times d$$

for the moment of strain,

$$M = \frac{W\,l}{4}$$

hence 3 tons per square inch being taken as a safe strain,

$$a = \frac{W\,l}{12\,D}$$

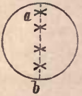
or if the load be equally distributed,

$$a = \frac{W\,l}{24\,D}$$

These general rules for estimating transverse strength apply to all kinds of machines; hence require no special illustration here, as their application will appear hereafter, as progress is made in the analysis of the laws which govern the proportions of prime-movers, machines and gearing.

Cylinders having Pistons working in them.—Two points have here to be considered: first, the bursting pressure; second, the wear and vibration. The first is very simple. The pressures in the two halves of the cylinder may be considered as acting and reacting against each other at any diameter, as shown in Fig. 22 by the arrows, tending to tear the two sections a and b; hence if p = pressure per square inch, and

Fig. 22.



r = radius of cylinder in inches, the strain on one part of the shell is

$$= p\,r$$

but the question of vibration is not so easily solved, and, in fact, must be determined by experience. Taking the two strains together the following formula is found to give good practical results :—

d = diameter of cylinder in inches, p = internal pressure per square inch, t = thickness of cylinder in inches—

$$t = \tfrac{1}{8}\left\{\frac{p\,d}{440} + \sqrt{d}\right\}$$

Cylindrical Pipes.—These are cylinders (cast-iron) having only to withstand pressure with a certain allowance for wear, hence the same notation as above being used,

$$t = \frac{p\,d}{6000} + 0{\cdot}66$$

Bolts and Nuts.—Let the number of bolts holding a cover on a cylinder or other vessel having internal pressure = n, the pressure = p, D = diameter of cover in inches, and d = diameter of bolts, then from the tensile resistance of iron it is found—

$$d = \frac{D}{75}\sqrt{\frac{p}{n}}$$

In order that the nut may have a sufficient hold on the bolt, its thickness should not be less than half the diameter of the bolt, but it is usual to make the thickness equal to the diameter of the bolt. In some cases, such as in bearings, check nuts are used, which are thin nuts screwed down upon the main nuts to prevent their turning, and so becoming loose.

Covers and Lids.—Covers and lids, under pressure, are subject to transverse strain, and from its laws, aided by practical observation, the following formulæ are drawn :—

t = thickness of cover in inches, p = pressure on it per square inch, D = diameter of cover, C = height of curve of cover, both in inches—

$$t = \frac{p\,D^2}{14400 \times C}$$

For flat covers let l = diameter, or if oblong, length of shortest side :

$$t = \frac{l}{120}\sqrt{p}$$

Rods under Tension only.—Allowing one tenth of the breaking strength as safe for working, the following formulæ are found :—Let W = the weight in pounds, d = diameter in inches—

$$\text{For cast-iron } d = \frac{\sqrt{W}}{60}$$

$$\text{For wrought-iron } d = \frac{\sqrt{W}}{36}$$

Rods under Compression.—Let the rods be moderately short, so as not to yield by bending, then,

$$\text{For wrought-iron } d = \frac{\sqrt{W}}{48}$$

$$\text{For cast-iron } d = \frac{\sqrt{W}}{88}$$

If these rods, either in tension or compression, are placed horizontally or at an angle, so that they are subjected to transverse strain, care must be taken to ascertain that they are sufficiently strong to bear such stress as may be due to their weights.

Hollow Cast-iron Pillars.—The following formulæ are derived from experiments, and refer to columns of which the length does not exceed thirty times the diameter:—Let d and d' = the external and internal diameters in inches, l = length in feet, and W = safe working load,

$$W = 4{\cdot}4 \; \frac{d^{3.6} - d'^{3.6}}{l^{1.7}}$$

It will be observed that the powers to which the quantities are to be raised are fractional, hence this formula can only be solved by the aid of logarithms; but the following approximate rule is accurate enough for practical purposes:—

$$W = 4{\cdot}4 \; \frac{\{d^2 \times \sqrt{d^3}\} - \{d'^2 \times \sqrt{d'^3}\}}{\sqrt[4]{l} \times \sqrt{l^3}}$$

Cast-iron Rocking Beams.—Let W = weight in pounds at the end of beam, l = length in feet from weight to axis of beam, t = thickness in inches, and d = depth in inches; then from the laws of transverse strain,

$$t = \frac{W\,l}{60\;d^2}$$

This rule is very suitable to determine the dimensions of main beams and side levers of engines, and other like elements.

Cranks.—Let W = the weight in pounds acting on the crank, D = the outer diameter of its boss, and d = the diameter of the aperture made to receive the shaft; l = length of the crank in inches from the centre of the crank pin to the centre of the shaft; b = the depth of the crank boss:—

$$\text{For cast-iron } b = \frac{W\,l}{720\;\{D^2 - d^2\}}$$

$$\text{For wrought-iron } b = \frac{W\,l}{800\;\{D^2 - d^2\}}$$

Revolving Shafts.—For transverse strain, load in the centre, let d = diameter in inches, W = load in pounds, l = length in inches—

$$\text{For cast-iron } d = \frac{\sqrt{Wl}}{2100}$$

$$\text{For wrought-iron } d = \frac{\sqrt{Wl}}{2240}$$

Tredgold's rule for water-wheel journals:—

d = diameter in inches, l = length in inches, W = load in pounds:

$$d = \tfrac{1}{9}\sqrt{l\,W}$$

Revolving shafts, through which power is transmitted, are subject to a twisting force or torsional strain, hence the shafts must have sufficient strength in this respect. Long shafts are mostly determined for transverse, but short ones for torsional strain. Many years back cast-iron shafts were in vogue, but now they are almost entirely displaced by wrought-iron. The following formula is convenient for determining the diameters of main-shafts for prime-movers:—Let HP = horse-power of prime-mover, R = number of revolutions of main-shaft per minute, d = diameter in inches—

$$d = \sqrt[3]{\frac{320\ HP}{R}}$$

A very general formula for finding the diameter of secondary running shafting is

$$d = \sqrt[3]{\frac{250\ HP}{R}}$$

The proportions most suitable for the journals of revolving shafts as determined by experience are, if

d = diameter and l = length of journal inches (the journal being the part in contact with the bearings),

$$\text{For cast-iron } l = 1{\cdot}5\, d$$
$$\text{For wrought-iron } l = 1{\cdot}75\, d$$

If the weight, such for instance as a fly-wheel carried upon a shaft, be placed close to the bearing, then the transverse strain becomes insensible, and the shearing force has to be considered; that is, the tendency of the weight to shear or cut the shaft close to the bearing. The ultimate resistance of wrought-iron to shearing force is about 54,000 lbs. per square inch of sectional area; hence the proper diameter being = d inches W = weight, will be

$$d = \frac{\sqrt{W}}{65}$$

Fly-wheels and Plain Pulleys.—In proportioning wheels of all descriptions sufficient strength must be provided to resist the tendency to rupture through the tension caused by the centrifugal force of the mass in motion. First, in regard to the rim, let v = velocity in feet per second at the periphery, n = number of revolutions per minute, d = diameter in feet, w = weight per foot of the rim of the wheel, a = sectional area of rim in square inches, c = centrifugal force. Then c for one foot of the rim of the wheel will be

$$c = \frac{w \times v^2}{16{\cdot}1 \times d}$$

Treating this simply as a radial force tending to burst the ring, we find for the strain (= S) on any section of the rim,

$$S = \frac{c\,d}{2} = \frac{w\,v^2}{32{\cdot}2}$$

Then, allowing 1,800 lbs. per square inch as the tensile working strength of cast-iron, the sectional area should be—

$$a = \frac{w\ v^2}{57{,}960}$$

but, from the specific weight of cast-iron, it is found that

$$a = \frac{w}{3{\cdot}2}$$

Also,

$$n = \frac{19\ v}{d};\ v = \frac{n \times d}{19}$$

wherefore the limit to the velocity of wheels will be—

$$\text{For cast-iron } n = \frac{2546}{d}$$

$$\text{For wrought-iron } n = \frac{4427}{d}$$

The arms of the wheels should be strong enough to resist the centrifugal force of the whole rim, so that if it should be broken or flawed between every pair of arms, yet it will not come to pieces. Cast-iron wheels very frequently have arms of the form shown in Fig 23, though sometimes they are made round or oval in section. The section *a b c d* must be sufficiently strong to resist the centrifugal effort of its portion of the periphery. Let a = the sectional area of the rim in square inches, d = diameter of wheel in feet, v = velocity in feet per second, and A = area of one arm, and N = number of arms in the wheel, then the weight of rim

Fig. 23.

$$W = a \times 3{\cdot}2 \times 3{\cdot}1416\, d = .\, a\, .\, 10\, d$$

hence the centrifugal force on all the arms may be—

$$c = \frac{W v^2}{16 \cdot 1 \times d} = \frac{a v^2}{1 \cdot 6}$$

but,

$$v = \frac{n \times d}{19}$$

hence,

$$c = \frac{a (n d)^2}{577 \cdot 6}$$

The safe resistance of all the arms will be—

$$= A \times N \times 1800$$

hence,

$$1800 \, A . N . = \frac{a (n d)^2}{577 \cdot 6}$$

$$A = \frac{a (n d)^2}{1{,}039{,}680 \, N}$$

The strength of arms necessary to transmit power must next be ascertained. In this case the part *a b* alone will be taken as carrying the whole strain, the feathers *c* and *d*, on either side of it, being left to give lateral rigidity, and, in point of fact, being near the neutral axis, they afford but little towards the resistance of the transverse strain.

Let D = diameter of wheel-boss in feet, l = length of arms in inches, n = number of revolutions per minute, HP = horse-power transmitted, b = width in inches of $a\ b$, t = thickness in inches, V = velocity of outer edge of wheel-boss in feet per minute, L = strain at same place, N = number of arms:—

$$L = \frac{HP \times 33000}{V}$$

but,

$$V = 3 \cdot 1416 \times D \times n$$

hence

$$L = \frac{HP \times 10504}{D \times n}$$

hence, from the formula for rectangular beams of cast-iron (there being n arms)—

$$b = \sqrt{\frac{HP \times l \times 13}{D \times n \times N \times t}}$$

TEETH OF WHEELS.—The strength of the arms of the wheels being determined, it is necessary to show the method of proportioning the teeth to the power to be transmitted.

Let S = the stress on a tooth, V = velocity of pitch circle in feet per minute, then

$$S = \frac{HP \times 33000}{V}$$

let t = thickness of tooth in inches, l = length in inches, b = breadth in inches, a = safe resistance of a bar one inch every way fixed at one end and loaded at the other, then

$$t = \sqrt{\frac{S \times l}{a \times b}}$$

if we assume $b = 2\,l$,

$$t = \sqrt{\frac{S}{2\,a}} = c\,\sqrt{S}$$

where c is a constant, which

For cast-iron - = 0·025
,, brass - - = 0·035
,, hard wood = 0·038

Tredgold's formula is as follows:

Let v = velocity of pitch circle in feet per second,

$$t = x\,\sqrt{\frac{HP}{v}}$$

where x is a constant, which

For cast-iron - = 0·587
,, brass - - = 0·821
,, hard wood = 0·891

In calculating the stress on teeth of wheels driven by steam-engines, the maximum power transmitted through the teeth should always be assumed as 25 per cent. greater than the mean power of the engine.

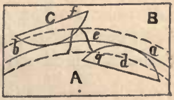
FORM OF THE TEETH OF WHEELS.—The strength of the teeth of wheels being calculated, the next step consists in setting out the shape of them, and this is a point requiring great attention, for if the teeth be not of the correct form the wheels will not work well together, whereas, if they be carefully set out and made properly, the wheels will work noiselessly. The following are the best relative proportions of the teeth as determined by practical experience :—

Let the Pitch of teeth . = 100
Then - Depth . . = 75
Working depth . = 70
Clearance . . = 5
Thickness . . = 45
Width of space = 55
Play . . . = 10
Length beyond pitch line = 35

The form of the faces of the teeth should be that of the epicycloid, which is a curve formed by one circle rolling upon the periphery of another; if outside the curve is an epicycloid, if inside it is a hypocycloid. The moving circle is called the generating circle, and should not exceed one half the diameter of the spur wheels.

The mode of setting out templates from which to form the teeth is shown in Fig. 24. Let *a b* be a portion of the pitch circle of the wheel, properly marked to show where the faces of the teeth cross it; make two templates, *A* and *B*, with edges to fit the said pitch circle. Place template *A* so as

Fig. 24.



to coincide with the pitch circle and against cause the segment *c* of the generating circle to roll, then a pencil fixed in its edge will draw the upper part of one face of a tooth at *e f*. Remove *A* and make template *B* coincide with the pitch circle, then place the segment of the generating circle as shown at *d*, and by it draw the part *e g* of the tooth within the pitch circle, and so forth for as many teeth as are required on the template.

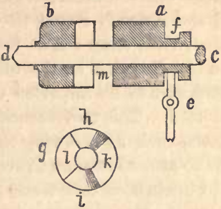
Other curves, such as the involute, &c., have been proposed for the teeth of wheels, but it is unnecessary here to enter into a discussion of them.

Not unfrequently, instead of casting wheels with the teeth on, they are cast with mortices in, and wooden teeth or cogs are inserted; a wheel of this description, working with one having iron teeth, gives very satisfactory results, and is very durable.

Engaging and Disengaging Gear.—Various mechanical arrangements are employed in workshops and mills, and other places where machinery is used, to afford means of starting and stopping any one machine independently of the others and of the prime mover. The simplest method is by the use of "fast and loose" pulleys when the machine is driven by a belt. Two belt pulleys or riggers are fixed on the driving-shaft of the machine, one of which is firmly keyed to the shaft, the other being left free to revolve upon the shaft. A forked guide leads the belt from one pulley to the other, both being close together, side by side. When the band from the driving shafting is guided on to the firmly fixed pulley the machine is set in motion, but when it is running upon the loose pulley the machine is at rest.

Another method of disengaging is by clutches, of which one kind is shown in Fig. 25. *c* and *d* are two shafts, of which the extremities meet but do not touch at *m.* The clutch is shown in section. *b* is keyed firmly on to the shaft *d*, but *a*, although having a sliding key which compels it to revolve with the shaft *c*, is capable of sliding endways upon it, being moved by the forked-lever *e*, the ends of which work in the annular grove *f*. Each part of the clutch has two recesses, *h* and *i*, and two projections, *k* and *l*, shown at *g*. When *a* is slided up to *b*, the projections on each part of the clutch fall into the recesses in the other part, and thus the motion is transmitted to the other so long as the clutch is closed ; but this transmission of power ceases as soon as it is again opened. Most of the clutches in common use are but variations of this one.

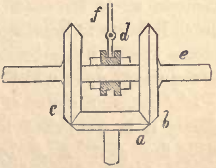
Fig. 25.



Spur-gearing may be engaged and disengaged by making one of the shafts so that it will slide longitudinally upon its axis, then by sliding it thus the teeth of the wheels can be thrown into or out of gear very readily.

Fig. 26 shows an arrangement of bevil wheels by means of which a shaft may be driven in either direction or left at rest at pleasure. *a* is the driving wheel, which is constantly moving in one direction and in gear with the two bevil wheels *b* and *c*, which revolve freely on the shaft *e*, one of them in each direction ; *d* is a double clutch capable

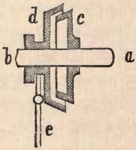
Fig. 26.



of gearing into recesses in either *b* or *c*, or of standing clear between them; it is regulated by the forked lever *f*, and is firmly keyed to the shaft *e*. In the position shown the shaft *e* is at rest, but by moving the clutch in one direction or the other, according to the motion required to be imparted to *e*, that shaft immediately is started. This movement is very useful in some machine tools, such as screwing machines, where it is necessary to be able to stop and reverse the machine instantly.

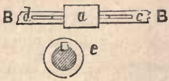
Clutches of this form, however, are not suitable for high speeds, as the sudden shock of bringing the clutch pieces together may cause breakage either in them or in the machinery to which they are applied; hence, in such cases it is better to use friction clutches, of which one is shown in *Fig.* 27: *a* and *b* are the two shafts to which the clutch is attached; the cone *c* is firmly keyed to the shaft *a*, but *d*, although compelled to revolve with *b*, may slide upon it when acted on by the forked lever *e*. When this clutch is closed the cone *d* grasps the cone *c* and by its friction turns it round. In this case, the strain being more gradually brought on to the shaft that was at rest, there is not much liability to breakage. Having alluded to sliding pieces it will be desirable to show how they are fitted to the shafts upon which they are intended to move.

Fig. 27.



In *Fig.* 28 *a* is a plan of a sliding piece; it is compelled to revolve with the shaft *B B* by a key which slides with it in the prolonged groove *c d* in the side of the shaft; or, on the other hand,

Fig. 28.



there may be a long feather fixed into the shaft upon which the piece *a* slides freely, but which compels it to revolve with the shaft; *e* shows a cross section of the shaft with the sliding piece upon it.

Where the shafting but seldom requires to be disconnected the two shafts may carry discs at their extremities fixed on and with their faces close together. These discs being drilled in suitable holes, are connected together by ordinary screw-bolts and nuts. Short coupling-boxes keyed on to both shafts may also be used to connect different lengths of shafting.

The various forms of plummer-blocks, brackets, and hangers for carrying the bearings of shafting are too well known to need any special description, and, of course, the strengths will be determined according to the weight of the shafting to be supported, and the strains produced by the power transmitted through it; the length of the bearings will be fixed by that of the journals which has already been given. It is always well, especially where there is much vibration, to have the bearings of ample length, as otherwise the shafts soon become shaky, and the general deterioration of the machine progresses at a greatly increased rate. We have seen steam-engines soon rendered comparatively useless from this cause alone.

In concluding this chapter, we would impress the necessity in designing machinery of always assuming maximum strains and minimum strengths; let no chance of increased strain pass unnoticed, and be careful to have good sound castings, or, if the machine is not to be constructed under the supervision of the designer, extra allowances of strength must be given to provide against possible inferiorities of material or workmanship. In designing framing and foundation plates for heavy machinery, cross strains should be avoided as much as possible, more especially when accompanied by jerking or jarring action; and wherever such action occurs the framework should be strengthened to resist such special stress by ties or struts, as the nature of the strain may indicate.

CHAPTER VIII.

STEAM AND HOT-AIR ENGINES.

Amongst prime-movers, in England at all events, the steam-engine occupies the first place: water-wheels are scarce, and air and gas engines are seldom heard of, whilst windmills are becoming obsolete; our attention will, therefore, in the first instance, be turned to the principles of the steam-engine.

The action of this motor is proximately due to the expansive force of steam, and it may easily be shown that the greater the extent to which the principle of expanding the steam when acting is carried, the greater will be the economy attained. Notwithstanding the simplicity of this axiom, and the fact that it is and has been for a very long time generally admitted, strange to say, at the present time, a great majority of the engines constructed give nothing like the economical results which would accrue from a more careful attention to the means by which the principle of expansion can most conveniently be applied in practice; in short, many of the steam-engines now constructed are a discredit to their manufacturers.

Before entering upon special details connected with steam machinery, it is necessary to consider the general principles upon which its action is based, and the nature of the expansive fluid by which it is propelled.

Steam is the vapour of water, generated from the latter by the addition of nearly 1,000 degrees of heat by Fahrenheit's thermometer. The total heat of steam is nearly constant for all pressures used in ordinary practice, ranging from 1178·9 degrees at atmospheric pressure to 1230·3 degrees at 200lbs. absolute pressure per square inch, which is equal to 185 lbs. pressure above the atmosphere. This total heat of the steam is considered as divided into two portions; one the sensible heat affecting the thermometer, the other latent heat, not affecting it.

The variation in the total heat of steam being comparatively small within the ordinary limits of working, may, with sufficient accuracy for all practical purposes, be regarded as constant; then if t_s = sensible heat t_l = latent heat, and T = total heat,

$$T = t_l + t_s$$

and taking T = 1,179 degrees,

$$t_l = 1179 - t_s$$

The sensible heat is increased and the latent pressure correspondingly reduced by increase of pressure; thus, at 15 lbs pressure per square inch, the sensible heat is 213·1 degrees, whereas at 50 lbs. pressure it is 281 degrees

In order to arrive at some approximate rule to show the relation of pressure to temperature or sensible heat, we must use empirical means, as by pure reasoning we cannot deduce a formula. It may be assumed that the pressure varies as some power of the temperature, and it is necessary to ascertain the index of that power.

Let t and t' represent a pair of temperatures corresponding to the pressures p and p', then

$$\frac{p}{p'} = \left(\frac{t}{t'}\right)^{n^{\text{th}}}$$

in order to ascertain the value of n recourse must be had to logarithms; the logarithmic equation will be

$$\log. p - \log. p' = n \left\{\log. t - \log. t'\right\}$$

therefore,

$$n = \frac{\log. p - \log. p'}{\log. t - \log. t'}$$

this being solved for a number of pairs of temperatures and pressures taken from Regnault's experiments, gives the following values for n, the pressures being—

$$\left.\begin{matrix}15\\35\end{matrix}\right\} - n = 4{\cdot}3$$

$$\left.\begin{matrix}20\\60\end{matrix}\right\} - n = 4{\cdot}4$$

$$\left.\begin{matrix}25\\50\end{matrix}\right\} - n = 4{\cdot}5$$

$$\left.\begin{matrix}140\\200\end{matrix}\right\} - n = 4{\cdot}5$$

$$\left.\begin{matrix}15\\200\end{matrix}\right\} - n = 4{\cdot}4$$

hence, for practical purposes, we may assume $n = 4{\cdot}4$, without being sensibly inaccurate, then the formulæ for temperature and pressure will become—

$$p = p' \times \left(\frac{t}{t'}\right)^{4{\cdot}4}$$

$$t = t' \sqrt[4{\cdot}4]{\frac{p}{p'}}$$

Boyle and Marriot's law concerning the pressure and density of gases and vapours shows the pressure to be inversely as the volumes of a given weight; but this will not hold quite good with steam, because the temperatures are different at different pressures. Thus, from one volume of water, 1,669 volumes of steam being evolved at 15 lbs. per square inch, the theoretical quantity at 30 lbs. pressure should be 834·5 volumes, but it is 881 volumes really.

No practical rule can conveniently be laid down to determine the addition or diminution necessary as correction to the volume determined by this law, as at different temperatures the steam holds in suspension different quantities of water finely divided, the steam in contact with water not being dry.

According to the views of J. Gill, of Palermo, the conversion of sensible steam into latent heat is the concomitant of work done, and the contrary that of work absorbed by or stored up in the steam; and it is a certain fact that as steam in doing its work expands, so sensible heat is rendered latent, and when steam is forcibly compressed the latent heat is rendered sensible.

The effect of heat or caloric has been supposed to consist in causing the molecules of matter to gyrate in greater or smaller spheres, according to the intensity of the heat; this is the "theory of molecular vortices," and by its aid some explanation may be given of the difference between sensible and latent heat. There being a certain addition of heat to a body of water, its molecules, or some of them, take the form of steam and gyrate in larger spheres than before, but so long as they have room for their enlarged gyrations, the caloric is by them taken up and remains *latent;* but if the molecules be crowded together by increased pressure, then the molecules being confined to spheres of gyration smaller than those they would naturally assume, they press against the neighbouring molecules, and give rise to the phenomena of sensible heat.

Mr. Charles Wye Williams elucidated a doctrine concerning steam and water of a very ingenious character, and deserving of much attention; it is as follows:—There is no such thing as warm water in the abstract meaning of the term; that is to say, a molecule of water cannot be warmed so as to remain water, but each certain increment of heat causes a molecule of water to assume tho proportions of a molecule of steam, although it may not escape from the water, by reason of the aqueous and atmospheric pressure. That steam formed in water is retained there is well known, as if steam be generated under pressure in a close vessel and in contact with water, and the steam accumulated in the space above the water be suddenly removed by condensation, or by letting it suddenly escape, a dense mass of steam will at once arise from the water, which steam up to that time had been as it were dissolved in or mixed with the water in the boiler or generating vessel: in point of fact, practically, the rush of steam would be so great from all parts of the mass of water, that the latter would, if the pressure were at all considerable, be carried up bodily with it.

If one ounce of steam be passed into 6·35 ounces of water at 60 degrees Fahrenheit, placed in a vessel wrapped round with some non-conductor so that no heat can be abstracted by the atmosphere, the whole will be raised to the boiling point, 212 degrees. Now, let this body o water be poured into a shallow pan, also protected from atmospheric chills, a cloud of steam will rise from it, and when it has reached the temperature of 60 degrees, it will have its original weight of 6·35 ounces. This experiment, published by Mr. Williams, has been repeatedly verified by the author of the present work; but let us see to what conclusion it points. According to the old doctrine, the one ounce of steam would be said to be *condensed;* but, if actually converted into water, why should it again resume the form of steam without any external agency being brought to bear upon it? It seems far more in accordance with common sense to regard the steam as *dissolved* in the water, and held there by the attraction of the water, aided by the pressure due to its depth; the steam escaping when by pouring the water so as to form a thin layer its pressure is reduced to a minimum. From this view it would appear that heat is incapable of being transmitted from one aqueous molecule to another, although it will freely pass between molecules of steam and certain solid bodies; for instance, if warm water (so called) be added to cold, the steam in the former will diffuse itself through the whole mass, which takes a mean temperature (being as it were a weaker solution of steam); but, if the two waters are separated by a metal plate, the steam on one side partly condenses, giving its heat to the metal, whence it generates steam in the water on the other side of the metallic plate.

We will now take some examples to give some idea of the amount of economy attained by carrying out the principle of expansion as far as can conveniently be done. The economy will be measured by the quantity of work done by the steam generated from a cubic foot of water, as under all pressures the same amount of coal will practically evaporate the same quantity of water.

In both cases let the steam be generated at a pressure of 50 lbs. per square inch, that will be equal to 7,200 lbs. per square foot—supposed to act upon a piston of which the area is one square foot. In the first case let the steam act with its full pressure for half the stroke, which half will be completed when one cubic foot of water is converted into steam (the pressure is absolute, not *above* the atmosphere), the distance will be 552 feet, because one cubic foot of water will supply 552 cubic feet of steam at 50 lbs. per square inch, hence the work done during this part of the stroke will be

$$= 552 \times 7200 = 3,974,400 \text{ ft. lbs.}$$

during the other half it will be expanded to a volume of 1,104 cubic feet, corresponding to 26 lbs. pressure per square inch; for the present purpose we may take the mean pressure during the second half of the stroke at 38 lbs. per square inch, or 5,472 lbs. per square foot; this is exerted through 552 feet, doing work

$$= 552 \times 5472 = 3,020,544 \text{ ft. lbs.}$$

the total work done being

$$= 3,974,400 + 3,020,544 = 6,994,944 \text{ ft. lbs.}$$

If, however, after the steam was all generated at 50 lbs. per square inch it were to be expanded to three times its bulk, much more work would be done by it. Its final volume would then be 1,656, corresponding to a pressure of 14 lbs. per square inch, and to a mean pressure for the last two-thirds of the stroke of 32 lbs. per square inch, or 4,608 lbs. per square foot, which would be exerted through a distance of 1,104 feet, doing work

$$= 1604 \times 4608 = 5,087,232$$

making the whole work during the stroke

$$= 3,974,400 + 5,087,232 = 9,061,632 \text{ ft. lbs.}$$

or more than half as much work again without any extra consumption of fuel.

It may be interesting to show the theoretical duty which might be attained by cutting off at one-tenth of the stroke. Assume the coal to be of such quality that one pound will evaporate 7·5 lbs. of water, the steam acting against a vacuum, *i.e.*, in a condensing engine and with an initial *absolute* pressure of 60 lbs. per inch,

The work done by one cubic foot will be, before expansion,

$$= 467 \times 64 \times 144 = 4{,}034{,}880 \text{ ft. lbs.}$$

during expansion

$$= 4203 \times 32{\cdot}3 \times 144 = 19{,}549{,}008 \text{ ft. lbs.}$$

the whole work done being

$$= 4{,}034{,}880 + 19{,}549{,}008 = 23{,}583{,}888 \text{ ft. lbs.}$$

But if 1 lb. of coal evaporates 7·5 lbs. of water it will require, to evaporate one cubic foot (62·5 lbs.) of water, 8·33 lbs. of coal; hence the duty done by 112 lbs. of coal would theoretically be

$$= 317{,}094{,}244 \text{ ft. lbs.}$$

however, the highest *nett* duty yet recorded is

$$= 109{,}000{,}000 \text{ ft. lbs.}$$

It is true that considerably higher duties (146 millions) have been reported from Cornwall, but examination showed that sufficient allowance was not made for loss of water in the pumps through the inefficiency of the valves. This statement is made on the authority of the late Thomas Wicksteed, Esq., M.I.C.E., through whose means principally the Cornish engine was first introduced into London.

Some years back a marine-engine in which the expansion was carried to twelve times, the consumption reported on the trial trip was only 1·08 lbs. coal per horse-power per hour, corresponding to a duty

$$= 205{,}333{,}333 \text{ ft. lbs.}$$

but statements based upon the results of short trials must always be received with caution, as many circumstances may occur, some accidental, to render the duty much higher on short trials than in ordinary working.

On the other hand, there may be urged against extreme degrees of expansion the larger size of engine required for a given power; but where the work is such as mine-pumping this is not of so much consequence; and besides this the difficulty may, to a great degree, be obviated by using steam of a very high initial pressure. Engines largely using expansion require heavier fly-wheels than others, as, from the great difference in the initial and final pressures, the propelling force of the piston varies in a greater degree than in those engines in which but a low degree of expansion is used.

Much was at one time expected from the employment of heated air, instead of steam, as a propelling power, but the hopes entertained of it were doomed to speedy disappointment. It is true that some air-engines of small power are at work in the United States of America and elsewhere, but there seems to be no present likelihood of their employment becoming at all general; some of the best we have seen owe their economy of working, not to the principles of the engine, but to the fact that the fuel has been consumed *under pressure*, a method which secures a great saving of fuel, as was abundantly proved some years back in the trials of the apparatus patented by Messrs. Moor and Shillitoe, by which something like 46 per cent. of fuel was saved.

One great objection to hot-air engines is the high temperature required to be maintained in them, which rapidly injures the machinery, and renders the application of ordinary lubricants almost useless. In order to obtain a pressure of 15 lbs. per square inch above that of the atmosphere, it is necessary to raise the temperature of the air by 480 degrees, a temperature which, applied to steam, would give a pressure of 43 lbs. per square inch above the atmosphere. It must also be remembered that with air-engines no vacuum can be created to give the benefit of the ordinary atmospheric pressure, which in a very large class of steam-engines forms a very considerable item in the working pressure; thus we find marine-engines commonly working with a steam pressure of 20 lbs. per square inch above the atmosphere, and with a vacuum of 13 or 13·5 lbs. per square inch, making a total effective pressure of 33·5 lbs. per square inch.

Mr. J. Gill, of Palermo, proposed an engine in which air and steam mixed were to be used to propel the piston, and according to his preliminary experiments, as published a few years since, this system promised great results, but from some cause or other the project seems to have been allowed to drop.

When a steam-engine is required of any considerable power, the purchaser should remember that his greatest economy is not to be attained by keeping the first cost down to the lowest possible price, for with steam-engines as with other articles of merchandise, the terms cheapness and badness are interchangeable, and in all cases it will be the best policy to engage the services of a competent mechanical engineer to design the engine, as his professional fees and the extra cost for patterns and the engine, involved in special designs, will be more than returned by the saving in fuel effected. Of course where a firm of contractors make an engine, and guarantee its duty, the same end is gained, the extra charges being all included in the price of the engine.

As regards the strength of the different parts of steam-engines, that may be determined from the rules set forth in Chapter vii. on construction, as the formulæ there given apply to the steam-engine as well as to other descriptions of machinery; but in the present part of this work the proportions generally will be treated of, efficiency, not strength, at present occupying our attention.

One of James Watt's improvements in the steam-engine was the jacket or steam-casing round the cylinder; this being filled with steam, and in communication with the boiler, supplied, as it were, a reservoir of heat which would, by raising the temperature of the expanding steam in the cylinder, retard the condensation therein due to the loss of heat consequent on expansion; but in parting with heat thus to the steam within the cylinder a portion of that in the steam-jacket is condensed, hence it is very questionable if any economy of fuel ultimately results from the adoption of the steam-jacket. In all cases, however, the cylinder, whether jacketted or not, should be surrounded by "lagging," that is, by a layer of some material which is a very slow conductor of heat, in order to prevent loss by radiation.

The amount of work which is termed one-horse power is 33,000 ft.-lbs. per minute, and according to this standard the value of engines is estimated. The calculation of the power of a steam-engine is exceedingly simple. Let HP = the horse-power, V = speed of piston in feet per minute, p = pressure of steam (producing effect) on the piston per square inch, d = diameter of cylinder in inches—

$$HP = \frac{\cdot 785 \times d^2 \times p \times V}{33{,}000} = \frac{d^2 . p . V}{42{,}038}$$

omitting the decimals.

For engines having peculiar movements, such as the "disc-engine," and the "semi-cylinder engine," where it is not so easy to compute the velocity of the piston as in the common engine (in which $V =$ the length of stroke multiplied by the number of strokes per minute), the following rule will be found convenient:—

Let $c =$ cubic contents of steam-chamber in feet, $n =$ number of strokes per minute, $p =$ pressure of steam per square inch, then

$$HP = \frac{c \,.\, n \,.\, p}{229}$$

To determine the effective pressure in the cylinder of a non-condensing engine, we must subtract from the absolute mean pressure that of the atmosphere and the resistance offered by the steam exhausting out of the cylinder through the exhaust passages ; this last is called "back pressure," and varies widely according to the construction of the engine and the velocity of the piston; let it $= a$ lbs. per square inch, $A =$ absolute pressure of steam—

$$p = A - (a + 15)$$

For a condensing engine, let $u =$ the vacuum in pounds per square inch in the condenser, then

$$p = A - (15 - u)$$

The *nominal* horse-power of an engine is a term used chiefly in commerce in buying and selling engines, and is not to be taken as a criterion of the real power of the engine, which may work up to three, four, or even six times its nominal horse-power. Many manufacturers determine the nominal power of their engines simply by the area of the piston, allowing a certain number of square inches to each horse-power. In the old rule, for nominal horse-power for condensing engines, seven pounds per square inch is assumed as the effective pressure per square inch on the piston, thus making the formula for nominal horse-power

$$N\,HP = \frac{7\,d^2\,V}{42{,}038} = \frac{d^2\,V}{6006}$$

if we assume the velocity of the piston at 240 feet per minute, then this formula becomes

$$N\,HP = \frac{d^2 V \times 240}{6006} = \frac{d^2}{25} \text{ omitting decimals.}$$

Let us compare this with what is actually done in practice. Assume the pressure at the commencement of the stroke to be 20 lbs. per square inch, and the supply to be cut off at one-third of the stroke—this pressure being above the atmosphere, the absolute pressure will be 35 lbs. per square inch—which at the end of the stroke has expanded down to 10·5 lbs. per square inch. The mean absolute pressure on the piston per square inch will therefore be 26·8 lbs. Let the vacuum in the condenser be 13 lbs. per square inch, then the mean effective pressure will be

$$= A - (15 - u) = 26{\cdot}8 - (15 - 13) = 24{\cdot}8 \text{ lbs.}$$

hence the rule for horse-power will be

$$HP = \frac{24{\cdot}8\,.\times 240 \times d^2}{42{,}038} = \frac{d^2}{7{\cdot}63}$$

or more than three times the nominal power found by the foregoing rule. These proportions, being tolerably common, we may adopt as an approximate rule for the type of marine-engines served by square boilers—

$$HP = \frac{d^2}{8} = \text{working power.}$$

To determine accurately the power exerted by the steam in an engine, that is, the gross or *indicated* horse-power, an instrument called an indicator is fitted on to the cylinder to register the pressure at every part of the stroke of the piston. The indicator comprises a small cylinder fitted with a steam-tight piston, carrying on its rod a pencil; this piston is held in a certain position by a spiral spring. When in communication with the engine cylinder, the indicator piston rises and falls with the pressure in the cylinder, the spring being more or less compressed or extended, according to the variations of pressure and vacuum. The pencil rising and falling with the piston draws a figure upon a card or piece of paper, moved (by being attached to some part of the engine) backward and forward once in every revolution of the engine: the kind of figure drawn is shown at Fig. 29. *a b* is called the atmospheric line, being drawn by moving the paper when the indicator is not in communication with the cylinder. As soon as the engine is started, the indicator being fixed and open to the cylinder, the pencil starts up to *c;* but when the pressure has overcome the friction of rest and the engine begins to move a little, the pressure falls slightly, then remains uniform, or nearly so, till the steam is cut off at *d*, and expansion continues to the end of the stroke at *b;* then the exhaust opening, the pencil descends below the atmosphere line to *e*, showing vacuum, and remains steady to *f*, where the valve begins to close the exhaust, when the pencil gradually rises to the starting point *a*. To ascertain the mean pressure from an indicator card the following method must be pursued:—Divide the

Fig. 29.

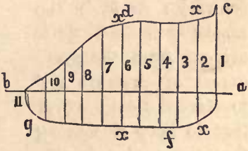


figure into any number of equal parts, say 10, as shown by the lines $x\ x$, &c., then mean absolute pressure

$$= \frac{2\,(2 + 3 + 4 + 9 + 10 + 1 + 11)}{20}$$

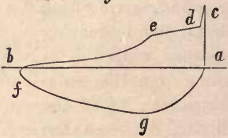
or if it be divided into n parts, the formula

$$= \frac{2\,(2 + 3 + n) + 1 + (n + 1)}{2\,n}$$

The value of the lines 1, 2, &c., are found from a scale of pressures corresponding to the tension of the spring in the indicator.

The indicator diagram forms a key to the construction of the apparatus for regulating the admission and emission of steam through the cylinder ports. That shown above shows a well-constructed engine; but that shown below, in Fig. 30, is illustrative of the contrary: $a\ b$ is the atmospheric line. It is evident from the great excess of pressure $c\ d$ to start the engine over that to keep it moving that the engine in this case works stiff; next, the pressure, instead of remaining steady to the point of cut-off e, falls, showing that the steam passages are too small and wire-draw the steam; thirdly, on the back stroke, instead of the vacuum being got at once it is not got till g is reached, showing too small an exhaust passage into the condenser.

Fig. 30.

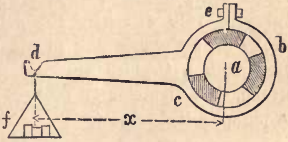


In such an engine as would give this diagram there is evidently a great loss of power due to the resistance of the steam passages and ports, or the defective vacuum may be partly due to insufficient injection water, or other defects in the condensing apparatus.

The horse-power found from the indicator diagram shows the gross amount of work done by the steam in the cylinder, but this is not all used in the work for which the engine is designed, a portion being absorbed in friction and in working feed and air pumps, &c.; hence other means must be adopted to show the actual amount of work *given off* by the engine to be expended usefully.

The apparatus used for this purpose is termed a friction dynamometer, and is of the general form shown in Fig. 31.

Fig. 31.



a is the main-shaft of the engine, *b c d* is the dynamometer, which is somewhat similar to a friction brake; between the adjustable belt *b c* and the shaft *a* are interposed blocks of wood to prevent any biting that would injure the main-shaft of the engine; these are tightened up by the screw-bolt *e* until the friction is sufficient to keep the arm *d* horizontal, the engine moving at a uniform rate (the shaft revolving within the belt *b c*) and the scale *f* being suitably loaded. Now, in sustaining this weight by friction on the shaft, the engine is virtually giving off as much work as if at every revolution the weight *W* on the scale *f* were moved through a distance equal to the circumference of a circle having *x* for a radius. Hence, to find the useful power of the engine, we have the following rule: *x* being in feet and *W* in pounds, *n* = number of revolutions per minute—

$$HP = \frac{3{\cdot}1416 \times 2x \times W \times n}{33,000} = \frac{x\,.\,W\,.\,n}{5252}$$

omitting decimals.

The useful effect of Cornish and other pumping engines is easily computed from the quantity of water raised in a given time. Thus let Q = gallons of water raised in twelve hours, h = the height in feet to which the water is pumped above the surface of the well, reservoir, or river from which the supply is taken, then (1 gallon of water weighs 10 lbs.)—

$$HP = \frac{Q \times h \times 10}{12 \times 60 \times 33{,}000} = \frac{Q\,h}{2{,}376{,}000}$$

If the valves of a pump (such as Harvey and West's double-beat) close exactly at the end of the stroke, the following rule will give the delivery in gallons per stroke for a single-acting pump, such as is commonly used with a Cornish engine. Let g = gallons per stroke, d = diameter of plunger in inches, S = stroke of pump in feet—

$$g = \frac{s \, . \, d^2}{29{\cdot}4}$$

For the power to work a pump:—Let g = gallons per stroke, h = height of lift in feet, n = number of strokes per minute, HP = horse-power (exclusive of friction) absorbed by pump—

$$HP = \frac{g \, . \, h \, . \, n}{3300}$$

To determine the useful effect—that is, the tractive force of a locomotive engine—a spring dynamometer is introduced as a coupling between it and the train, which registers the traction on a paper moved by clockwork if the horse-power is required. By means of a similar dynamometer, the dragging power of steam-tugs may be ascertained.

In former times it used to be the practice to allow one-third of the total power of an engine as absorbed in its own friction; but if it be well designed, and of good workmanship, there is no necessity for the friction of its parts to absorb more than from 6 to 8 per cent. of its total power

In discussing the points connected with the apparatus for regulating the admission and egress of the steam to and from the cylinder, let it be particularly understood that we do not pretend to give examples of the different forms of valves, &c., used for that purpose at length, but rather to explain the principles which should guide the designer in his endeavours to produce an efficient machine; those who desire to study the *different forms* of valves are referred to the author's PRACTICAL TREATISE ON MECHANICAL ENGINEERING.

The steam which is left in the steam passages at the end of each stroke is evidently so much waste, hence the passages between the valves and the cylinders should be made as short as possible in order to reduce this waste; also the room allowed above and below the piston to prevent its coming in contact with the cylinder covers should be small: this is called clearance, and in our opinion a quarter of an inch is sufficient clearance for ordinary engines.

The area of the ports and steam passages must be determined according to the velocity at which the piston is intended to travel and the difference between the pressures in the boiler and the steam cylinder, this difference representing the pressure by which the steam is caused to flow through the passages and ports from the boiler into the cylinder.

Let D = diameter of cylinder in inches, S = speed of piston in feet per minute, p = absolute pressure per square inch in cylinder, P = absolute pressure per square inch in boiler, a = area of port in square inches.

Then, according to the laws which regulate the flow of gases, the minimum area of the steam-ports will be—

$$a = \frac{D^2}{15,000} \times S \,.\, \sqrt{\frac{p}{P - p}}$$

If we assume the difference between the pressures in the cylinder and boiler (P—p) to be always equal to four pounds per square inch, the formula will become—

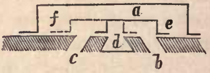
$$a = \frac{D^2}{30,000} \times S \sqrt{p}$$

For example, let the diameter be 10 inches, the speed of piston in feet per minute 250, and the pressure 40 lbs. per square inch—

$$a = \frac{100}{30,000} \times 250 \sqrt{40} = 5{\cdot}26 \text{ square inches.}$$

the exhaust-port is commonly made not less than twice the area of the steam-ports.

Fig. 32.



In Fig. 32 *a* is an ordinary short slide-valve acting on the ports communicating with the ends of the cylinder through the passages *b* and *c*, *d* is the exhaust passage. The edges of the valves must be at least ⅛th of an inch wider than the steam-ports to ensure the closing of one port before the other is opened. The full and dotted lines show the two extreme positions of the valve. In the former the steam is passing from the slide-jacket *f* into the end *c* of the cylinder, whilst it is exhausting from the end *b* through *d*. If the edges are made as above stated, as soon as one port begins to open to the exhaust the other opens to the steam, and they close together in the same way.

In order to ensure that the engine shall move in a specified direction, it is necessary that the valve shall be somewhat ahead of the piston, so that when the piston arrives at the top of the cylinder the top port shall be partly open, so that the piston gets steam early in the stroke. The reason that this arrangement controls the direction of the engine's revolution is as follows:—Let the piston be on the up-stroke, then, on reaching the top of the cylinder, the steam-port will be (say) half-way open, and if the engine continues in the right direction the valve will continue to open till the middle of the down-stroke, but if the piston on the down-stroke pulls the crank back on the wrong side of the centre, the valve which was half open will close again and open the bottom port. This advance which is given to the valve is called its "lead." The number of degrees which the eccentric driving the valve should be put in advance of the crank is called the "angular lead," and, with the aid of a table of natural cosines, may be found from the following formula:—Let a° = the angular lead, d = distance in inches over which the valve has passed when the piston is at the end of its stroke, t = travel (or stroke) of valve in inches, then

$$\text{Cos}\, a^\circ = 1 - \frac{2\,d}{t}$$

$$a^\circ = \text{Cos}^{-1}\left\{1 - \frac{2\,d}{t}\right\}$$

As an example, let the travel of a valve be 3 inches, and $d = 2$ inches, then

$$\text{Cos}\, a^\circ = 1 - \frac{2\,d}{t} = -\ 0{\cdot}33$$

hence, from a table of natural cosines,

$$a^\circ = -\ 70 \text{ degrees, } 30 \text{ minutes.}$$

The effect of the angular position of the eccentric rod driving the valve is too slight to require any practical notice.

Sometimes the edges of the slide-valve are extended outwards, the effect of which is to give a cut-off at a certain definite portion of the stroke; but of course, when the engine is once made, this cut-off and the corresponding degree of expansion cannot be altered: this is called giving the valve "lap." If, however, the expansion frequently requires altering, a separate valve, which controls the supply of the steam entering the slide-valve jacket, is used, working independently of the slide-valve; by this means, or by using a link motion with the slide-valve, the degree of expansion may be varied at pleasure.

The exhaust is usually closed some short space before the piston reaches the end of the stroke, thus confining a portion of vapour which acts as a "cushion," and obviates part of the jarring consequent upon the sudden reversal of the motion of the reciprocal parts of the machine. Nothing is lost by this, as, although some work is done in compressing the "cushion" of vapour, yet in the return stroke this is given up again.

The various parts of a steam-engine when moving have of necessity a certain amount of work accumulated in them, which must be absorbed at the end of each stroke from such parts as change the direction of their motion, and this work must be expended in friction, concussion, and compressing the cushion of steam; hence it is advisable to avoid high velocities in reciprocating parts. Heavy cranks also produce vibration, as on one side of the centre they aid, but on the other hinder, the revolution of the main-shaft; these, therefore, work smoother where counterbalanced, or they may, in some cases, be replaced by crank wheels, which are discs carrying crank pins near the periphery.

There are many causes which interfere with uniformity in the motion of the steam-engine, such as sudden variations in the work to be done, by the throwing into or out of gear any machine in a factory or workshop; but we will first deal with the irregularities which arise in the engine itself; these are due to the varying angle of the crank, and also to the varying pressure of steam in the cylinder due to expansion. These latter imperfections are met, and to a great extent remedied, by the use of a heavy fly-wheel, which serves as a reservoir of force, absorbing work, and storing it as accumulated work, when the engine is imparting the maximum power to the main-shaft, and again yielding it up when the engine is exerting little or no power, as is the case at and near the dead points, and thus by giving and taking, according to whether there is a deficiency or excess of power, something approaching to a mean velocity is attained.

It is not, however, only the fly-wheel that serves thus to regulate the speed of the engine, for the momentum of the whole mass of shafting and running gear also assists; hence, when an engine is working a factory, we cannot calculate the fly-wheel as absorbing all the excess of power and storing it until it is wanted. If we suppose a six-horse high-pressure engine to be running alone and merely overcoming its own friction, having a 4-foot fly-wheel moving at 30 revolutions per minute, the accumulated work would be in the rim of the fly-wheel weighing 600 lbs.—

$$= \frac{600 \times v^2}{64 \cdot 4}$$

but the velocity per second is

$$v = \frac{30 \times 4 \times 3 \cdot 1416}{60} = 6 \cdot 2832$$

therefore the accumulated work

$$= \frac{600 \times 39{\cdot}47}{64{\cdot}4} = 367{\cdot}73 \text{ ft.-lbs.}$$

The work required to overcome the friction of the engine being taken at 5 per cent. of its full power, that done in each revolution would be about 330 ft.-lbs.; hence the excess of work to be taken up and stored would be probably about 45 ft.-lbs.; hence the total accumulated work when this is taken up would be

$$367{\cdot}73 + 45 = 412{\cdot}73 \text{ ft.-lbs.}$$

from which we find,

$$\frac{600 \times v^2}{64{\cdot}4} = 412{\cdot}73$$

$$v = \sqrt{\frac{412{\cdot}73 \times 64{\cdot}4}{600}} = \sqrt{44{\cdot}29} = 6{\cdot}655$$

but the mean velocity is 6·2832 feet per second, hence the variation in velocity is

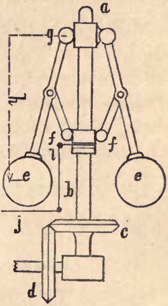
$$6{\cdot}655 - 6{\cdot}2832 = 0{\cdot}3718$$

which is equal to

$$\frac{0{\cdot}3718 \times 100}{6{\cdot}2832} = 5{\cdot}91 \text{ per cent. of mean velocity.}$$

When the variations of power are considerable, as from the varying amount of work to be done or number of machines to be driven, an apparatus called a governor is attached to the engine. A great number of different descriptions of governors have been invented, but that most generally in use is the conical pendulum applied by James Watt, which is shown in Fig. 33. *a b* is a vertical shaft driven by bevil gearing *c*, *d*, or other suitable means, so as to revolve at a rate proportioned to the speed of the engine; at the top of the shaft are two joints, *g*, *g*, carrying the arms *g*, *e*, having heavy balls *e*, *e*, at their lower extremities; there is also on *a b* a sliding collar connected by links *f*, *f*, with the arms *g*, *e*. The quicker the engine goes the faster will this governor revolve, and the centrifugal force will cause the arms to fly outwards about the centres *g*, *g*, thereby raising the sliding collar, which lifts the end of a forked lever moving on a centre at *i* and through a link *j*, controlling the steam supply either by partially closing a valve in the steam-pipe from the boiler, or by causing the flow of steam into the cylinder to be cut off at an earlier period than when there was more work upon the engine. To determine the height of the points *g*, *g*, above the plane of revolution of the balls is sufficiently simple: it is equal to the length of a pendulum which would make two beats while the governor makes one revolution. Let h = height in inches, n = number of revolutions per minute, then

Fig. 33.



$$h = \left\{ \frac{187{\cdot}7}{n} \right\}^2, \text{ and } n = \frac{187{\cdot}7}{\sqrt{h}}$$

Engines are almost always fitted with feed-pumps for supplying water to the boiler from which to generate steam to work the engine, and, as a matter of precaution, these pumps are made large enough to supply at least twice the minimum quantity of water required for use in the form of steam. From the relations of pressure and comparative volumes already referred to, the following rule for the size of a feed-pump is deduced:—

Let p = pressure of steam in pounds per square inch above the atmosphere,
s = stroke of piston in feet,
D = diameter of steam cylinder in inches,
c = contents of feed-pump in cubic inches, then

$$c = \frac{s \,.\, D^2}{40} \left\{ \frac{p}{15} + 1 \right\}$$

According to the quantity of steam used must the water for condensation also be regulated; the temperature at which the water is desired to leave the condenser being determined, the quantity of injection water required will be found from the following formula:—

C = cubic feet of condensation water required per cubic foot of water used as steam in the engine, t' = temperature of water entering the condenser, t = temperature of water leaving the condenser, then

$$C = \frac{1212 - t}{t - t'}$$

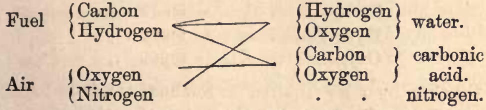
Having made these practical observations on the designing of steam-engines, we shall now conclude this chapter by stating that examples of different kinds of engines and their details may be found in the work on "Mechanical Engineering" already alluded to.

CHAPTER IX.

BOILERS AND FURNACES.

In arranging the proportions of boilers and furnaces an amount of care and experience equal to that exercised in preparing the plans of the engine is demanded, for a well-designed engine will not work economically if the boiler be badly constructed, without due regard being had to the principles which regulate combustion and the transmission of heat.

The heat obtained from combustion is due to the oxidation of the carbon and hydrogen of the fuel used, which oxidation consists in the decomposition of those elements from each other and their recombination with oxygen gas from the atmosphere or from some other source. Thus the carbon becomes converted into carbonic acid, and the hydrogen into steam; the chemical change is shown in the following diagram:—



In this case the fuel is supposed, for simplicity, to consist of hydrogen and carbon only; in fact, to be a pure hydro-carbon.

The heating value of fuel may be given in pounds of water evaporated per pounds of fuel used, or units of heat, one unit of heat being that quantity which is required to raise the temperature of one pound of water one degree Fahrenheit. The theoretical calorific value of fuel may be determined from the following formula, in which the constants are, of course, obtained from experiment.

Let $C =$ weight of carbon in one pound of fuel, $H =$ ditto of hydrogen, $O =$ ditto of oxygen, and $L =$ pounds of water evaporated from 212 degrees by one pound of fuel:—

$$P = 15 \left\{ C \times 4{\cdot}28 \left(H - \frac{0}{8} \right) \right\}$$

Practically, however, it may be taken that one pound of good average coal will evaporate about 7·5 lbs. of water from a temperature of 212 degrees, and this is a more reliable datum than that calculated from the chemical analysis.

We have now to consider the quantity of air required for combustion, and the mode of bringing it into contact with the fuel. According to the doctrine of chemical equivalents, every pound of carbon in being converted into carbonic acid will require 2·66 lbs. of oxygen, and every pound of hydrogen will require 8 lbs. of oxygen. Assuming a fuel to be of the following composition:—

Carbon . .	0·855 lbs.
Hydrogen . .	0·053 ,,
Oxygen . .	0·092 ,,

the quantity of air required for combustion will be found as follows: for the carbon the oxygen required—

$$0{\cdot}855 \times 2{\cdot}66 = 2{\cdot}274 \text{ lbs.}$$

and the quantity for the hydrogen—

$$0{\cdot}053 \times 8 = 0{\cdot}424 \text{ lbs.}$$

but in the composition of the fuel there is 0·092 oxygen; hence this must be deducted from the total quantity required, which will then be

$$2{\cdot}274 + 0{\cdot}424 - 0{\cdot}092 = 2{\cdot}606 \text{ lbs. oxygen;}$$

but oxygen exists in the atmosphere to the amount of

20 per cent. of the whole mass of air, hence the quantity of air required per pound of fuel will be

$$2{\cdot}606 \times 5 = 13{\cdot}03 \text{ lbs.}$$

and as air is 773 times lighter than water, the volume of air required will be

$13{\cdot}03 \times 12{\cdot}37 = 49{\cdot}85$ cubic feet of air per lb. of fuel;

this would be required for actual combustion; but, in reality, a much greater quantity of air would require to be passed in when ordinary furnaces are used, as nothing near the whole quantity of oxygen is taken from the atmospheric air passing through the fuel.

It may be assumed that the quantity of air required on the average will be 150 cubic feet per pound of coal consumed, and this, after combining with the gaseous and solid portions of the fuel, will produce about 164 cubic feet of heated air and gases. The heat of a furnace in a boiler may be taken as 1,000 degrees, and this will expand the air and gases to about three times their previous bulk, making the above

$$= 164 \times 3 = 492 \text{ cubic feet,}$$

the velocity of which, according to Dr. Ure, would be 36 feet per second, requiring a minimum area of flue of 0·516 inch per pound of coal consumed per hour. In practice, however, about 2 inches is the allowance in the narrowest part of the flue, and 1·5 inches at the top of the chimney per pound of coal per hour.

If a high-pressure engine requires the consumption of 6 lbs. of coal per horse-power per hour, and is 10-horse power, the total consumption per hour will be

$$6 \times 10 = 60 \text{ lbs. coal;}$$

hence the least area of flue (that over the fire-bridge at the back of the furnace) will be

$$60 \times 2 = 120 \text{ square inches;}$$

ditto area at the top of the chimney,

$$60 \times 1{\cdot}5 = 90 \text{ square inches.}$$

To ascertain the quantity of hot air which will be evolved at any special temperature per hour, the following formula will serve :—Let Q = lbs. of coal consumed per hour, n = volume of cold air required in cubic feet per lb. of coal, V = volume of heated gases per hour, t = temperature in chimney—

$$V = Q \, . \, n \, . \, (1 + 0{\cdot}00365 \, t)$$

or, taking n as generally equal to 150—

$$V = Q \left\{ 1 + 0{\cdot}5475 \, t \right\}$$

The comparative evaporative values of different kinds of fuel may be found from the following table, which has been compiled from the most reliable experiments; it shows the quantity of water in each case evaporated from a temperature of 212 degrees by the combustion of 1 lb. of the fuel under experiment :—

Name of Fuel.	Water evaporated.
Oak seasoned	4·95
,, dried	5·53
Nut-wood	5·41
White-pine	5·41
Yellow-pine	5·74
Coal, Welsh	12·24
,, Newcastle	12·20
,, Wigan	10·15
,, Belgium	11·36
,, Durham	12·49

Name of Fuel.	Water evaporated.
Coke, good	10·24
„ common	7·62
Anthracite, French	11·36
„ Pennsylvania	9·88
Peat	4·09

Such high results as these, however, are not obtained in the actual working of steam-boilers in practice, because the circumstances under which the combustion takes place necessarily are different from those attending on an experiment.

There is a very noticeable difference between the evaporative values of wood and coal; it may, therefore, be interesting to ascertain whether this may be accounted for by the difference in chemical composition. As is well known, coal is a species of fossilized wood, the most striking difference being in the loss of hydrogen and oxygen wood sustains in the transition from the ligneous to the carbonaceous state; these two analyses indicate the difference in composition:—

Constituents.	Wood.	Coal.
Carbon	49·1	82·6
Hydrogen	6·3	5·6
Oxygen	44·6	11·8
	100·0	100·0

In the wood all the hydrogen is combined with oxygen, or nearly so, or, otherwise, with carbon in such manner that its liberation requires as much heat as its subsequent oxidation will yield; hence the theoretical evaporative values would be per pound of fuel:—

Wood $= 0·491 \times 15 = 7·36$ lbs. water.

$$\text{Coal} = 15\ \{82{\cdot}6 + 4{\cdot}28\,(5{\cdot}6 - 11{\cdot}8)\} = 15 \text{ lbs. water,}$$

the ratio being

$$\frac{15}{7{\cdot}36} = 2{\cdot}038$$

Taking the averages of wood and coal from the experiments as recorded in the above table, the ratio is

$$\frac{11{\cdot}323}{5{\cdot}408} = 2{\cdot}104$$

which does not differ widely from that found theoretically.

From a comparison of practical with theoretical values, a factor may be found to correct the latter so as to more nearly approximate to the former, thus :—

$$\frac{\text{Theoretical number - - } 15}{\text{Experimental number - } 11{\cdot}383} = 1{\cdot}317 \text{ divisor.}$$

It is now necessary to consider the relations of the dimensions of boilers to the proposed power. In the first place, the proportion of heating surface to grate surface and fuel consumed may be determined. This is a subject which has been very fully investigated by Mr. D. K. Clarke, with the following results. To secure equal evaporative efficiency :—

1. If the grate surface is constant, the quantity of fuel consumed per hour should vary as the square of the heating surface.

2. If the heating surface is constant, the quantity of fuel should vary inversely as the grate surface.

3. If the consumption of fuel is constant, the quantity of fuel should vary as the square of the heating surface.

If *C* represent a constant depending on the type of boiler used, then these three laws will be embodied in the formula :—

$$Q = C \cdot \frac{h^2}{a}$$

Where Q = pounds of fuel per hour, h = area of heating surface, and a = grate surface, a Cornish boiler will burn from 6 to 10 lbs. of fuel per square foot of grate surface per hour ; hence, taking the average duty of Cornish engines at 80,000,000 ft.-lbs. per 112 lbs. of coal, the rule for grate surface will be as follows :— Let the average consumption of coal be 8 lbs. per square foot of grate per hour, HP = horse-power, G = area of grate in square feet—

$$G = \frac{HP}{3} \text{ nearly—}$$

the heating surface required for the proper absorption of caloric would be, if S = heating surface in square feet, all taken as horizontal—

$$S = 8{\cdot}5 \times HP$$

Vertical heating surface has only half the efficiency of horizontal ; hence, all vertical surface taken from the area found by this rule must be doubled ; comparing the two formulæ, the ratio of heating surface to grate surface in the Cornish boiler is found to be—

$$\frac{S}{G} = 8{\cdot}5 \times 3 = 25{\cdot}5$$

or it will be accurate enough for practice to make the heating surface 26 times the area of the grate surface The value of C for Cornish boilers will be—

$$C = \frac{Q \times a}{h^2} = \frac{3 \times 1}{676} = 0{\cdot}0118.$$

An ordinary factory boiler will burn about 15 lbs. of coal per square foot per hour; hence, if the engine is working with a consumption of about 5 lbs. of coal per horse-power per hour, the grate surface will be in the same proportion as above, and also the heating surface; but, if an engine (condensing, for instance) be working at a consumption of 3 lbs. of coal—

$$G = \frac{HP}{5}$$

and

$$S = 8{\cdot}5 \times HP$$

$$\frac{S}{G} = 8{\cdot}5 \times 5 = 42{\cdot}5 \text{ (say 43)}$$

hence the value of C for such boilers will be—

$$C = \frac{Q \times a}{h^2} = \frac{15 \times 1}{1849} = 0{\cdot}0081.$$

In locomotive furnaces the greatest quantity of fuel is consumed per square foot of grate surface per hour, varying, in fact, from 40 lbs. to upwards of 100 lbs.; but this is, of course, due to the strong draught created by the blast. The range being so wide, it would be useless to give a special formula for grate surface, but the following general rule may be found useful:—Let F = equal consumption per square foot per hour, f = consumption per horse-power per hour—

$$G = \frac{HP \times f}{F}$$

With some high-pressure engines the consumption of fuel per horse-power per hour is very heavy, amounting to 9, 10, or 12 lbs. of coal, and this would give a ratio of grate surface to heating surface as 1 to 11; but past experience indicates that a mean between this and the ratio for a Cornish boiler will give most satisfactory results as regards evaporative efficiency; the mean ratio will be

$$\frac{26 + 11}{2} = 18 \cdot 5$$

As to the proper capacity for steam-boilers per horse-power, there has been much conflict of opinion. Mr. Fairbairn, after many years' experience, fixed upon 15 to 20 cubic feet as the proper allowance, after deducting the space taken up by the flues; but the late Mr. Armstrong always maintained that 27 cubic feet per horse-power should be allowed, one-half of this space being for water, and the other half for steam.

No rule, however, can be laid down in regard to the capacity of boilers which shall apply generally to all types, for much depends upon the construction of the boiler, the arrangement of the steam dome or chest, and other incidental matters too numerous to mention. The object in having plenty of steam space is to prevent great fluctuation from occurring in the boiler pressure every time steam is taken into the cylinder; and also the steam, if drawn off close to the surface of the water, would be loaded with aqueous particles, which, being deposited as water at the bottom of the cylinder, cause much inconvenience, and even, in some cases, accident. This passing of water over into the cylinder along with the steam is called priming. When super-heating arrangements are applied, this suspended water is converted into steam, and the steam is then called dry; in this state it is much less liable to condense in the cylinder, but it has the disadvantage, if highly super-heated, of drying and rendering inefficient the packings of the engine.

The super-heating of steam does not largely increase its pressure, as so soon as all the suspended aqueous particles are converted into steam, and it becomes dry, it follows the law of permanent gases, and its expansion is slow.

A very quick draught is not economical, as the quicker the draught the greater the quantity of heated air passing off, and the less time is allowed for the fuel to abstract the oxygen from the atmospheric air; hence, any means which will so far cool the gases in the chimney, after they have passed over all the heating surface of the boiler, as to check the excessive velocity of the current, and at the same time apply the heat abstracted to some useful purpose, will effect some considerable economy in fuel.

The waste gases from boiler furnaces commonly escape at a temperature of from 400 to 600 degrees; but a considerable portion of this heat may be utilized, for, by causing the products of combustion to pass through tubes surrounded with the water intended to be supplied to the boiler, they will yield up as much as 225 degrees of heat to such feed-water. A fair allowance of feed-water-heating surface is 10 square feet per horse-power.

A little reflection will show that it is easy to abstract heat from the escaping gases by the feed-water when none will any longer be yielded up to the water in the boiler. The transmission of heat from one body to another varies in rapidity as the difference of the temperature of the two bodies; hence the water in the boiler takes up the heat quickest at the furnace end of the flue, after which, the rate of transmission gradually decreases as the temperature of the heat, air, and gases more nearly approaches that of the water and steam in the boiler, until, if the process is continued long enough, the difference will not be sufficient to cause the heat to pass through the metal by which the water is separated from the heated gases in the flues.

If steam is being generated in a boiler at a pressure of 60 lbs. per square inch, the corresponding temperature of the water and steam will be 293 degrees; hence, if the temperature in the furnace is 1,000 degrees, and that at the end of the flues 400 degrees, the differences of temperature will be for each place respectively,

$$1000 - 293 = 707 \text{ degrees}$$
$$400 - 293 = 107 \quad ,,$$

the ratio of the two differences being

$$\frac{707}{107} = 6{\cdot}6$$

hence the rate of transmission of heat at the commencement of the flues is nearly seven times that at the end of the same; or, in other words, one foot of heating surface at the furnace end is equivalent in evaporative power to seven feet at the chimney end of the flues. The thickness of the metal of which the boiler is made also affects the passage of caloric, hence the parts which are heating surfaces should not be made unnecessarily thick. To return to the question of abstracting heat by the feed-water from the gases leaving the boiler flues, we find the difference of temperatures, if the feed-water be at 60 degrees, to be

$$400 - 60 = 340 \text{ degrees}$$

hence the feed-water surface will commence absorbing heat half as fast as the most efficient portion of the heating surface of the boiler, and this abstraction may be continued until the water is heated up to 200 degrees, or in some cases more.

The rapidity of the conduction of heat also varies according to the metal through which it has to pass; thus the relative conducting powers of copper, brass, and iron are as under:—

Wrought-copper	100·0
Wrought-brass	96·6
Sheet-iron	41·5

While treating of furnaces, the subject of smoke consumption may properly be dealt with. To consume coal-smoke has been, and often is, said to be a matter of ease, only requiring care to effect the object sought; yet it is remarkable that generally the smoke is *not* consumed, although it is manifestly to the advantage of the users of steam-power to utilise it as much as possible, for smoke, properly so called, consists of a great number of very minute and finely-divided particles of carbon, which are carried up by the ascending draught, only ultimately to fall again as soot or "blacks" as soon as they come into cold or damp air. This carbon of course has a certain calorific value, and would serve to assist in evaporating the water in the boiler. In order to ensure the combustion of the smoke and gases not previously oxidised, a sufficient supply of air must be furnished for their thorough oxidation, the fire-bridge being a very good place to supply it; but its temperature must not be so low as to cool down the unconsumed products of combustion to a temperature below that at which they will burn, otherwise the introduction of the extra quantity of air will be worse than useless, as its sole effect will consist in cooling the heated air and gases before they pass over the heating surface of the boiler, thus lessening the rapidity of the transmission of the heat, and in addition to this, increasing the bulk of waste air, which, leaving the chimney at a temperature higher or lower, according to circumstances, carries away a quantity of heat proportional to the volume of air escaping into the atmosphere.

It is very evident that, if the air could be kept in contact with the fuel until all its oxygen was taken up by the carbon and hydrogen of the same, a great increase of economy would ensue, as was shown by experiments with a plan patented by Moor and Shillitoe. According to Moor and Shillitoe's method of working, instead of there being a free outlet from the flues into the atmosphere, the combustion was carried on under pressure, and the results obtained from some experiments conducted at Manchester were in the highest degree satisfactory.

The up-take from a portable engine-boiler was closed by a valve lightly weighted, and the air required for combustion was forced into the fire-box; a very vivid combustion was thus produced, accompanied by a great saving of fuel. By using this mode of working, the air is held in contact with the fuel until the latter has absorbed nearly all its oxygen, hence a much smaller quantity of air is required than that consumed in an ordinary furnace, and the quantity of waste gases is correspondingly reduced; hence, also, the quantity of heat escaping through the chimney. If, instead of 150 cubic feet of air, 50 per lb. of fuel will suffice, the quantity of heat carried off by the waste gases will be greatly reduced. In combining with the gaseous and solid parts of the coal the products of combustion formed will be in amount about 64 cubic feet, whereas in the ordinary way of managing the furnace it would never be less than 164 cubic feet per lb. of coal, and very often amount to considerably more. Thus, by the use of the patent furnace, the loss of heat by waste gases is always reduced by about 60 per cent., and generally by a much larger per-centage. Also, the air being kept in contact with the fuel under pressure, the oxygen in contact with the fuel is a much larger quantity per cubic foot of air than when the draught is free, hence the combustion is far more rapid, and of necessity more vivid, than under ordinary circumstances, and being more vivid the furnace is heated to a higher temperature, which favours the absorption of heat by the water in the boiler. The combustion being more rapid, the grate surface may be reduced to about one quarter of that used with a free draught; and as the difference of temperature between the gases in the furnace and the water in the boiler is increased, the amount of heating surface may be proportionately reduced; in short, for a given amount of steam evaporated per hour, the whole proportions of the boiler may be very materially reduced, and a saving of upwards of 40 per cent. of coal will be effected and all the smoke consumed.

It may be interesting here to give some idea of the saving effected by letting into the furnace only sufficient air to maintain the combustion. In the ordinary case, 150 cubic feet of air are required per lb. of coal, of which 50 feet are sufficient to supply the oxygen actually required for combustion. Of this air there will be 100 cubic feet over and above that actually required, and the specific heat of air, according to the experiments of Delaroche and Bernard, is 0·267, that of water being 1·000. Supposing the gases and products of combustion to leave the chimney at a temperature of

400 degrees, the normal temperature of the air being 60 degrees, then the 100 cubic feet of air will have been heated

$$400 - 60 = 340 \text{ degrees.}$$

The weight of the air will be equal to about 8 lbs., hence the number of degrees of heat lost, which might otherwise have been transmitted to the water to be evaporated, would be sufficient to raise the temperature of one pound of water 213·6 degrees. There is good reason, however, to believe that practically a much larger quantity of air than that above mentioned passes through ordinary furnaces.

It may at first seem unaccountable that a system affording such beneficial results should not be generally adopted, but this is attributable to the fact that circumstances prevented the inventors from introducing their plan at the time when it was first brought before the public, and since that the patent has been allowed to lapse.

Although the principle of combustion under pressure has not been adopted in connection with the steam-engine, yet it is practically in use in some classes of hot-air engines—Messer's, for instance, in which the piston in the working cylinder is driven by the pressure of the products of combustion issuing from a closed furnace. The air requisite for combustion and to propel the machinery is forced into the furnace by an air-pump worked by the engine; after yielding sufficient oxygen to the fuel the spare air and the heated gases are passed through suitable valves into the working cylinder. Some years back, when we examined one of these engines, it was reported to be working very economically, a result which is immediately referable to the mode of working the furnace. In this case the coal was manifestly burned under a pressure somewhat in excess of that driving the engine. The conclusions then arrived at are that for the greatest economy of fuel there should be—

1. A slow draught current,
2. A rapid and vivid combustion,
3. A minimum quantity of waste gases at a minimum temperature;

and, by means of the above method of working, these conditions, impossible in the ordinary apparatus, may be easily satisfied. If this process be carried to perfection, the escaping gases would consist simply of nitrogen, carbonic acid, and probably a little sulphurous acid; and in the case of steam-ships, it might be discharged into the water. Thus, also, is a means afforded of raising steam of a very high pressure, as the increased temperature of the furnace will allow of the equally rapid transmission of heat to the water when steam is being generated under a higher pressure, and of course higher temperature.

During the last few years very strenuous efforts have been adopted to introduce liquid fuels into use in steam-boilers, and there has been much controversy upon the merits and demerits of such a system. Undoubtedly the evaporative value of such fuel, when properly applied, is high, and it is compact for stowage (as in sea-going vessels); but, on the other hand, in hot climates there is a danger to be apprehended from the accumulation in the tanks of quantities of inflammable gases which may by some accident become ignited, when, of course, all efforts at extinction would be futile, and that such inflammable vapours would be formed is certain; for instance, if a vessel were to start on a voyage with tanks full of hydro-carbon oils, although there would be no danger so long as the tanks remained full, but as soon as space was formed above the surface of the oil inflammable vapours would begin to accumulate, and more especially in tropical climates. We are informed, however, that under the directions of the Admiralty this subject is now being investigated, in order to determine some means by which this apprehended danger may be obviated.

Where tried liquid fuel has given very good results, both with stationary and marine boilers, the system which appears to give the best practical results being that invented by Mr. E. H. Aydon. By this process the liquid fuel is carried into the furnace by a jet of steam acting through an appliance similar to the Giffard Injector, now commonly used for supplying steam-boilers with water.

In considering the circumstances under which the combustion occurs, it is very desirable not to be misled as to the chemical re-actions which take place, as some people have thought that some decomposition of the super-heated steam associated with the dead oil takes place, which, if even it did occur, could not ultimately affect the results, as the decomposed steam would yet, by combustion, resume the condition of steam. In applying the "Aydon" system, steam is first got up in the boiler by a coal fire, after which a thin layer is kept merely to ensure the ignition of the oil spray scattered into the fire-box by the steam jet. In the early part of 1867 an experiment was tried at Lambeth on this system, applied to a Cornish boiler of the ordinary construction, of which the following is an account:—The oil was allowed to fall through a narrow orifice in a continuous stream (the worst kind of creosote refuse being used) about one-eighth of an inch in diameter, at a rate of about three gallons per hour. With this consumption the steam was maintained at a pressure of from 32 lbs. to 35 lbs. pressure per square inch. The amount of water evaporated was 10 cubic feet per 100 square feet of heating surface in the boiler. The cost of creosote refuse was from £1 10s. to £2 per ton; hence, taking the creosote used at 1d. per gallon, the cost of fuel burned per hour would be 3d., and the work done was equivalent to that which would be given by 56 lbs. of the best Aberdare coals at £1 2s. per ton, the value of which would be rather more than 6d. The evaporation of water, so far as it could be determined from the experiments, amounted to 19·5 lbs. of water per lb. of fuel consumed.

The composition of creosote is as follows: in 1lb. of creosote there is

Carbon	0·775 lbs.
Hydrogen . . .	0·080 ,,
Oxygen	0·145 ,,

hence the theoretical evaporative value of this creosote will be

$$= 15 \left\{ 0{\cdot}775 + 4{\cdot}28 \left({\cdot}08 - \frac{0{\cdot}145}{8} \right) \right\} = 15{\cdot}6 \text{ lbs.}$$

water per lb. of fuel.

This, however, is the general analysis of creosote; hence it must be concluded that the quality used in trying the "Aydon" method must have been superior to that of which the analysis is given, for, even if it were admitted that the super-heated steam which enters with the oil is decomposed, yet, for reasons given above, this action could not ultimately affect the amount of water evaporated.

The theoretical calorific value of petroleum may be found from the following analysis :—

Hydrogen .	12·5 = ·125	lbs. per lbs. of oil.
Carbon . .	87·5 = ·875	„ „

hence the evaporative value

$= 15 \{·875 + 4·28 \times ·125\} = 21·15$ lbs. water per lb. of oil.

The great economy of liquid fuel over coal is quite evident from the above statements; but it has been further shown that a steamer making a round from London to Rio Janeiro, Monte Video, and Buenos Ayres, out and home, would actually effect a saving of £1,230 out of £2,235 by burning oil instead of coal.

We will now pass from the furnace and fuel to the proportions of the various descriptions of boilers.

General rule for horse-power of boilers.—Let $HP =$ horse-power, $a =$ horizontal heating surface in square feet, $A =$ vertical heating surface in square feet, then

$$HP = \frac{a + \frac{A}{2}}{8·5}$$

or let $A = \frac{a}{n}$, then

$$HP = \frac{n . a + a}{8·5 . n}$$

if, for instance, $a = 100$ feet and $n = 4$, then

$$HP = \frac{4 \times 100 + 100}{8·5 \times 4} = 14·7 \text{ horse-power.}$$

TUBULAR BOILERS.—For tubes having half their surfaces exposed to the heat (as in the Cornish and

Manchester boilers), let $l =$ length in feet, $d =$ diameter in inches, then

$$HP = \frac{l\,d}{60}$$

for tubes having their entire surface exposed to the heat, it will be

$$HP = \frac{l \,.\, d}{30}$$

To find the proper thickness for the outer shell of the boiler to resist safely the internal pressure, the following formula will serve:—Let $t =$ the thickness in inches, $p =$ internal pressure in pounds per square inch above the atmosphere, $r =$ radius of tube in inches, 8,000 lbs. $=$ the safe working tension per square inch, allowing for wear for solid work, and 6,000 lbs. for rivetted work, then

$$\text{Solid work} \quad . \quad . \quad t = \frac{p \,.\, r}{8000}$$

$$\text{Rivetted work} \quad . \quad t = \frac{p \,.\, r}{6000}$$

The resistance of wrought-iron tubes to external or crushing pressure has been experimentally determined by Mr. Fairbairn, and the following formula, deduced from the experiments, will give the proper thickness of metal. Let $t =$ thickness of metal in inches, $l =$ length of the tube in feet, $d =$ diameter of tube in inches, or, if it be elliptical, the diameter corresponding to the flattest part of the tube, $p =$ the pressure in pounds per square inch on the exterior of the tube, above the atmosphere, then

$$t = \sqrt{\frac{p \,.\, l \,.\, d}{161{,}200}}$$

If the tubes be very long they may be virtually divided into shorter tubes by fixing in or round them stout angle-iron or tee-iron rings.

Let there be a tube 30 feet long divided into three parts by two rings, then the virtual length of the tube will be 10 feet; let the diameter be 24 inches, and the pressure of steam 30 lbs., then the thickness of the tube should be

$$t = \sqrt{\frac{30 \times 10 \times 24}{161200}} = 0{\cdot}21 \text{ inch}$$

In boilers having flat sides, such as the common square marine-boiler, and the water space outside the fire-box of a locomotive engine, it is necessary to use stays, in order to prevent the sides from being bulged out. In this case it is evident that the plates are under the influence of transferable pressure; hence the rule to determine the thickness of such plates is found from the general laws of the resistance of materials to that description of strain.

Let p = the pressure in pounds per square inch,
d = the greatest distance between stays in inches,
t = thickness of stayed plate in inches, then

$$t = 0{\cdot}008\, d \sqrt{p}$$

Let $d = 10$ inches, $p = 25$ lbs.,

$$t = 0{\cdot}008 \times 10 \sqrt{25} = 0{\cdot}4 \text{ inch.}$$

The stays supporting the plate are, of course, subject to tensile strain.

Let a = vertical distance between stays in inches, b = horizontal distance between stays in inches, p = pressure in pounds per square inch on the stayed surface, p = diameter of stays in inches, then

$$d = \frac{\sqrt{a\, b\, p}}{70}$$

Let $a = 10$, $b = 8$, $p = 25$, as in the last case, then

$$d = \frac{\sqrt{10 \times 8 \times 25}}{70} = 0{\cdot}64 \text{ inch.}$$

If the vertical and horizontal distances are equal, the formula will then become

$$d = \frac{a}{70} \sqrt{p}$$

The designs or types of boilers that have from time to time been brought forward are almost innumerable; hence but a few of the leading forms will be noticed here.

The old waggon-shaped boiler, fired underneath, has long been out of date, although a few of them may now be seen in some parts of the country utilized as tanks. These boilers were not intended to raise steam at higher pressure than 4 lbs. to 6 lbs. per square inch, the steam being then used only as a means of getting a vacuum, so that the effect of the atmospheric pressure upon the piston should propel the engine. The Cornish boilers are now very generally used for large engines where very high pressures are not required to be employed. These boilers consist simply of a cylindrical shell with flat ends, and a tube running from end to end through the boiler. The ends require to be stiffened by means of stays connecting them either with the shell of the boiler or with the tube. These boilers may have the furnace either placed inside the tube, or under the bottom of the boiler, in which case the tube is used as one of the return flues. Egg-ended boilers have a cylindrical shell, terminated at each end by a hemispherical dome: they have nothing particular to recommend them, and appear somewhat more liable to explosion than other classes of boilers.

Multitubular boilers are those which have in them a considerable number of small tubes through which the flame and heated air pass from the furnace. The object gained by this arrangement is that a large amount of heating surface is obtained with a comparatively small area of flue, for whilst the sectional area of the tubes decreases as the square of their diameter, the heating surface diminishes as the diameter only; hence, if the total area of the tubes be constant, the amount of heating surface will vary as the number of tubes used to make up such total.

In determining the number of tubes to be put into a boiler, it requires care to be taken to follow a middle course, for by putting in too many tubes they crowd each other so that the steam cannot get away quick enough from between them to allow the water to circulate round them as rapidly as is desirable, in which case the evaporative value of the boiler is deteriorated, and the tubes are liable to be very soon burnt out, because the water fails to take away from them the heat absorbed from the products of combustion with sufficient promptitude.

About the worst case of crowding the tubes which has come under our notice occurred in a French locomotive, in which the space between the tubes was little more than three-eighths of an inch; but we have known of cases in England where the evaporative efficiency of locomotive boilers which had been over filled with tubes was actually increased by plugging up some of the tubes.

Vertical tubes in multitubular boilers may, however, be put closer together than those which are fixed in a horizontal or inclined position, as they do not so much tend to retard the ascending and descending currents of water as the latter, as these currents rise and fall between the tubes instead of having to go round them.

Although almost all multitubular boilers use the tubes as flues or passages for the heated air and products of combustion, yet this is not the most advantageous mode of construction; it is better to have the water in the tubes and the fire outside them; but for a long time makers were deterred from adopting this arrangement on account of certain practical difficulties connected with the circulation of the water. The superior strength of boilers having water tubes highly recommends their use in cases where very great pressures are required, for as the strength of a boiler varies inversely as its diameter, the relative strength of two boilers of the diameters D and d, for the same thickness of metal, will be

$$\frac{D}{d}$$

but as the larger boilers must be made of separate plates rivetted together, this will practically become

$$\frac{1\cdot 5 \,.\, D}{d}$$

For actual strength let Craddock's boiler be considered; n this the water tubes are three inches in diameter, and the metal is about one-eighth of an inch thick. From one of the formulæ for thickness we have for solid work

$$t = \frac{p \,.\, r}{8000}$$

$$\therefore p = \frac{8000\, t}{r}$$

hence, in this case, the safe pressure per square inch on the tubes will be

$$p = \frac{8000 \times 0\cdot 125}{1\cdot 5} = 666\cdot 66 \text{ lbs. per square inch,}$$

and the metal being thin will also favour evaporation by offering a comparatively small resistance to the transmission of heat from the products of combustion to the water in the tubes.

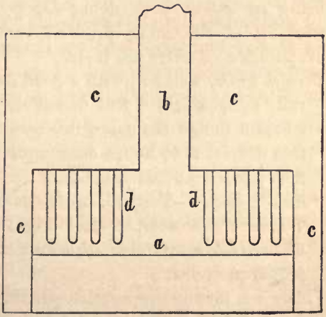
Compare this with a cylindrical boiler, the shell of which is 4 feet 6 inches in diameter and ⅜ths of an inch in thickness, being of rivetted work; the safe pressure in this case will be

$$p = \frac{6000 \times 0{\cdot}375}{27} = 83{\cdot}3 \text{ lbs. per square inch.}$$

In the construction of tubular boilers care must be taken to make the joints of the tubes perfectly sound, for if a leakage occurs the metal will rapidly corrode and the leak become worse; a good and rapid circulation of the water must also be ensured to prevent the tubes from being burnt out.

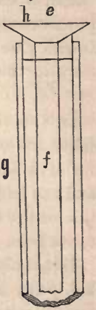
Of tubular boilers, having water inside the tubes, probably the best is that invented by Mr. Edward Field, and generally known as the "Field" boiler. The tubes used hang down into the furnace, and may be applied to various kinds of boilers. A very usual form of this boiler is shown in Fig. 34: *a* is the furnace, *b* the chimney, *c*, *c*, water and steam space, *d*, *d*, the tubes fixed in the tube-plate *i*, *i*, and hanging down into the furnace. The detail shows a section of the upper part of one of

Fig. 34.



these tubes. Into the outer tube *g*, and reaching nearly to the bottom of it, is dropped a smaller tube *f*, supported at the top by a metal feather and funnel-shaped deflector *h*. When the boiler is in action a very rapid current circulates down the interior tube and up outside of it, that is, in the annular space between the interior and exterior tubes. Without the deflector *h*, Mr. Field found he could get no circulation at all, and the result was that the water was blown out of the tubes and the tubes burnt accordingly, but with it the circulation is perfect. The tubes are usually about 3 feet 6 inches long and 2¼ inches or 3¼ inches diameter and ⅛th of an inch thick, though, in special cases, they vary from these dimensions. One of these boilers was tried in comparison with a Cornish boiler, the particulars being as under, both doing exactly the same work, working at the same pressure, and with the same evaporation of water per hour.

Fig. 35.



Cornish boiler, well set, with a good draught, and generally economical; 4 feet diameter, 14 feet long, flue 2 feet 8 inches diameter, fire-bars 2 feet long, duration of trial 116½ hours, consumption of coal 4 tons at 20s. per ton=8·24d. per hour.

"*Field*" *boiler*.—Vertical, with descending flue 3 feet 7 inches diameter, 9 feet high, duration of trial 69 hours, consumption of coke 2 chaldrons at 16s.= 5·56d. per hour.

This gives for the evaporation per lb. of coal in Cornish boiler 5·79 lbs. water, and for the same per lb. coke (the coke weighed 3,584 lbs.) in "Field's" boiler 8·57, which is greatly in favour of the latter, as the evaporative value of coke is less than that of coal generally.

The saving in cost of fuel by the "Field" boiler was 39 per cent.

The heating surface of the Cornish boiler was 124 square feet,

whereas that of the "Field" boiler was only 100 feet. The usual proportions for the "Field" boiler are 10 square feet of heating surface, and 0·5 square foot grate surface per horse-power.

A 15 horse-power "Field" boiler was tested to ascertain its evaporative efficiency; it had then been two years at work. It was an upright boiler, 4 feet diameter and 10 feet high; duration of trial 5 hours. 1,344 lbs. of coke evaporated 11,022 lbs. of water, or 8·2 lbs. per lb. coke. This, reduced to lbs. water per lb. of coke evaporated from 212 degrees, would be 9·8 lbs. The tubes were 2¼ inches in diameter.

In 1867 a Manchester boiler, 20 feet long, 6 feet 6 inches diameter, having two flues, each 2 feet in diameter, was fitted with 270 tubes 1 foot long, 2¼ inches diameter, radially fixed in the flues. The results of its trial were as follow:—

Duration of experiment 46 hours, consumption of Aberdare coals, at 20s. 6d. per ton, 3½ tons, content of feed-water cistern 99 gallons, quantity of feed-water used 80 cistern-fuls, total quantity of water used 7,920 gallons, or 79,200 lbs., = 10·1 lbs. of water evaporated per lb. coal from atmospheric temperature, which, reduced to the boiling point, gives an evaporation of 12·3 lbs. of water evaporated per lb. of coal.

The results obtained from a "Field" boiler fitted to a steam fire-engine show very strikingly the capacity given by this mode of construction. The water and steam space is entirely above the furnace, there being no water space round it. The diameter is 3 feet 6 inches, and the depth 2 feet 4 inches. The total height of furnace and boiler 5 feet 2¾ inches. The length of the tubes varies from 2 feet 3¼ inches to 1 foot 7¼ inches; they are 1 inch in internal diameter, 1-16 inch thick; total length of tubes 797 feet; heating surface 235 square feet (corresponding to a nominal horse-power of 23½ h.-p.); steam pressure 160 lbs. per square inch.

The engines which work without expansion have two cylinders each 8¾ inches diameter, with 2-foot stroke, making 100 revolutions per minute. Total weight of machine 2 tons 18 cwt. The engine on trial sent a jet 210 feet high, discharging 1,200 gallons per minute; allowing nothing as lost by friction and disturbances of the atmosphere, this gives 76 horse-power as the useful effect, yielding 1 horse-power for every 3 feet of heating surface, which, be it remembered is *vertical*, and in the old-fashioned boilers 17 square feet of vertical heating surface would be allowed per horse-power.

The thinness of the tubes seems remarkable at first sight, but they are amply strong, as shown by the annexed calculation.

Let S = strain in pounds per sectional square inch of metal, then

$$S = \frac{160 \times 0{\cdot}5}{0{\cdot}0625} = 1280 \text{ lbs.}$$

Showing ample strength. We have seen a portion of one of these tubes which has for a considerable time been in use, but it is not in the slightest degree worn or deteriorated. The metal being thin, of course enhances the rapid transmission of heat.

Before concluding the present chapter it is desirable to offer a few brief observations on the subject of boiler explosions.

The theories which have been put forward to account for the explosion of steam boilers are numerous, and many of them extremely far-fetched, such as the electrical theory and the theory which presumes that the steam is first decomposed into its constituent gases, oxygen and hydrogen, which subsequently recombined with sudden and destructive violence. Instead of wandering so far into the field of speculation, a brief consideration of the plain facts under immediate observation will occupy our attention.

In the first place, a great proportion of the boiler explosions which occur are due to weakness in the boiler, and such weakness may gradually be increasing and insidiously rendering it unfit for the duty it has to perform, unless a rigorous system of periodical examination be adopted. As was the case with the boiler of a steam-tug which exploded on the Thames a short time since, stays in the interior of the boiler may yield or break and pass unnoticed until some catastrophe occurs, and perhaps even then the original cause of the accident may not be discovered, as all damage found in the boiler may be attributed to the final explosion. Other kinds of injuries may proceed unnoticed, such as corrosion from the exterior through dampness of the boiler setting, or the lodgment of water on the rivetted joints. Also the joints of the boiler, where angle-irons are used, may suffer burning from the heat not being taken up quick enough by the water to keep the joint rings or angle-irons at a sufficiently low temperature. If any part of the furnace crown be left uncovered by water it will become heated, and then being softened, will be forced out of its normal shape by the steam pressure. Danger is not to be anticipated by the sudden formation of steam through contact with red-hot metal which has been left uncovered, for, from the low specific heat of iron, that quantity of caloric which will raise one pound of water a given number of degrees will increase the temperature of eight pounds of iron by the same amount; hence every pound of red-hot iron possesses but heat enough in cooling down to 300 degrees to evaporate one-tenth of a pound of water into steam; hence, assuming in a ten-horse boiler 150 cubic feet of steam space, then, if the plate became red-hot to such an extent that 50 lbs. of the iron is so heated, only 5 lbs. of water would be evaporated; and supposing the normal pressure to be from 60 to 70 lbs. per square inch, even this comparatively large surface of iron becoming red-hot would only increase the pressure by about one-fifth, causing it to rise so as to range from 70 to 84 lbs., certainly not enough to explode a boiler having a safe working pressure of 60 to 70 lbs. per square inch.

One of the causes of boiler explosions (which we believe was first pointed out by Mr. Z. Colburn) rests in the body of steam interspersed throughout the mass of water, which, upon the pressure being removed from the surface of the water, will in escaping tend to carry up the whole body of water, and cause it to strike a violent blow on the crown of the boiler. The pressure of steam may easily be accidentally suddenly reduced, as by the introduction of cold water, the sudden escape of steam from the safety valve, or by starting the engine, &c.

Over-pressure being put upon boilers, through the carelessness or ignorance of those in charge, may also be added to the causes of boiler explosions, but the means of preventing this are obvious.

The accumulation of scale in boilers is a source of danger, inasmuch as, by obstructing the passage of heat from the plates to the water (the calcareous matter of which it consists being a very slow conductor), it allows of the plates getting heated or burnt, in either case weakening them; and although many things have been patented, and more proposed, to prevent scaling in boilers, yet none of them appear to be satisfactory enough to be generally adopted.

The precautions to be taken against boiler explosions may be stated thus:—

1. Always keep plenty of water in the boiler.
2. Never open the steam valve or safety valve suddenly.
3. Have one of the safety valves properly weighted under lock and key, so that the attendant cannot overpress the boiler.
4. If tolerably pure water cannot be obtained, have the scale removed sufficiently often from the boiler.
5. Do not overstrain the boiler in the testing prior to use (twice the maximum working pressure is quite high enough for the test to be carried).
6. Have the boiler periodically examined by a competent boiler-engineer.

If these precautions be borne in mind and taken, there will be no danger of boiler explosions.

As regards the inspection of boilers, some years back an attempt was made to organise a boiler association in London, similar to that established some years since in Manchester, but it did not succeed, and the undertaking had to be abandoned almost before its existence was made generally known; this was in 1862, and it does not appear that any attempts have been made since to revive the plan in the metropolis, a matter to be regretted, because such an association, besides saving manufacturers heavy losses, is also instrumental in preventing accidents which but too often end fatally.

CHAPTER X.

WATER-WHEELS.

WATER-WHEELS, although occurring of great number of different designs, may be classified in four general divisions, as follows:—

Undershot wheels, overshot wheels, breast (or pitch-back) wheels, and turbines. The motion of the first class is obtained from the velocity of a running stream of water which impinges against the floats of the water-wheel. The second and third classes are actuated by the weight of the water falling upon them; and the fourth by reaction.

In this first place it is necessary to explain the laws of liquid pressure and motion. Let $h =$ the height in feet of a column of water, $p =$ pressure in lbs. per square inch at the base of the column, then, since one cubic foot of water weighs 62·5 lbs.,

$$p = 0{\cdot}434\, h$$

the pressure of a column of water 45 feet in height will therefore be

$$p = 0{\cdot}434 \times 45 = 19{\cdot}53 \text{ lbs. per square inch.}$$

FLOW OF WATER THROUGH ORIFICES.—If in a vessel of water an opening be made at a distance, x, below the level of the water surface in the vessel, then the velocity of the water flowing therefrom will be the same as would be acquired by a solid body falling through the distance x. This at first sight may appear somewhat incomprehensible, but the following remarks may serve to set the matter in a clearer light:—

If any perfectly elastic body be dropped and unacted upon by friction, it will, upon coming into contact with another solid body, be compressed (by the accumulated work within it) and rebound to the height from which it descended, the accumulated work contained in the body at the moment of contact being equal to the weight multiplied by the height of the fall. If the body be so controlled that it cannot rebound, but is retained in its most compressed state, then, if it be subsequently released, it will spring up to the height from which it originally fell, by virtue of the accumulated work within it. If the body be released by the removal of the lower or supporting surface, the accumulated work would be expended downwards; and if the atoms of the body be separate, it may be all expended in projecting one atom. If a quantity of water be poured into a vessel, it will be compressed by its own weight to some extent, although the amount may not be sensible, and this compression will represent a certain amount of accumulated work; if this accumulated work can be expended on one atom, it may produce motion proportionate to the weight of the mass above such atom. Let us suppose that an aperture is made in the vessel so that the bottom layer of atoms of water may escape, then will the whole mass above descend through a distance equal to the thickness of such a layer, and in so doing will do work the same as would have been done by the descent of one layer of atoms through a distance equal to the *height* of the entire mass of water; hence the velocity of efflux of water under pressure will be equal to that attained by a body falling the height of the head-water producing such efflux.

Theoretically, if S = area of orifice in square feet, h = head of water in feet, and Q = cubic feet of water discharged per minute—

$$Q = c \, . \, S \sqrt{h}$$

c being a constant determined by experiment, replacing it we have

$$Q = 297{\cdot}6 \; S \sqrt{h}$$

and by transposition,

$$S = \frac{Q}{297{\cdot}6 \sqrt{h}}$$

$$h = \frac{Q^2}{88565{\cdot}76 \, . \, S}$$

Flow of Water over Weirs.—Applying the same laws to the flow of water over weirs and notch-boards, we have, if l = length of weir in feet, the other notations remaining the same as above—

$$Q = 192{\cdot}6 \; l \sqrt{h^3}$$

Flow of Water in Canals, Troughs, &c.—Let s = sectional area in square feet, l = length of channel in feet, c = wetted perimeter in feet, V = velocity in feet per minute—

$$V = 774{\cdot}6 \sqrt{\frac{h \, . \, s}{l \, . \, c}}$$

and for the quantity discharged

$$Q = V \, . \, s$$

Flow of Water through Pipes.—The gravitating force which causes the flow of water in pipes evidently varies as the head of water divided by the length of pipe through which the water has to flow; hence, if $h =$ head or height of water in feet, and $l =$ length of pipes in feet, the accelerating force will vary as

$$\frac{h}{l}$$

The resistances are of a frictional character, and are represented by the following formula:—Let $v =$ velocity in feet per second, $C =$ circumference of the pipe, $S =$ sectional area of the pipe, and $c =$ a constant to be determined by experiment, then the resistances

$$= v^2 \times \frac{C}{S} \times c$$

and as action and reaction are equal and opposite, the accelerating force must be equal to the resistances; hence, if $d =$ diameter of pipe in feet,

$$\frac{h}{l} = v^2 \times \frac{C}{S} \times c$$

hence,

$$v^2 = \frac{h}{l} \times \frac{d}{4} \times c$$

Let Q = the discharge in cubic feet per minute, then

$$Q = v \times 0{\cdot}7854\, d^2 \times 60$$

$$v = \frac{Q \times 60}{0{\cdot}7854\,.\,d^2\,.\,60}$$

From Smeaton's experiments the constant c was found to be $= \frac{1}{10{,}000}$; hence the above formula becomes—

$$Q = 2356 \sqrt{\frac{h}{l} \times d^5}$$

or if D = diameter of pipe in inches,

$$Q = 4{\cdot}72 \sqrt{\frac{h}{l} \times D^5}$$

The following coefficients may be found useful in practice:—

To reduce	cubic feet	to gallons	multiply by	6·25
,,	,,	pounds	,,	62·50
,,	gallons	to cubic feet	,,	0·16
,,	pounds	,,	,,	0·016

There are two methods of action by which water impresses motion and imparts power to water-wheels, either by its weight pressing on the wheel, or by impact of flowing water against float-boards, the work done being due to the *vis vivâ* of the moving water; sometimes water acts in both ways at once, the work done being partly due to the weight, and partly to the *vis vivâ* of the water. In any case, if the water is acting by weight, and h = difference of level of water at its point of supply to the wheel and at its point of discharge, and Q = quantity in pounds of water falling per minute, the power theoretically is

$$HP = \frac{Q\,h}{33000}$$

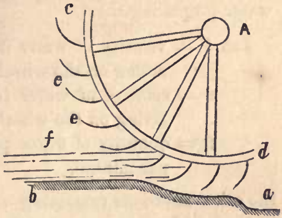
or if v = velocity of water per second,

$$HP = \frac{Q\,v^2}{2{,}125{,}200}$$

but of course the actual work done is much less than this, being diminished by friction and loss of water.

UNDERSHOT WATER-WHEEL.—The undershot water-wheel is usually made with floats placed radially, or curved slightly backward, so as to get free of the water in leaving the tail-race. These floats may be so curved that the water does not act by direct impact, but by pressure, as shown in the arrangement of Fig. 36: *a* is the shaft carrying the wheel of which *c d* is the periphery carrying the curved floats *e e*; *a b* is the bottom of the wheel-race, and it will be observed that the water comes tangentially and without shock upon the wheel; the sides of the race should fit tolerably close to the wheel to prevent loss of water. A clearance of about one inch is sufficient.

Fig. 36.



If the wheel were moving at the same velocity as the water it would receive no pressure from the latter, and if it were held still it would receive the greatest amount of pressure; but being at rest would give off no work or power, hence there is some relation intermediate between these two conditions existing between the velocities of the wheel and water which will produce a maximum effect. The less velocity that the water leaving the wheel has the more work is being done, as if H and h represent the virtual heads to produce the velocities V and v before and after the water acts on the wheel, the work done will vary, as

$$Q\,\{H - h\}$$

$$\text{varies as } Q\left\{\frac{V^2}{64\cdot4} - \frac{v^2}{64\cdot4}\right\}$$

$$\text{varies as } V^2 - v^2$$

and it is evident the smaller v is the greater will be the amount of work done.

It has been found that undershot water-wheels give as good a coefficient of useful effect as can be obtained when running at half to one third the speed of the water propelling them.

Let $V =$ velocity of water in feet per second before acting on the wheel,
$v =$ velocity of water in feet per second after acting on the wheel,
$Q =$ quantity of water passing wheel in pounds per minute,

the other notations remaining as above, then the horse-power will be

$$HP = \frac{Q \cdot c}{33000} \left\{ H - h \right\}$$

where $c =$ the coefficient of efficiency, hence

$$HP = \frac{Q \cdot c}{33000} \left\{ \frac{V^2 - v^2}{64 \cdot 4} \right\}$$

$$= \frac{Q \cdot c}{2,125,200} \left\{ V^2 - v^2 \right\}$$

but for falls under 6 feet $c =$ from 0·33 to 0·4, hence the rule becomes practically,

$$HP = \frac{Q}{6,440,000} \left\{ V^2 - v^2 \right\}$$

but the wheel be so designed that $v = o$, as should be the case to obtain the greatest economy, we have

$$HP = \frac{Q \cdot V^2}{6,440,000}$$

These are for radial floats, but if curved floats be used the value of $c = 50$ to 60, hence the above formulæ become

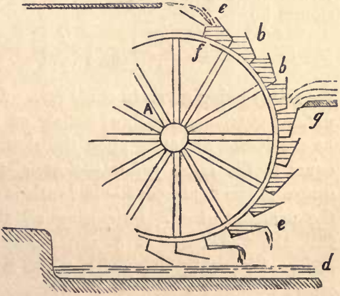
$$HP = \frac{Q}{4{,}000{,}000}\left\{V^2 - v^2\right\}$$

and if $v = o$

$$HP = \frac{Q\ V^2}{4{,}000{,}000}$$

Overshot Water-wheels.—Overshot wheels are principally worked by the weight of the water in the buckets of the wheel, which weight being always on one side of the wheel causes it to revolve; if, however, the water has any velocity, which by impact assists in moving the wheel, the virtual head corresponding to such velocity must be added to the distance through which the water passes in acting on the wheel.

Fig. 37.



A, Fig. 37, is the axis of an overshot water-wheel *b*, *b*, the buckets to catch the water from the pen-trough *c*, which subsequently flows out as at *e* into the tail-race *d*. Let h = the height of the water in the pen-trough above that in the tail-race, and Q = the quantity of water discharged in pounds per minute, then the horse-power will be

$$HP = \frac{Q \,.\, h \,.\, c}{33000}$$

but for overshot wheels $c = 0{\cdot}6$, hence

$$HP = \frac{Q \,.\, h}{55000}$$

The duty done by overshot wheels will to some considerable extent depend upon the form and size of the buckets, which should be arranged so as to avoid as much as possible the too early discharge of water from the descending buckets at *e*. When the buckets have openings, as shown at *f*, they are termed ventilating buckets. This form has come much into use of late. The buckets should be designed of ample size, so that they may not be more than two-thirds filled with water. If $Q =$ quantity of water in lbs. per minute, $N =$ number of revolutions per minute, $n =$ number of buckets on wheel, then practically the content of each bucket should be

$$C = \frac{Q}{62{\cdot}5 \,.\, N \,.\, n \,.}$$

the result being given in cubic feet. In the case of the undershot wheel, the force acting on the wheel might be considered as acting upon the shaft with a leverage equal to the mean radius,—that is, the radius to the centre of the float-board,—but such is not the case with the overshot wheel. Supposing all the buckets to be full, the whole weight of water may be regarded as acting at its centre of gravity, which is distant from the centre

$$0{\cdot}636\, r$$

r being equal to the mean radius at which the buckets are placed.

To find the force or pressure exerted at the periphery of a spur-wheel of which D = diameter, and fixed on the water-wheel shaft, we have W = weight of water in buckets in lbs., p = pressure—

$$p = W \frac{1 \cdot 272 \, . \, r}{D}$$

If Q = quantity in lbs. discharged per minute, the other notations being as above—

$$W = \frac{Q}{2\,N} \times c$$

for c being a constant to allow for loss by the spilling of water out of the buckets, hence the practical formula will be, neglecting the friction of the shaft, which is about 5 per cent.—

$$W = \frac{0 \cdot 45 \;\; Q}{N}$$

whence,

$$p = \frac{0 \cdot 572 \, . \, Q \, . \, r}{N \, . \, D \, .}$$

As regards the speed of overshot wheels, it may be observed that from 4 to 6 feet per second is very good in the results yielded, this velocity being at the periphery of the wheel.

Let D = diameter of wheel in feet,
S = velocity of periphery in feet per second,
N = number of revolutions per minute—

$$S = N \, . \, D \, . \, 188 \cdot 5$$

$$D = \frac{S}{188 \cdot 5 \, . \, N}$$

$$N = \frac{S}{188 \cdot 5 \, . \, D}$$

hence, if S — 5 feet,

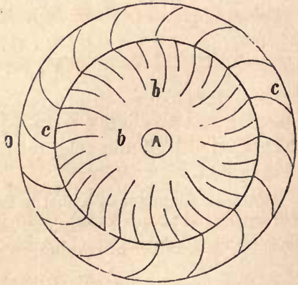
$$D = \frac{1}{37\cdot7\ N},\ N = \frac{}{37\cdot7\ .\ D}$$

Breast or Pitch-back Wheels.—These wheels are somewhat similar in their action to overshot wheels, only the supply, instead of coming over the top of the wheel, is poured at some point lower down, as at *g*, Fig. 37. These wheels give a very good result. They are divided into two classes, high and low breast wheels, according to whether the water comes upon the wheel above or below the centre. The power of the wheel may be determined by the formula—

$$HP = \frac{Q\ .\ h}{44{,}000}$$

Turbines.—Fig. 38 shows a horizontal section of a turbine of modern construction. This wheel is fixed horizontally; that is to say, with the axis vertical. *A* is the centre of the wheel where the supply of water is brought to it, *b*, *b*. *fixed* guides which lead the inflowing water into the most suitable direction to impinge upon the vanes *c*, *c*, in the moving rim *D*. Not only is this wheel driven by the impact of the water against the floats or vanes, but also by the pressure or reaction of effluent water on such

Fig. 38.



vanes. If the wheel be properly constructed the water as it leaves should have been deprived of all motion, having given up its *vis vivâ* to the turbine, hence the peripheral velocity of the wheel should be equal to that due to the head of the water under which it is working.

Let D = diameter of wheel in feet,
h = head of water in feet,
N = number of revolutions per minute,
v = peripheral velocity per second, then

$$v = \sqrt{64 \cdot 4\, h}$$

but

$$v = \frac{3 \cdot 1416 \,.\, D \,.\, N}{60}$$

hence,

$$N = \frac{153 \cdot 2 \sqrt{h}}{D}$$

For example:—Let h = 20 feet, D = 2·5 feet.

$$N = \frac{153 \cdot 2 \times 4 \cdot 47}{2 \cdot 5} = 684 \cdot 8 \text{ revolutions per minute.}$$

If Q = lbs. of water passing through turbine per minute then the power is

$$HP = \frac{Q \,.\, h \,.\, c}{33{,}000}$$

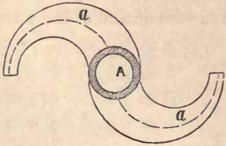
For turbines c varies from 0·6 to 0·8, so for the better class of wheels taking the last constant,

$$HP = \frac{Q \,.\, h \,.}{4{,}125}$$

These wheels are exceedingly valuable for neighbourhoods where there are high sources of supply; they will work well either in or out of water.

Fig. 39 illustrates Whitelaw's turbine or reaction wheel viewed in plan. This wheel has two arms *a*, *a*, revolving about a centre *A*, the water being supplied through this centre. As in the last case, the best peripheral space is

Fig. 39.



$$v - \sqrt{64{\cdot}4\,h}$$

the water leaving the turbine without motion. The arms are formed in the shape of an Archimedean spiral. The proportions of the machine may be determined by the following formula—using the same notation as above—

$$HP = \frac{Q\,.\,h\,.\,c}{33{,}000}$$

but $c = 0{\cdot}74$ to $0{\cdot}78$, hence, assuming its value as $0{\cdot}76$, we have

$$HP = \frac{Q\,.\,h\,.}{43{,}421}$$

Let w = width of each discharging orifice, and D = diameter of machine, N = number of revolutions per minute—

$$w = \sqrt{\frac{135\,.\,HP}{1000\,h\,\sqrt{h}}}$$

Width of each arm . . . = $4\,w$
Diameter of machine . . = $50\,w$
,, central opening . = $10\,w$

$$N = \frac{149{\cdot}43\,\sqrt{h}}{D}$$

VORTEX WHEEL.—A vortex wheel is in construction similar to a turbine, but instead of the water being supplied at the centre and flowing outward towards the periphery of the wheel, it is supplied at the outer edge of the wheel and flows inward towards its centre.

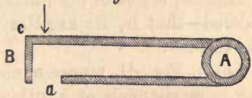
Professor Thompson's vortex wheel gave an efficiency equal to 75 per cent. of the theoretical quantity of work, hence the formula for power will be

$$HP = \frac{Q \cdot h}{44{,}000}$$

It seems desirable, before leaving the subject of turbines, to explain the principles upon which the operation of reaction machines in general depends.

Let A, B, Fig. 40, be a horizontal section of a hollow arm capable of revolving about an axis at A through which water or other liquid is supplied to the arm. So long as the arm is perfectly closed no motion will ensue, because the pressure of the liquid acts equally on each side of the hollow arm, hence has no tendency to cause it to revolve in either direction about the axis A. If, however, an aperture be made near the end of the arm as shown at a, then the pressure on the other side of the arm at c is unbalanced over an area equal to that of the opening a, and there is a tendency to cause the arm to revolve in the direction of the arrow; the force theoretically would be found as follows:—Let s = area of orifice in square inches, l = length of arm from centre of orifice to centre A in feet, p = pressure of

Fig. 40.



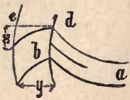
liquid in pounds per square inch, $M =$ moment of force about A—

$$M = p \times S \times l$$

If the machine be moving at the most economical velocity, the water will simply fall from the orifice a, being, as it were, *left behind* by the revolving arm by virtue of its inertia. The disadvantages of this machine when used with light fluids, such as gas, air, or steam, are so great as to quite preclude its application in connection with such sources of power, but it answers admirably when used with *non-elastic* fluids. That a very high result is got is evident from the fact that turbines have actually yielded as much as 78 per cent. of the total work theoretically to be got from the water used in driving, which is very good considering what has to be deducted on the score of friction of the bearings and friction of the water in the pipes and guide curves of the machine.

Another action of the water has, however, to be considered—that is, its angular pressure on the vanes of the turbine.

Fig. 41.



Let a, Fig. 41, represent one of the guide channels of a turbine, b being one of the cells comprised between two vanes of the turbine ring, of which c is the outer and d the inner ring. It is evident the water is delivered on the vane tangentially to d. But when the guides are radial its mean velocity will be

$$= \tfrac{1}{2} \sqrt{64{\cdot}4 \; h} = 4{\cdot}01 \sqrt{h}$$

and the velocity of the periphery of the wheel

$$= 8{\cdot}02 \sqrt{h}$$

hence the relation between x and y will be

$$x = 2\,y$$

in order that the water may reach the periphery deprived of all *vis vivâ* and leave the wheel radially.

In the case, however, of curved guides, the direction of the water being tangential to d, it will travel in a direction mid-way between radial and tangential in giving up its energy:=

$$x = \frac{y}{1{\cdot}414}$$

REGULATION OF POWER OF WATER-WHEELS TO SUIT VARYING AMOUNTS OF RESISTANCE.—The amount of power given off by a water-wheel of any description can of course be regulated by adjustment of the quantity of water supplied to it, which may be determined either by valves or by sliding sluices in the pen-trough, and such valves may be under the control of any ordinary conical governor, which will regulate the supply of water in the same way that it does the supply of steam to the steam-engine.

Other kinds of governors may of course be used if thought desirable, but the simplicity and durability of the apparatus commonly used greatly recommend its adoption, and although, under different loads, the speed will not be mathematically uniform, yet the variations of velocity are not sufficiently great to affect practically the working of the machine.

One great advantage possessed by water-wheels over steam-engines may here be mentioned: it exists in the constancy of the dynamic effort which causes the revolution of the shaft. As is well known in a single-cylinder engine, the moment of force about the main-shaft varies from the maximum when the piston (working without expansion) is at half-stroke to 0 at the dead points, and when expansion is used there are more variations of force, all of which have to be equalised as much as possible by the use of a heavy wheel.

If, however, a water-wheel be the prime mover, these irregularities do not occur, and so long as the supply of water is maintained the moment of pressure about the main-shaft of the wheel is regular and uniform throughout each revolution, a matter of some considerable importance where delicate processes are being effected.

The dimensions of the arms, &c., of the wheels may be determined from the general formulæ for strengths already given.

CHAPTER XI.

PUMPS AND OTHER HYDRAULIC MACHINES.

The ordinary form of pump is too well known to require any special description, but those used for purposes dealing with large quantities of water require particular attention paid to their details.

To find the quantity of water discharged by any given single-acting pump:—

Let Q = quantity of water discharged in gallons per minute,
d = diameter of piston in inches,
s = stroke of pump in feet,
n = number of strokes per minute, then

$$Q = \frac{n \, . \, s \, . \, d^2}{29 \cdot 4}$$

Thus a plunger pump attached to a Cornish engine in London has a diameter of 50 inches, stroke 11 feet, number of strokes per minute 6—

$$Q = \frac{6 \times 11 \times 2500}{29 \cdot 4} = 5612 \cdot 2 \text{ gallons per minute.}$$

The following formula will give the power required to work a pump, exclusive of the friction of the parts :—

Let h = height of lift in feet, the other notations being as above. The work done in one minute is evidently (as 1 gallon weighs 10 lbs.)—

$$\frac{10 \times n \,.\, s \,.\, d^2 \,.\, h}{29 \cdot 4}$$

hence the horse-power to work a pump (excluding friction, which may be taken at 5 to 10 per cent., according to the description of pump,) will be

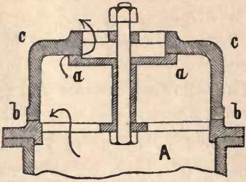
$$HP = \frac{n \,.\, s \,.\, d^2 \,.\, h}{97{,}020}$$

with the pump referred to in the last case the lift is 100 feet, hence

$$HP = \frac{6 \times 11 \times 2500 \times 100}{97{,}020} = 170 \text{ horse-power.}$$

In very large pumps, such as the one just referred to, common butterfly or clack valves could not be used, as, from their not closing until the column of water begins to return, there is a great concussion in shutting; at some times as much as from 10 to 15 per cent. of the water is lost through the delay in the valves closing, hence, amongst others, the double-beat valves applied by Harvey and West have been much used. One of these valves is shown in section in Fig. 42. *A* is a pipe guarded by a valve at the top, *a*, *a*, and *b*, *b*, are the seatings which carry the valve *c c*. When this valve lifts the water flows out over both seatings in the direction of the arrows.

Fig. 42.



Now it is evident in this arrangement that this valve is heavier in proportion to its annular area than is the common valve in proportion to its whole area, hence the former, at the termination of the stroke of the pump, falls *through* the column of water at once instead of waiting to fall *with* the water. The pressure requisite to open such a valve may be found in the following manner :—

Let p = pounds pressure per square inch requisite to open the valve,

w = weight of valve in pounds,

a = area of valve in square inches against which the water acts, then

$$p = \frac{w}{a}$$

let $w = 100$ and $a = 80$,

$$p = \frac{100}{80} = 1{\cdot}25 \text{ lbs. per square inch.}$$

In large pumps the work done in lifting the valves becomes an item worthy of notice in estimating the power lost by friction, &c.

Let l = lift of the valve in inches,
w = weight in pounds of both valves,
n = number of strokes per minute,
P = power absorbed by two valves (suction and discharge)—

$$P = \frac{n \cdot w \cdot l}{396000}$$

Let each valve weigh 1,800 lbs., and have a lift of 7 inches, then the number of strokes being 6 per minute,—

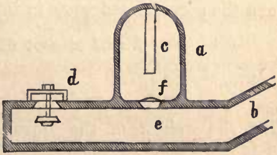
$$P = \frac{6 \times 3600 \times 7}{396000} = 0{\cdot}38 \text{ horse-power,}$$

which would probably amount to about 3·5 per cent. of the whole frictional resistances.

In the construction of such pumps as those referred to, the suction and outlet pipes should, where practicable, have a diameter equal to that of the pump plunger or piston, in order to reduce the friction to the lowest possible amount.

Hydraulic Ram.—An ingenious apparatus known as the hydraulic ram is shown in Fig. 43; its object is, where there is a great supply of water with a moderately high fall, to cause a certain part of the supply to be forced up into a cistern by the flowing away of the greater bulk of the supply: *a* is an air-vessel, from which a delivery-pipe *c* proceeds to the cistern. *b* is the supply-pipe leading into a

Fig. 43.



chamber *e*, whence the water flows away through a valve *d* until it acquires momentum enough to shut the valve *d;* the sudden check thus put upon the flowing water causes it, by virtue of the work accumulated in it, to open the valve *f* and force a portion of water into the air-chamber *a*, whence it passes away through the delivery-pipe *e*, after which the valve *d* again opens by its weight.

The velocity to be acquired by the water in order that it may close the valve *d*, must be somewhat in excess of that which it would receive from a head that would give a pressure equal per square inch to the weight of the valve *d*.

Let w = weight of valve *d* per square inch multiplied by 1·05,

l = length in feet of supply-pipe,

a = area in square feet of supply-pipe,

v = velocity of water in feet per second,

h = corresponding head of water,

Q = water raised in foot-pounds, then

$$h = \frac{w}{0·434}$$

$$v = 12·15 \sqrt{w}$$

the quantity of water in the conduit-pipe in pounds,

$$l \times a \times 62·5 = q$$

and the accumulated work in this will be

$$q \times h = l \times a \times 62·5 \times \frac{w}{0·434}$$

hence,

$$Q = 144 \,.\, l \,.\, a \,.\, w \,.$$

Let the weight of the valve *d* per square inch be 0·25 lbs., then

$$w = 0·25 \times 1·05 = 0·262 \text{ lbs.}$$

Let $a = 0{\cdot}3$ square foot, and $l = 50$ feet, then

$$Q = 144 \times 50 \times 0{\cdot}3 \times 0{\cdot}262 = 565{\cdot}9 \text{ ft.-lbs.}$$

but this has to be reduced by a coefficient, as there exists a loss due to the shock of the water and the currents created thereby.

A general coefficient cannot with confidence be given, as so much will depend upon the design of a ram, for if the passages are properly curved much better results are obtained than if they be left square. It is evident that by means of this machine a proportionately small quantity of water can be raised to a level above that whence it is supplied. Amongst other similar things for raising water may be mentioned the application of water-wheels working pumps.

Hydrostatic Press.—The general arrangement of the hydrostatic press has been described in Chapter iii., but the mode of calculating the power of the complete machine is not there given. Usually the hydrostatic press is fitted with two plunger pumps, one of larger diameter than the other. The largest one is first used to bring the ram of the press up to its work, when the smaller one is employed to get the highest pressure.

Let $P =$ the greatest pressure in tons,
$D =$ diameter of ram in inches,
$d =$ diameter of small pump in inches,
$l =$ length of pump-handle or lever from point of application of power to the fulcrum,
$L =$ distance between fulcrum and axis of small pump,
$f =$ force in pounds applied to pump lever, then

$$P = \frac{D^2 . f . l}{2240 . d^2 \ L}$$

Let $D = 10$ inches, $f = 50$ lbs., $l = 40$ inches, $d =$ 1 inch, $L = 3$ inches, then

$$P = \frac{100 \times 50 \times 40}{2240 \times 1 \times 3} = 29{\cdot}76 \text{ tons.}$$

The thicknesses of the pumps and cylinders, &c., may be calculated from the general rules already given, but great care should be exercised in order to ensure the supply of *good castings*, as a cylinder cast with bad metal, even if strong enough to sustain the pressure, will allow the water to sweat out through its pores, thus causing the pressure to be lost, an important difference in some trades where goods are left in the presses all night.

The tables of presses are calculated as beams to resist cross strain, and ample strength should be allowed them, as it not unfrequently happens that they get unfairly strained through twisting or unequal stress coming accidentally upon them.

HYDRAULIC LIFTS are in principle similar to the hydrostatic press, but, being used for raising weights, they have a greater stroke, and are usually worked by a head of water supplied from an elevated tank or other convenient reservoir.

Let $W =$ greatest weight in pounds to be lifted,
$D =$ diameter of lift-ram in inches,
$h =$ height in feet of water supply above the highest point to which the lift is designed to work—

$$D = 1{\cdot}71 \sqrt{\frac{W}{h}}$$

Let $W = 2000$, $h = 30$

$$D = 1{\cdot}71 \sqrt{\frac{2000}{30}} = 13{\cdot}88 \text{ inches.}$$

WATER-PRESSURE ENGINES.—In some places engines somewhat similar in general construction to steam-engines, but worked by the pressure of water, are used.

The great difference in the two kinds of engines consists in the fact that, whilst the steam-engine is worked by a very compressible and elastic fluid, the one now under consideration receives its motion from a liquid practically incompressible, a quality which very materially modifies the arrangement of the valve-gear.

The water being incompressible, it follows that the exhaust or outlet valve should remain open until the completion of the stroke, as otherwise the piston would be stopped by the confined water, or the machine strained or broken. The most convenient valves for these engines will be either equilibrium puppet-valves or piston-valves, opened and closed by means of tappets or cams. The speed of these engines is necessarily slow, the usual velocity of the piston being from 3 to 6 feet per second. The available pressure will be that produced by the head of water minus the head due to the speed of the piston.

Let h = head of water in feet, H = ditto due to velocity of engine,

V = velocity of piston in feet per second, p = pressure in pounds per square inch on piston—

$$p = 0{\cdot}434 \left\{h - H\right\}$$

$$H = \frac{V^2}{64{\cdot}4}$$

$$p = 0{\cdot}434 \left\{h = \frac{V^2}{64{\cdot}4}\right\}$$

but if V = 6 feet per second,

$$p = 0{\cdot}434\, h - 0{\cdot}242$$

hence, if the total head were 30 feet, the effective pressure would be

$$p = 12{\cdot}778 \text{ lbs. per square inch.}$$

If the valves be balanced the friction of the machinery may be taken at 6 per cent. of the effective power; hence, if P = pressure per square inch available for useful work,

$$\begin{aligned} P &= 0{\cdot}94 \left\{0{\cdot}434\, h - 0{\cdot}242\right\} \\ &= 0{\cdot}408\, h - 0{\cdot}227 \end{aligned}$$

This, of course, only applies to the best-constructed engines having but little friction in the water passages leading into the working cylinder. The thicknesses of the cylinder and pipes may be found from the rules given in Chapter vii.

The horse-power of a water-engine may be determined as follows:—

Let d = diameter of piston in inches, v = velocity of piston in feet per minute—

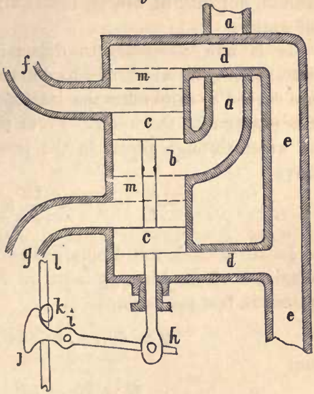
$$HP = \frac{h \,.\, v \,.\, 0{\cdot}785\, d^2 \,.\, 0{\cdot}434 \,.\, c}{33{,}000}$$

taking c the constant as 0·8,

$$HP = \frac{h \,.\, v \,.\, d^2 \,.}{122{,}222}$$

ARRANGEMENT AND PROPORTIONS OF VALVES AND WATER PASSAGES.—Fig. 44 represents a piston-valve arrangement, the principle of which is that the pressure of the water acts between two pistons of equal area fixed on the same stem or piston-rod, hence it has no tendency to move them in either direction, the pressure on one piston being balanced by that on the other, so that the two together form a perfect equilibrium valve, which requires no force to move it except that necessary to overcome its friction. The pistons may have metallic packing.

Fig. 44.



a a is the supply or pressure pipe leading from the reservoir to the engine, and discharing the supply of water into the valve-case *b*; *c*, *c*, are the two pistons fixed on the rod *b* to constitute the valve; *d*, *d*, are exhaust passages leading into the waste-pipe *e e*, into which the water flows after doing its duty in the working cylinder, which is in this case supposed to be double-acting; *f* and *g* are passages leading to opposite ends of the cylinder; *i* is a fixed pin or stud, on which a lever moves connected with the valve-rod *h*; *l l* is a tappet-rod carrying two tappets, one of which is shown at *k*, and these, acting on the horns *j*, move the valve at each end of the stroke. In the position of valve shown by the full lines the water is flowing into the cylinder through *g* and out through *f*; but, if the pistons be moved to the position shown by the dotted lines, the reverse occurs. In some cases an auxiliary valve-case and pistons are used to move the main valves, but this, of course, incurs an extra consumption of water.

It is now necessary to determine the area of the water passages, which will be done assuming that they are curved so as to offer the least possible resistance to the passage of the water. From the formulæ for flow of water through pipes, in the preceding chapter, we have

$$\frac{h}{l} = v^2 \times \frac{C}{S} \times c$$

Let Q = cubic feet discharged per minute, and D = diameter of working cylinder in feet, s = speed of piston in feet per second—

$$Q = 60 \,.\, s \,.\, 0{\cdot}7854\, D^2$$

but

$$Q = 60 \,.\, v \,.\, S$$

$$v = \frac{s \,.\, 0{\cdot}7854\, D^2}{S}$$

but

$$v = \sqrt{\frac{h}{l} \times \frac{S}{C} \times c}$$

hence

$$\frac{s \,.\, 0{\cdot}7854 \,.\, D^2}{S} = \sqrt{\frac{h}{l} \times \frac{S}{C} \times c}$$

$$\frac{0{\cdot}617 \,.\, s^2 \,.\, D^4}{S^2} = \frac{h}{l} \times \frac{S}{C} \times c$$

therefore

$$S = \sqrt[3]{\frac{s^2 \,.\, D^4 \,.\, l \,.\, C}{16200\, h}} = \frac{1}{25{\cdot}3}\sqrt[3]{\frac{s^2 \,.\, D^4 \,.\, l \,.\, C}{h}}$$

But the speed of the piston should for economy be

$$s = 3 \text{ feet per second,}$$

and h will be the head corresponding to the difference of pressure in the pressure-pipe and cylinder :—

$$h = \frac{s^2}{64{\cdot}4} = \frac{9}{64{\cdot}4} = 0{\cdot}14$$

or,

$$\frac{s^2}{h} = 64{\cdot}4$$

hence this quantity is constant, and may be replaced in the formula making it, with sufficient accuracy for practice,

$$S = 0{\cdot}16 \sqrt[3]{D^4 . l . C}$$

if the passages be square, however,

$$C = 4 \sqrt{S}$$

hence, in this case,

$$S = 0{\cdot}19 \sqrt[2.5]{D^4 \, l}$$

Let the length of the water passage be 5 feet, and the diameter of the working cylinder 9 inches, or 0·75 feet, then

$$S = 0{\cdot}19 \sqrt[2.5]{\frac{4}{0{\cdot}75 \times 5}}$$

$$= 0{\cdot}225 \text{ square feet} = 32{\cdot}4 \text{ square inches,}$$

hence the inside length of one side of the water passage should be

$$= 5{\cdot}7 \text{ inches nearly;}$$

the areas of the valves will of course be not less than that of the water passages, and the area of the exhaust passages and waste-pipe should be larger.

If the above speed of piston and square passages be adopted as a general practice, the following formula will give the breadth of the passage :—

Let b = breadth in inches, and D = diameter of working cylinder in inches,

$$b = 0{\cdot}714 \sqrt[5]{D^4 l}$$

which, with the above figures, will become

$$b = 0{\cdot}714 \sqrt[5]{9^4 \times 5} = 5{\cdot}7 \text{ inches,}$$

the same as in the last formula.

WATER METERS.—In some instances water is supplied to consumers by quantity instead of on the principle of rating, and in such cases it is evidently necessary to have some convenient means of measuring the quantity so supplied.

This has been most commonly effected by small machines on the principle of the turbine or reaction wheel, the number of revolutions of which registers the qantity of water transmitted. Some forms have been made like water-pressure engines, the number of strokes of the engine registering the amount of water passed through the meter. If well constructed the latter class are most *certain* as to accurate measurement, but the former possess the advantage of allowing an uninterrupted current of water to pass through, which of course the latter cannot do, as the inlet and outlet valves must alternately be opened and closed to allow each meterful to be discharged and the registering vessel to be refilled. We have, however, seen and tried meters on the turbine system through which water was obtained without so much as one quarter of it being registered.

CHAPTER XII.

MARINE ENGINEERING.

Although the subject of marine propulsion may properly be regarded as one requiring separate treatment, yet, so far as proportioning the power to the resistances to be overcome, and correctly arranging the dimensions of the propelling machinery, it may be dealt with in this chapter—it being understood that the question of the form of lines will not be discussed, it being assumed in formulæ for ascertaining the power requisite to propel a given vessel that its lines are trochoidal.

The resistance to the motion of a vessel passing through the water is caused by the friction of the water against the sides of such vessel, the same as in a pipe the resistance to the flow of water is due to friction. In the case of a vessel the distance through which the resistance is overcome varies, as

v for a given time, v being $=$ to velocity of motion in feet per second.

Also the number of atoms moved in a given time varies as v, and the velocity with which they are displaced varies as v also, hence the sum of the frictional resistance varies as

$$v^3$$

Filling in the constants found by experiment, we have the following formula for indicated horse-power:—

Let $L =$ length of ship in feet at water-line,
$G =$ mean girth under water,
$v =$ velocity in feet per second,

Let L = sum of lengths of bow and stern in feet,
B = greatest breadth in feet—

$$HP = \frac{L \,.\, G \,.\, v^3}{95500} \left\{ 1 + \frac{9{\cdot}87 \,.\, B^2}{L_{,}{}^2} \right\}$$

or if $L = L_{,}$

$$HP = \frac{G \,.\, v^3}{95500} \left\{ L + \frac{9{\cdot}87\, B^2}{L} \right\}$$

For example:—Let $L = 160$ feet, $G = 15$ feet, $B = 16$ feet, $L_{,} = 160$ feet, $v = 25$ feet per second—

$$HP = \frac{15 \times 15625}{95500} \left\{ 160 + \frac{9{\cdot}87 \times 256}{160} \right\} = 420$$

horse-power.

Comparative Efficiency.—To find the comparative efficiencies of two or more vessels, criterion numbers may be obtained from the following formula, based upon the laws of fluid resistance:—

Let C = the criterion number,
P = indicated horse-power of engine,
D = displacement,
S = speed—

$$C = \frac{S^3 \sqrt[3]{D^2}}{P}$$

Thickness of Iron Skins.—The nature of the strain to which the iron skins of ships are subjected by the pressure of the surrounding water is evidently of a transverse nature, and to determine the thickness to withstand this pressure, the following formula, based on the laws of resistance to transverse strain, and the intensity of liquid pressure under given heads, may be used. The wrenching strain due to the yielding of the ship is supposed to be carried by the framing.

Let t = thickness of the plate in inches,
l = distance between ribs in feet,
d = depth of immersion in feet—

$$t = \frac{l}{20}\sqrt{d}$$

CHAPTER XIII.

MATERIALS USED IN CONSTRUCTION.

ALTHOUGH, in some parts of this treatise, we have had occasion to allude to some of the properties of certain materials, yet, in order to render the treatment of our subject complete, it is necessary to dilate more generally upon those substances used for the purposes of construction, which we now proceed to do.

The strength of metals having been given already, will not again be inserted here.

TENSILE RESISTANCE OF WOOD PER SECTIONAL SQUARE INCH.

	lbs.		lbs.
Oak	17,300	Mahogany	8,000
Do.	13,950	Walnut	8,130
Do., English dry	8,000 12,000	Teak	15,000
Beech	17,709	Poplar	6,641 4,596
Do.	11,500	Fir	13,448 11,000
Alder	14,186	Do.	8,506
Chestnut, Spanish	13,300	Scotch Pine	7,818
Ash, very dry	17,850 15,784	Norway Pine	7,287
Do.	12,000	Larch	10,224
Elm	13,489	Cedar	4,973
Acacia	20,582		

Compressive Resistance of Wood in Cubes of One Inch.

	lbs.		lbs.
Elm	1,284	White Deal . . .	1,928
American Pine . .	1,606	English Oak . . .	3,860

Before the art of working in metal was to any considerable degree developed, timber was an almost universal material for the construction of various kinds of machinery, and at the present time in such localities as abound in timber it is very largely employed for those purposes, to which in countries possessed of predominating mineral resources the metals are applied.

In the felling and subsequent preservation of woods considerable care must be exercised, as if timber be not properly seasoned it soon becomes a prey to decay, and in consequence worthless. The usual time for felling timber is during the cold months, when the vegetative powers of the tree are almost dormant, and when they are also most free from sap. None of the woods, however, are fit for use in the state in which they are cut down, for although no distinct circulation is going on within the heart-wood, yet the capillary vessels which permeate the tissue keep the tree moist throughout its substance, and therefore in an unfit state for use. If green or wet woods are placed in confined situations they become stained, and speedily yield to decay, a result which is avoided by careful drying with free access of air.

On this account the timbers for ships should be cut out to their shapes and dimensions about a year before they are framed together, after which they should be left a year longer in the skeleton state to complete the seasoning, as in that state they become better qualified to resist the effects of exposure than if they were immediately covered in with planking.

Other mischiefs almost as serious as decay also occur to improperly-seasoned woods; round blocks cut out of the stem of green wood, or the same pieces divided into quarterings, split radially, and sometimes, but more rarely, in annular directions. Round blocks cut from the entire section contract pretty equally, and nearly retain their circular form, but those from the quarterings become oval from their unequal shrinking.

SEASONING AND PREPARING OF WOODS.—The woods immediately after being felled are in some cases immersed in running water for a few days, weeks, or months, according to circumstances; otherwise they are boiled or steamed. The object of thus treating the timber appears to be the dilution of the sap, after which the process of drying is carried on quicker and better, and the colours of the white woods are improved. The ordinary course, however, is merely to subject the material to a process of air-drying simply, but then the timber is usually reduced to sizes more nearly approaching those required for use, such as square logs and beams, planks or boards of various thicknesses, short lengths or quarterings, &c.

The stems and branches of such trees as alder, birch, and beech, used largely by turners, frequently require no reduction in size; if they do, they are split into quarterings; but in either case they are stacked in heaps to dry.

The smaller hard woods are much more wasteful than the timber woods, as, independently of their thick bark, their sections are frequently very irregular, indented, and ill-defined. Others are almost constantly unsound in their growth, and either exhibit central hollows or cavities, or cracks and radial divisions, which part the section into three or four pieces.

All the harder woods require extra care in their seasoning, the difficulty of satisfactorily effecting which is often increased by exposure to the sun and hot winds in their native climates. The closeness of their texture also renders them less easily penetrable by the air, thus increasing the liability to crack, while their scarcity and expense also render their preservation a matter of great importance. It is therefore advisable to prepare them for their passage from the yard or store to the turning shop by removing those portions which must be necessarily wasted, so as the more thoroughly to dry them by more complete exposure to the air, before they are taken into a house, and care should be taken not to place them near a fire, or at first in a hot room.

Many of the timber woods are divided in the saw-pit into planks, in order to increase the number of surfaces upon which the air can act in the process of drying, and also to leave less distance for its penetration; after sawing they should never be allowed to remain in contact, and the partial admission of air often causes staining and other mischief to arise. They should therefore be placed either horizontally or vertically in racks, or stacked in a pile with slips of wood in between them.

Thin pieces will be about sufficiently seasoned in one year's time, but thick wood requires two or three years' preparation before it is fit to be removed into hot rooms to complete the drying. Mahogany, cedar, rosewood, and other large foreign woods, require to be very carefully dried when they are cut into planks, as, notwithstanding the great length of time which elapses between their being felled and brought into use, they retain a great proportion of moisture as long as they remain in logs.

The drying of woods, technically speaking, cannot be said to be completed until the wood ceases to lose weight by evaporation on the continued application of heat; but to arrive at this degree of dessication would require two or three times as long as is usually allowed for the seasoning of timber. A good and expeditious method of completing the seasoning of wood consists in placing it in hot rooms having a free circulation of air, which enters at the lower part heated and dry, and therefore in an excellent condition to absorb moisture, and it leaves the upper part of the room charged with aqueous vapour taken from the wood which is undergoing the process of dessication. This mode of procedure is so expeditious that by its adoption two-thirds of the time required for common air-drying is saved.

As a general rule, the specific gravities of woods will give a very fair idea of their comparative degrees of hardness.

In order to render timber more durable than it is when merely air-dried various special processes have been invented, such as injecting its pores with corrosive sublimate, sulphate of copper, or creosote, the latter being practised to a very great extent for railway sleepers and other timbers placed in very exposed situations, liable to the combined action of moisture and air.

General Characteristics of Wood.—Timber, on account of its great flexibility, comparatively speaking, is but little adapted for the manufacture of parts of machinery which reciprocate at high velocities, but its cheapness, toughness, and facility of being wrought render it useful for framework and parts of machines at rest or always moving in one direction.

Although the specific gravity of timber is very low, yet in its use there is seldom any saving in weight, as from its correspondingly slight resistance to strains a much larger sectional area is required to resist a given strain where it is used than if metal be the material applied.

The liability of wood to twist and warp, especially when exposed to damp and to alternations of temperature, as well as its liability to combustion, are also disadvantages weighing heavily against its use if other materials are available at a moderate cost. Some of the toughest kinds of wood are, however, used to a considerable extent for the teeth of wheels, and for this purpose are found to wear as well as iron; in fact, in some cases, wheels with wood teeth will outlast the iron-toothed wheels in gear with which they work. Wood is also very useful as a packing material to place under portions of machines subject to concussion, so as to deaden the shock which would otherwise be transmitted to the parts below with almost its normal force.

IRON.—The various descriptions of cast and wrought irons and steels used in commerce for the multifarious purposes of the manufacturer are obtained by suitable processes from certain minerals containing more or less iron, and which are known as iron ores. In these ores the iron exists chiefly in the form of oxides and carbonates. The oxides of iron are two in number: the protoxide and peroxide, or sesquioxide of iron. The first contains one atom or chemical equivalent of oxygen to each atom of iron, its chemical symbol being Fe. O. (Fe. representing Ferrum, Lat., Iron, and O. Oxygen). But the chemical equivalents, or atomic weights, are,—

Iron = 28, Oxygen = 8*; hence the composition of protoxide of iron is,—

	Parts.	Parts.
Iron	28	77·78
Oxygen	8	22·22
		100·00

The sesquioxide of iron contains two equivalents of iron to three of oxygen; hence its formula is $Fe_2\ O_3$, and its composition

		Parts.	Parts.
Iron	28 × 2	= 56	70·00
Oxygen	8 × 3	= 24	30·00
			100·00

There exist also in the ores containing the iron other substances, such as silica, graphite, alumina, &c., from association with which the iron must be removed; but with many of these the iron is not *chemically* combined, and may, therefore, be readily freed. Carbonate of iron is a salt consisting of protoxide of iron combined with carbonic acid, the latter being composed of one atom of carbon and two atoms of oxygen, and, therefore, being represented by the formula $C.\ O_2$. Carbonate of iron will have the formula $Fe.\ O.\ C.\ O_2$, or $Fe.\ C.\ O_3$. It occurs in many countries in the form of a light grey or buff massive stone in large quantities. The celebrated Styrian steel is prepared from this ore, which is commonly termed Spathic Iron Ore, or Spherosiderite, and from this most of the English iron is prepared. The composition of carbonate of iron is

	Parts.	Parts.
Iron	28	48·27
Carbon	6	10·34
Oxygen	8 × 3 = 24	41·39
		100·00

---

* In the use of chemical nomenclature throughout this treatise, the old or Daltonian system of equivalents and formulæ will be used.

PROPERTIES OF VARIOUS ORES OF IRON.

DESCRIPTION.	IMPURITIES.	IRON IN 100 PARTS.	COLOUR.	SPECIFIC HARDNESS.	Specific Gravity Water = 1,000.
Meteoric iron (magnetic)	Arsenic, chrome, cobalt, copper, molybdenum.	94·00	Silvery to bluish white	4 to 4·5	5·95 to 7·34
Magnetic iron (octohedral ore)	Quartz, calcareous, and fluor spars	72·40 to 67·47	Lustrous black	5·5 ,, 6·5	— 5·00
Specular oxide (red hematite)	Matrix and water	70·00	Brilliant black iridescent	5·5 ,, 6·5	— 5·10
Do., 2nd variety			Dark red	— 7·0	— 5·00
Carbonate of iron	Carbonates of lime and magnesia	44·91	Grey	— 4·0	3·0 ,, 3·50
Red hematite		67·67			
Compact red ore		56·50			
Red ochre		40·53			
Brown hematite, compact		59·18			
,, ,, fibrous		56·98			
,, ,, ætites		54·97			
,, ,, volitic		44·45			
,, ,, granular		42·21			
Brown ochre		45·85			
Bog iron ore		29·54			
Carbonate, lithoid		33·54 to 40·79			

The iron is separated from the oxygen with which it is combined by the action of substances which, aided by heat, have a greater attraction or *affinity* for oxygen than the iron has, and, therefore, deprive it of that element. Thus, if finely divided oxide of iron be subjected at a red heat to the action of hydrogen gas, the latter combines with the oxygen of the former to form water ($H. O.$), and pure iron is left. In commercial processes, however, carbon in the form of coal or charcoal is the principal deoxodizer employed to free iron from its oxygen.

The conditions of the iron in combination with the most important ores from which it is manufactured are as under:—

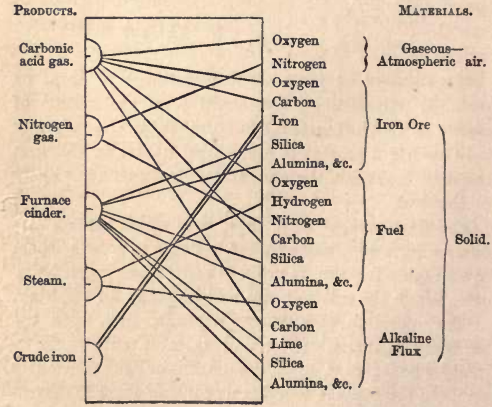
In Magnetic iron ore . .	$Fe. O. + Fe_2 O_3$
,, Spathic or clay ironstone	$Fe. O. C. O_2$
,, Red hematite . .	$Fe_2 O_3$
,, Brown iron ore (yellow ironstone, ochre, &c.)	$F_2 O_3 + 3 HO$

Metallurgy of Iron.—The metallurgy of iron, or practical extraction of the metal from the masses of matter in which it naturally occurs, is, as has already been shown, a process of a chemical nature in the first instance, although the subsequent treatment is chiefly mechanical.

The first process with those ores which contain carbonic acid, water, and sulphur, consists in *roasting* them in a suitable furnace, in order to expel those ingredients, after which the calcined ores will be ready for smelting.

The operation of smelting depends, first, upon the tendency of most earthy and metallic substances to melt by heat; next, upon the affinities of the substances put into the furnace together as causing them to decompose each other in fusion, and form new compounds by recombination of the different elements, and then upon the excessive gravity of the metallic iron, which causes it to sink through the mass to the bottom of the furnace. As regards this last point, it may be observed the specific gravity of all the other solid materials likely to come together in smelting (even in a coal or coke furnace) is not much more than twice that of water, whereas iron is seven times as heavy as water, bulk for bulk, and its gravitating tendency is, therefore, more than three times as great as that of the materials by which it is surrounded. In charcoal furnaces the gravitating tendency is considerably greater.

The following diagram shows the materials which are usually brought to act upon each other in smelting furnaces, and the products which result from their mutual decomposition and recombination.

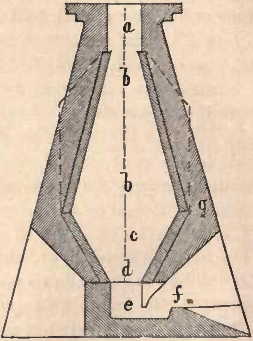


From this it will be seen that the fuel in combustion takes oxygen from the substances surrounding it, and its hydrogen passes away as water, its carbon as carbonic acid and carbonic oxide (C. O.), whilst the flux dissolves the siliceous matrix, and so frees the iron, which, melting by the heat, descends to the bottom of the furnace, leaving the slag and cinder floating above in a nearly fluid state.

The success of the process, of course, depends upon the means employed to carry it out; if there be plenty of air and plenty of fuel, heat can be generated sufficient to fuse the most refractory and voluminous materials. As, however, both air and fuel are costly in their supply, it behoves the smelter so to mix and proportion the quantities of his ores and fluxes that fusion of both shall take place at the lowest possible temperatures, that it shall be the most perfect, and that it shall afford the greatest facilities for the separation and descent of the metal. Also, that by the presence of suitable substances all, or as many as possible of accidental impurities, may be neutralised or taken up, so that after its first separation the iron shall not in its passage through the furnace enter into new and injurious combinations.

This was very tersely but accurately expressed a very long time since by Rogw, the Welsh founder, who said, "In order to make iron you must first make glass." To cause all the substances which do not pass away from the furnace in the gaseous condition,—of course excepting the iron,—to assume the condition of a glassy cinder is the aim of the smelter, and it is from the quality of the cinder coming from the furnace that its working is practically judged of. In early times, and even now with some, the determining of the proportions of the different materials involved a tentative process, and the rules laid down were the results of experience; but, with the development of chemical science and the extension of theoretical knowledge, methods of calculating those proportions and the dimensions of the furnaces have arisen.

Fig. 45.



In Fig. 45 a general outline of a blast furnace for iron-smelting is shown in vertical section. *a* represents the mouth of the furnace at which the fuel, fluxes, and ores to be treated are thrown into the furnace; the part *b b* represents the shaft or cuvette of the furnace; *c* the boshes, *d* the crucible, and *e* the hearth where the metal after reduction accumulates, being retarded by the dam *f*; *g* is termed the stack, and *h* the lining. Above the hearth the air necessary for combustion of the fuel is forced in through pipes called *tuyères* (pronounced tweers), or, more commonly amongst workmen, "tue-irons." It would be exceeding our intentions to describe the mode of constructing the furnace, as its form is only introduced as necessary to make clear the explanation of the method of extracting iron from the ores in which it naturally exists, but it is important to give some idea of its average proportions according to the fuel intended to be used in it. They are contained in the following table:—

Dimensions.	Charcoal.	High Furnaces using Coke.	Anthracite Coal.
Stack—height from foundation	25 feet.	50 feet.	35 feet.
width at bottom	28 ,,	50 ,,	40 ,,
width at top	16½ ,,	25 ,,	33 ,,
Cuvette—diameter at top	4 ,,	8 ,,	6 ,,
height of conical in-walls	25½ ,,	33 ,,	11 ,,
height of cylindrical in-walls	...	...	8 ,,
width of boshes	9½ ,,	15 ,,	12 ,,
angle of boshes	55 deg.	65 deg.	75 deg.
height of boshes	4½ feet.	10¾ feet.	11 feet.
Crucible—height of hearth	5 ,,	6¼ ,,	5 ,,
mean of length and breadth at top	2½ ,,	5 ,,	6 ,,
mean of length and breadth at bottom	2 ,,	4 ,,	4 ,,
height of tuyère above hearth	1⅓ ,,	2 ,,	1⅚ ,,
Approximate capacity	1000 cubic ft.	4200 cubic ft.	
Time of descent of charges	20 hours.	40 hours.	

The form of cuvette used with anthracite coal is shown by the dotted lines in Fig. 45. The action of the furnace upon the ingredients placed in it as they pass downwards, is as follows:—

In the upper portion of the shaft the ore is heated to redness—that is to say, it is roasted; the water, carbonic acid, and sulphur being expelled, and also the carbonic acid of the limestone in the flux escapes here. Further down, under the influence of more intense heat, the carbon of the fuel reacts upon the oxide of iron, carrying off its oxygen in the form of carbonic oxide, which on coming in contact with the atmosphere at the mouth of the furnace is consumed and converted into carbonic acid, occasioning in its combustion the bright flame which is seen to issue from the mouths of blast furnaces.

In the boshes, where the greatest temperature is maintained, the reduced iron melts and falls in drops upon the hearth, together with the silica, lime, and clay; these latter form a slag which floats upon the top of the iron, whence it can be drawn off when necessary. After having heated to 200 degrees or more the air requisite for combustion, it is forced by suitable blowing machinery into the crucible part of the furnace, where a heat of from 2,200 degrees to 2,550 degrees Fahrenheit may be produced.

In proportion as the melted iron and slag are drawn off from the hearth, fresh charges of ore flux and fuel are fed into the mouth of the furnace, and thus the smelting may be continuously carried on for five or six years, according to how the furnace holds out.

Fuel is one of the most important materials in smelting both as regards quality and cost. The object in the use of fuel is principally to obtain the requisite heat, but it also acts as a reducing agent in separating the metallic iron; hence its value will be proportionate to the amount of carbon it contains.

Wood, which may generally be taken as half carbon, and half oxygen and hydrogen, in the proportions to form water, is too poor in carbon to be serviceable, and compared with coke, bulk for bulk, its capacity to generate heat is but one-fifth of that of the latter. The presence of *hydrogen* in fuel, although it promotes inflammability, does not in blast furnaces act as a reducing agent on the ore, hence it is a disadvantage in fuels for smelting purposes. Therefore, *raw* coal, *turf*, *lignite*, *and brown coal* are unsuitable; but pressed and charred turf is extensively used on the Continent, and is said to produce a charcoal of peculiar value.

The general fuels used are wood in the form of charcoal, coal, and coke. Charcoal is prepared by charring wood either in stacks or ovens, and coke may be obtained from coal charred in gas retorts or in ovens constructed on purpose, the latter producing a much harder and better material than the former.

The yield of charcoal in proportion to the wood from which it is made, is found to be—

Charcoal prepared in kilns . .	18 to 22 per cent.
,, ,, ovens . .	20 ,, 25 ,,

The quantities of coke yielded by coal are very variable; but ovens give a yield about 10 per cent. greater than that obtained from gas retorts. Gas-coke is cheap, but unsuitable for furnace use.

Coal in coking yields . .	45 to 90 per cent.
Average of all qualities .	63 ,,

In regard to VOLUME, most coals expand in coking; some, however, do not alter in bulk materially, and those of which the earthy matters are principally of an aluminous character sometimes shrink.

The average composition of good coke may be thus represented:—

	Parts.
Carbon	82
Earthy matters	15
Volatile	3
	100

If coke contains more than 15 per cent. of earthy matters it is not suited for smelting, for, in all cases, these earthy matters can serve no useful purpose, and merely act as absorbents of heat.

Good coke may be inferred from its not having undergone great change in *volume* or *shape*, its *colour* being iron grey, or nearly that of graphite,—from its having a *lustre* more *silky* than metallic—from much *hardness*, *elasticity*, and *resistance to impact*,—from a texture more fibrous than compact, imparting *sonorousness* when struck, and its specific gravity should somewhat exceed that of water.

The following table shows the probable consumption of fuel per cent. of crude iron from ores of different degrees of richness:—

Kind of Ores.	Per-centage of Metal in Ore.	Per-centage of Fuel Consumed.	
		Charcoal.	Coke.
Fusible Ores . . .	25 to 30	66 to 90	110 to 150
” ” . . .	30 ” 35	90 ” 110	150 ” 180
” ” . . .	35 ” 40	110 ” 130	180 ” 220
Ores of mean fusibility .	30 ” 40	110 ” 140	180 ” 240
” ” .	40 ” 50	140 ” 180	240 ” 300
” ” .	50 ” 60	180 ” 210	300 ” 360
Refractory Ores . .	30 ” 40	160 ” 200	275 ” 350
” . .	40 ” 50	200 ” 250	350 ” 400
” . .	50 ” 60	250 ” 300	400 ” 500

Anthracite coal may be regarded as very similar to *hard-coked coals*, whose constitution its own much resembles, as is shown by the subjoined analysis:—

	Parts.
Carbon	88·7
Earthy matters	7·4
Volatile matters	3·9
	100·0

Fluxes.—It is but very seldom that ores of iron can be smelted by the fuel without the use of fluxes, which are matters containing no metal, or but very little, the object of their use being to promote fusion. Although the earthy bases most easily accessible, silica, lime, alumina, and magnesia, are, when taken singly, almost infusible, yet when combined, two and two, three and three, &c., they become fusible at readily attainable temperatures, and their addition to the ferruginous ores in the furnace materially assists in bringing the latter into a state of fusion. It may here be observed, as a practical maxim, that, in addition to the silica, alumina, &c., constantly present in the ores and fuel, the positive flux most commonly used is *lime*, in the form of shells, limestone or chalk, and the proportions in which it is supplied, on the average, are :—

In charcoal furnaces 1-14th the weight of the other solid ingredients;

In coke furnaces 1-8th the weight of the other solid ingredients.

In general, the whole of the solid material (except the metallic iron) may be taken as of the following composition :—

	Parts.		Parts.
Silica	45	to	60
Lime	20	,,	30
Alumina	10	,,	15
Magnesia	10	,,	25
Oxide of Manganese	15	,,	20
	100		

If all the four first mentioned are together present at one time, the most fusible proportions in which they can exist are—

	Parts.
Silica	35·2
Alumina	31·7
Lime	19·1
Magnesia	14·0
	100·0

The atmospheric air now remains to be considered as the only material used in smelting not yet treated of, and which must be regularly blown into the furnace to keep up the combustion. It is, therefore, of very great importance that its supply should be properly managed, and when the enormous quantities of it that are required are taken into consideration, its influence and effect can be better appreciated. The following is an average statement derived from practice :—

	Charcoal Solid.	Furnaces Gaseous.	Coke. Solid.	Furnaces. Gaseous.
Volume of materials in cub. ft. per. min.	0·295	900·0	1·06	3000·0
Volume of do. proportionate	1·000	3050·0	1·00	2830·0
Weight of do. in lbs. per min.	26·82	75·0	102·12	269·0
„ do. proportionate	1·00	3·022	1·00	2·634

In round numbers the volume of the air injected into the furnace in a given time is 3,000 times that of the other materials supplied, and its weight three times as great. The elements used above would also show that about nineteen tons of air are required for the manufacture of one ton of iron.

Iron is manufactured both with cold and hot blasts, and there has been a great deal of discussion as to the relative strengths of the products, a strong prejudice having existed against hot-blast iron ; but this opinion is exaggerated beyond what is warranted by actual experiments. The following statement shows the relative resistances of metals prepared with hot and cold blasts to resist strains of different descriptions :—

	Stretching.	Crushing.	Transverse.	Impact.	Stiffness.
Cold-blast iron	1000	1000	1000	1000	1000
Hot-blast .	913	1033	963	1005	935

The hot-blast method works easier, and produces a greater yield than the cold-blast, and by it more refractory materials may be reduced than by the latter, and it is also accompanied by a notable economy of flux and fuel; the saving in fuel on the average may be stated for

Coke furnaces at 32 per cent. from temperature of 330° F.
Charcoal do. at 20 " " 390° F.

Moreover, the use of hot blast allows of the adoption of certain *raw* coals, which could not otherwise be employed. As regards the general quality of the metal produced, it is a grey foundry iron with a more uniformly cubic crystalline form than is observed in the iron yielded by cold blast.

We must now speak of other products of the blast-furnace. The following analysis shows the composition of cinder averages when the furnace is doing good work:—

	Charcoal Cinder.	Coke Cinder.
Silica	53	43
Lime	22	35
Alumina	16	14
Magnesia	5	4
Protoxide of Iron	4	4
	100	100

The gaseous products of the furnace may be taken to consist on an average of—

	Parts.
Nitrogen	56
Carbonic acid	19
Carbonic oxide	16
Carburetted hydrogen	2
Steam	7
	100

The physical properties of iron now require our careful attention. The colour varies according to the proportion and mode of combination of the crude iron with its chief foreign ingredient, carbon, from dark grey to silvery white. Dark grey crystalline iron, with its small facets, is considered suitable for foundry purposes for making castings; as its colour brightens and becomes more silvery it is considered more suitable for conversion into wrought-iron.

In order to produce malleable or wrought-iron from crude iron it is necessary to eliminate the carbon contained in the latter, which is done by subjecting it to the action of atmospheric air while in a state of fusion, thereby oxidizing the carbon and carrying it off as carbonic acid or carbonic oxide. This process may be accomplished by stirring the molten metal about in a refinery, or in a puddling furnace, or by forcing air through the liquid mass, as in Bessemer's process.

Steel in composition is between cast and wrought iron, as it contains a certain proportion of carbon, that element existing in combination with the metal in the proportion of about 2 per cent. Steel may be made from malleable bars by keeping them for a length of time at a red heat in contact with powdered charcoal, then the iron, taking up a suitable portion of carbon, becomes converted into steel. This process is termed *cementation*, and the furnace in which it is carried out a cementing furnace.

Steel may also be produced from crude iron by Bessemer's process, by forcing air through the melted cast-iron until all the carbon except that required to constitute steel is eliminated from the mass under treatment.

The average specific gravities of different irons are (water being 1·00)—

Crude iron—foundry or grey iron . .	7·0
Crude iron—forge-pig or white iron .	7·5
Malleable iron	7·6

The effects produced by various foreign ingredients upon the quality of iron are worthy of careful study:—

Sulphur renders iron exceedingly fusible and brittle at all temperatures, especially when hot, thus giving rise to a quality which is known as red-short-ness.

Phosphorus imparts cold-short-ness to iron, making it brittle at low temperatures, though not to the same extent that sulphur does. Occurring in quantities not exceeding ¼ per cent., it increases the hardness without injuring the tenacity of bar iron, but in larger proportions it exerts a deleterious effect on the metal.

Antimony has a great affinity for iron, and, combined with it in the proportion of ¼ per cent., renders it very brittle when hot. When the metals are in proportion of their chemical equivalents—iron 28 parts to antimony 129—the elements are inseparable by the highest degree of heat.

Arsenic in the proportion of 1·6 per cent. has been noticed to entirely destroy the tenacity of iron.

Chrome united with iron produces alloys—hard, brittle, and crystalline. When the chrome is present to the amount of 60 per cent. the alloy is hard enough to scratch glass as deeply as a diamond. 1 to 2 per cent. hardens cast steel without diminishing its malleability.

Copper in the proportion of 1 to 2 per cent. increases the tenacity of crude iron, but its presence in malleable iron injures its property of welding, and in large proportions makes it red-short.

Manganese is most commonly found associated with iron in small quantities; up to 1¾ per cent. it hardens the metal without impairing its tenacity; it also diminishes the fusibility of iron. The tendency of ores containing manganese is to yield a metal easily convertible into steel.

Nickel renders iron whiter, less oxidizable, and less ductile than it is when unalloyed, otherwise the iron is of good quality.

Palladium, *Rhodium*, *Iridium*, and *Osmium* cause iron to become hard and brittle; the presence of any of these to the extent of 3 per cent. enables the iron to be tempered like steel.

The following table is interesting as showing how the quality of iron is affected by different proportions of carbon associated or combined with it:—

Iron half-converted into steel contains one 150th of carbon.

Soft cast-steel capable of welding contains one 120th of carbon.

Cast-steel for common purposes contains one 100th of carbon.

Cast-steel requiring more hardness contains one 90th of carbon.

Steel bearing a few blows, but unfit for drawing, contains one 50th of carbon.

First approach to steely-granulated fracture contains one 30th to one 40th of carbon.

White cast-iron contains one 25th of carbon.

Mottled cast-iron contains one 20th of carbon.

Carbonated cast-iron contains one 15th of carbon.

Super-carbonated crude iron contains one 12th of carbon.

Cast-iron and steel admit of being prepared in hard or soft state. Thus, if a casting is required to have a portion of its surface hard, that side of the mould consists of some substance (as iron) which will rapidly cool the metal which is run in contact with it, thus producing a very hard surface. Castings thus made are called, from the method employed, *chilled castings.*

Steel is hardened by raising it to a red heat and plunging it into salt water; but this process renders it absolutely hard and brittle, hence, for most purposes, this must be lowered by *tempering,* which consists in heating the hard steel to a temperature depending upon the purpose for which it is intended to be used; the right temperature is commonly recognised by the workman from the colour of the film of oxide which forms on the steel, as shown by the following table :—

Colour of Film.	Temp.	Use.
Very pale straw yellow	430 deg.	Tools for metal.
A shade of darker straw yellow	440 ,,	
Darker straw yellow	470 ,,	Tools for wood and screw taps, &c.
Dark yellow	490 ,,	
Brown yellow	500 ,,	Hatchets, chipping chisels, and other percussive tools, saws, &c.
Yellow tinged slightly with purple	520 ,,	
Light purple	530 ,,	
Dark purple	550 ,,	Springs.
Dark blue	570 ,,	
Pale blue	590 ,,	Too soft for the above purposes.
Paler blue	610 ,,	
Paler blue tinged with green	630 ,,	

Iron castings are rendered soft by abstracting a portion of their carbon, whereby they are partially (or, if thin, entirely) changed to the condition of malleable iron. In order to effect this decarbonization the castings are put into boxes or cases surrounded with pounded ironstone and submitted to heat, or metallic oxides may be used. Thus the carbon is oxidized out of the metal to a certain depth from the surface. After being heated for a sufficient length of time the castings are allowed to cool very gradually.

Wrought-iron may be case-hardened by a very simple process, which converts the outside of the forging or casting for a certain limited depth into steel, which is hardened in the usual way by sudden cooling. The articles to be case-hardened are placed in a case and surrounded on every side by powdered bones, hoofs, skins, or leather, with which the case is filled up, being then securely fastened air-tight, and put in a furnace raised to a red heat, and maintained at that temperature for a period of from one to five hours, according to the depth to which it is desired that the case-hardening may penetrate. On removal of the partially-converted articles, while still hot, they are hardened by sudden immersion in cold water.

A very thin, or even perhaps discontinuous, coating of steel may be produced on iron by burying the latter at a red heat for two or three minutes in powdered ferrocyanide of potassium (the common yellow prussiate of potash of commerce), a salt which is prepared from various animal matters.

The steely surface thus obtained is not nearly so good and durable as steel made in the usual way and hammered, and generally the cementation does not penetrate to a depth of more than one-sixteenth of an inch; nor is it necessary that it should do so, as the object of case-hardening is to increase the durability of the surface without impairing the general strength and toughness of the article operated upon.

The introduction of cheap steel has done much to decrease the practice of case-hardening certain small articles of manufacture. According to Dr. Thompson's analysis of some cast-steel from a manufactory near Glasgow, it contains a very slight proportion of silicon, but this does not appear to be essential. The composition of the sample was

	Parts.
Iron	99
Carbon with some silicon . .	1
	100

This very nearly corresponds to the formula, $Fe_{20}C$., which would give

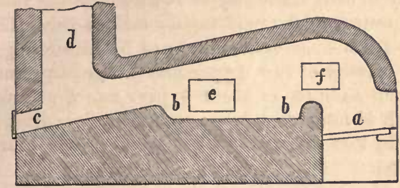
	Parts.	Parts.
Iron . .	28 × 20 = 560 . .	98·94
Carbon . . .	6 . .	1·06
		100·00

Copper is the next material demanding attention. The ore from which the copper of commerce is principally obtained contains the metal in combination with sulphur, as a sulphuret or sulphide of copper, generally accompanied by sulphide of iron, as in *copper pyrites;* thus, in addition to the sulphur, there is the iron to be eliminated. The process of extracting copper from its ores is exceedingly lengthy and tedious, and requires great care on the part of those conducting it; and it consists of a considerable number of separate operations, through all of which the material must pass before it is fit for the market. In the first place, the ores must be roasted or calcined, in order to convert the copper into oxide of copper and the iron into protoxide of iron, the sulphur being expelled in the form of sulphurous acid. Secondly, the roasted ore must be melted with charcoal and some siliceous substance in a suitable furnace, by which means metallic copper and carbonic oxide are formed from the oxide of copper and charcoal, and silicate of protoxide of iron (or iron slag) from the protoxide of iron and quartz. This appears simple enough as thus stated, but the actual establishment of the reactions to bring about the desired end in practice is in reality so difficult that the roasting and melting have to be repeated from ten to twenty times alternately in some cases, in order to get rid entirely of the sulphur and iron with which the copper is associated. The melted mass, which is obtained when about half the sulphur and iron is removed, is called *matt*, or crude copper, and *black copper* when it contains only about 5 per cent. of these two substances.

The ultimate refining of black copper is effected by remelting the metal, exposing it at the same time to the action of the air, whereby the remaining iron, sulphur, and foreign metals, such as lead and antimony, which may be present, are oxidized before the copper (which has a less affinity for oxygen), and thus are separated from it. During the various processes some of the slags which are rich in copper may be reworked with fresh ore. In some stages the removal of the sulphur may be facilitated by stirring the molten metal with a stick of green wood, which probably acts by the moisture supplied by it decomposing the sulphide of iron, and forming oxide of iron and sulphuretted hydrogen.

The species of furnace chiefly used in the reduction of copper is that known as the reverberatory furnace, of which a vertical section is shown at Fig. 46; it admits of the regulation of the chemical reactions to a very great nicety. *a* is the fire-grate, and *b b* the bed or sole of the furnace, whereon the materials to be treated, together with any re-agents which may be requisite, are placed; *c* is an outlet which can be opened at pleasure for the withdrawal of slag, &c.; *e* and *f* are doors to allow of the observation of the state of the furnace; *d* is the chimney-shaft. The charges of metal are drawn through a door in the side of the furnace.

Fig. 46.



Now, it is evident in this arrangement that, by regulating the quantity of fuel and air admitted to the furnace, there may be either excess of air passing over the sole, producing an oxidizing effect, or, on the other hand, by reducing the quantity of air below that requisite for the complete combustion of the fuel, there will be carbonic oxide passing over the materials tending to deoxidize them.

When the ores are combined with oxygen instead of sulphur, the operation of working them is much easier, as they yield metallic copper by merely treating them with charcoal, which abstracts the oxygen; but such ores are unfortunately too rare to afford anything approaching to a sufficient supply of copper to meet the demand.

Copper possesses certain physical characteristics which render it especially suitable to particular purposes. It is slow to oxidize when compared with iron; is tough and extremely ductile, the latter property allowing wrought copper to be drawn into exceedingly fine wire and beaten into almost any conceivable shape. Thus copper pans, kettles, and parabolic reflector-backs may be beaten up out of flat sheets of copper. It is useful for lining air-pumps, and as a material for other pumps when alloyed with some other metals, and more especially in such machinery as is subject to sea water or foul water, which would rapidly corrode iron. Copper may be to some extent hardened by hammering, and the tenacity of cast copper may be greatly increased by the addition of about 3 per cent. of phosphorus, which is introduced into molten copper without great loss by first coating it with a layer of copper for protection.

Lead, the next of the useful metals upon which we shall dilate, is largely used in the arts. The following ores of lead are the most important:—

Galena, or sulphide of lead, has metallic lustre and a crystalline structure distinctly derived from the cube. It is a compound of lead and sulphur in atomic proportions, consisting of

	Parts.
Lead	86·67
Sulphur	13·33
	100·00

and has a specific gravity of 7·6. Its colour is blackish grey.

Native minium, or red lead, is of a lively red colour, but sometimes inclining to orange; it has an earthy aspect, and specific gravity from 4·6 to 8·9: it is rare.

Carbonate of lead (white lead), when pure, is colourless, and transparent like glass; its specific gravity is from 6 to 6 7.

Galena, or sulphide of lead, is, however, the only ore which is sufficiently abundant to become the object of mining and metallurgy, and in its treatment, after the due sorting, cleaning, and grinding, is usually reduced in reverberatory furnaces. The sulphur, in combination with the metals as sulphides, is so firmly associated with them by chemical affinity that it cannot easily be expelled, hence it is necessary to have recourse to a circuitous method; first, the sulphide must be converted into an oxide of the metal, and the oxygen must then be expelled to free the metal. The galena is heated or roasted with free access of atmospheric air, the result being that the lead becomes oxide of lead, the sulphur escaping as sulphurous acid, but there is also a small portion of sulphate of lead formed during the process.

After roasting, then, the galena leaves a mixture of oxide of lead with some sulphate of lead, which may be reduced by heating in a blast or reverberatory furnace with charcoal.

Another method of freeing lead from sulphur consists in heating the galena with a metal which has a greater affinity for the sulphur, and therefore replaces the lead: such a metal is iron. Thus iron and sulphide of lead, heated together, will yield lead and sulphide of iron. In the reaction one atom of iron replaces one atom of lead: hence 28 lbs. of iron will suffice to throw down 104 lbs. of metallic lead.

Physically the characteristics of lead are distinctive; it has little or no elasticity, is very ductile and flexible, possesses but little strength in any direction, and is fusible at a low temperature (600° F.), and has a very high specific gravity—11·5.

TIN is a white metal possessing considerable lustre, in bars; it makes a peculiar cracking noise when bent; its specific gravity is 7·2, and melting point 446° F.

Tin is prepared in the smelting houses in a simple manner from tin stone, which consists of peroxide of tin with some arsenic and iron. The ore is first finely stamped, after which it is roasted, whereby the arsenic is volatilized and the iron oxidized. It is then washed with water, whereby the lighter particles of stone, and to a great extent the oxide of iron, are carried away. Finally, it is fused with charcoal in a blast furnace, and a reaction taking place, carbonic acid and metallic tin result, the latter flowing from the bottom of the furnace. In the mechanical arts tin is almost entirely used in connection with other metals.

ZINC has a specific gravity of 6·8, is a white metal, and will show a certain amount of ductility at a moderate heat. It is prepared from carbonate of zinc, which by the miners is called *calamine*, in order to convert which into metallic zinc the carbonic acid and oxygen must be expelled.

The first is effected by calcination in furnaces, the latter in the same way as is applied to iron ores, by heating to redness with charcoal; but this cannot be done in open furnaces, as the reduced zinc would evaporate and burn, again becoming converted into oxide of zinc. The vessels used in which to treat the zinc ores are called muffles, and are, in fact, a species of retorts made of clay; into these retorts the calamine and charcoal are put and raised to a red heat, then the carbonic acid and evaporated zinc pass away through the neck, the former to escape, the latter condenses and falls in drops into a vessel of water.

The zinc of commerce always contains a small quantity of iron and lead, but if the amount of the latter is more than 1½ per cent., the zinc becomes brittle and cannot be rolled into sheets even when heated.

There are several alloys which are largely used in the construction of machines, and which must therefore not be overlooked. An alloy is a mixture or a *mechanical* combination of two or more metals, in contradistinction to a compound which is a *chemical* union; but although the combination of the different components is mechanical, yet the physical properties of the alloy are not to be deduced from those of the metals entering into its composition.

Brass, much used for bearings for the revolving shafts of machinery, and for bushes, and various minor details, consists of copper and zinc. Gun-metal or bell-metal is a very hard alloy, useful for small cams, valves, pumps, &c.; it is composed of copper and tin. There are also other alloys of copper, such as Muntz's yellow metal, German silver, &c., which are applied to specific purposes.

The following is a list of the most useful alloys, and the proportions in which their component metals are associated:—

Bismuth 1, tin 2—Cowper's alloy, for rose-engine and eccentric-turned patterns to be printed from.
Bismuth 2, lead 4, tin 3 } Constitute pewterers' soft solders.
Bismuth 1, lead 1, tin 2 }
Copper 5½, zinc 1—red sheet brass, made at Hegermühl.
Copper 2⅔, zinc 1—brass that bears soldering well.
Copper 2, zinc 1—ordinary brass.
Copper 16, zinc 9 } The two extremes of Muntz's metal.
Copper 16, zinc 10⅔ }
Copper 4, zinc 3—spelter solder for copper and iron.
Copper 1, zinc 1—spelter for brass.
Copper 1, zinc 8—metal used for lap and polishing discs.
Copper 16, tin 1—soft gun-metal.

Copper 12, tin 1—gun-metal for mathematical instruments.

Copper 10, tin 1—wheel metal for small-toothed wheels.

Copper 8, tin 1—Brass ordnance or hard bearings for machinery.

Copper 6, tin 1—very hard bearing metal, too brittle for general use.

Copper 2, tin 1—speculum metal.

Copper 2½, lead 1—pot metal.

Copper 32, tin 3, zinc 1—pump metal; has great tenacity.

Copper 32, tin 5, zinc 1—bearing metal for very heavy weights.

Lead 3, tin 1—coarse plumbers' solder.

Lead 1, tin 2—fine solder.

There are a variety of other alloys made, but they are used for purposes which do not come within the compass of the present work, being applied to the manufacture of articles of ornament rather than utility, or as substitutes for the precious metals.

CHAPTER XIV.

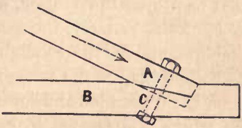
THE MANIPULATION OF TIMBER AND THE METALS.

IT is most essential that anyone designing machinery shall be thoroughly acquainted not only with the intrinsic properties of materials, but also with the methods of manipulation by which they are converted to such purposes as they may suit. Otherwise it is not only possible but probable that details of machines may be drawn and specified to be made of materials which are highly insuitable, or which can be wrought into the required form only at great expense, or in some cases not at all.

TIMBER.—Although timber is but little used in the construction of machinery in localities where iron is plentiful and cheap, yet in some places it is applied for framework or even for some of the moving parts; hence it is necessary to explain the proper method of making the connections between different parts so as to secure the requisite strength and rigidity.

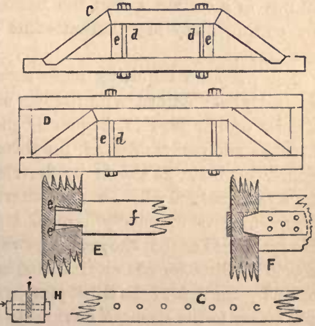
In Fig. 47 *A* represents an inclined timber liable to a thrust; it is jointed to the tie *B* as shown, the end resting in a notch, and having a rib or feather on it, shown by the dotted line *c*, to maintain its lateral position; it is held in its place by a bolt and nut, or by an iron strap passing the end of *A* and bolted through *B*.

Fig. 47.



A trussed frame is illustrated at *c*, Fig. 48; it consists of three top pieces in compression, one horizontal tie at the bottom, two upright struts *e*, *e*, and two iron tie-bars *d d*, by the tightening up of which the whole frame is brought firmly together and the different parts are prevented from slipping out of their proper positions.

Fig. 48.



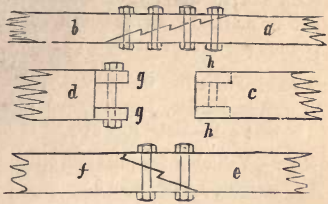
By an addition to this arrangement a rectangular frame is produced as shown at D; it is in construction similar to the last.

The parts of frames are in many instances joined by means of tenons and mortises, and in making these particular care should be taken. *E* is a section of a bad or slovenly joint, *F* of a good one; in the former the mortise is cut true on the surface, but somewhat undercut towards *e e*, hence the tenon *f*, being parallel, will not fit firmly, and there will therefore be a tendency to wriggle or shake about, which, if the joint be subject to vibration, will soon render it defective. In *F*, on the contrary, the mortise is cut to a pattern or template, and is tapered slightly so as to be smaller at the bottom than at the surface where it commences; the tenon is cut paralled and forced or driven into the mortise, where it is secured by an iron strap, as shown by the dotted lines passing round the joint and secured by bolts to the timber carrying the tenon; this strap may rise above the surface of the timber, or a recess may be cut to allow of its lying flush where necessary, but of course to a certain extent the framework is weakened by cutting away any portion of its substance to form such recesses.

For purposes requiring more rigidity than can conveniently be obtained with timbers of a reasonable size, a piece of bar iron is frequently placed in the centre between two layers of wood, the three being secured together by bolts, as shown by the elevation G and the transverse section H. In the latter *i i* is the piece of iron, which is commonly termed a flitch plate. It is always placed so that the bending strain upon the timber acts in the direction of *i*, as, if it acted in the direction indicated by the arrow, the flitch plate would not materially add either to the strength or rigidity of the element.

When timbers require to be joined in the direction of their length, it is effected by a process termed scarfing, which may be either lateral or transverse. Three methods are shown in Fig. 49; in the two lateral methods the ends of the pieces to be joined are tapered off and notched according to the direction in which the strain will act; the extremities thus prepared are placed in contact, and retained so by bolts and nuts, as shown. *a b* represents a suitable scarf to resist a tensile strain, and *e f* the mode of notching when the timber is subject to a compressive strain; *c*, *d*, are the ends of two timbers prepared for transverse scarfing; the tenon-like projections *g*, *g*, on the piece *d* enter the recesses shown by the dotted lines at *h*, *h*, on the piece *c*, and are there secured by a bolt and nut. This style of scarfing is chiefly suitable for compressive strains, such as come upon uprights, &c.

Fig. 49.



When timber is used for the manufacture of spring beams to receive accidental impact, as in the spring beams of Cornish pumping-engines, &c., they are made of a number of thin layers of timber put together somewhat after the fashion of carriage springs, the ends being carried in iron boxes or straps which, while holding them laterally in position, will yet allow them in bending to slide slightly one upon another; similar beams may be used to quicken the strokes of tilt-hammers, &c.

We will conclude our remarks upon timber by showing the different purposes to which the various species are specially adapted, together with their weights, the latter being given for them both in the green or wet state and in the dry or seasoned condition; the first will be marked *g*, the second *d*, and the weights given in pounds per cubic foot:—

Acacia—For sills, wall-plates, posts, fences, and tree-nails, harder, tougher, and more elastic than the best oak—weight, *g* 63·2, *d* 48·5.

Alder—Valuable for piles and other subaqueous work—weight, *g* 62·3, *d* 39·5.

Ash—Useful for beams, joists, and wheels—weight, *g* 65·0, *d* 50·0.

Beech—Useful for piles and for teeth of wheels—weight, *g* 66·0, *d* 50·0.

Elm—Used for planking, piles, and wheels—weight, *g* 70·0, *d* 48·5.

Fir—Is much valued for its timber, which is used for a great variety of purposes. Its quality varies according to the soil on which it is grown—weight, *g* 54 to 74, *d* 31 to 41.

Pine—Of this there are several varieties, much used for planking, &c.; it is of the same family with fir.

Hornbeam—Used for the teeth of spur-wheels—very tenacious and durable, hard and heavy—weight, *g* 64, *d* 51.

Laburnum—Valued for making pulleys and blocks—weight, *d* 53.

Larch—A wood useful for all kinds of carpenters' work, and for beams and principals of frames.

Lignum Vitæ—A very dense, hard wood, used by millwrights—weight, *d* 83·3.

Mahogany—Used in various parts of machinery—weight, from 35 to 53.

Oak—Very useful where rigidity is wanted—weight, *g* 74, *d* 53.

Poplar—For flooring and boards generally—weight, *g* 58, *d* 38.

Poplar—(Black poplar)—Used by turners and wheelwrights—weight, *g* 60·5, *d* 29.

Walnut—A solid compact wood which will not warp or crack, but bends under ordinary weights, and, therefore, is not suited for machinery.

Willow—(Red willow)—Is light, pliable, elastic, and tough. Before wheels were rung with iron this kind of willow was much employed by wheelwrights for making the fellies, as it will endure under friction and exposure a much longer time than most other woods.

Iron Wood—The hardest wood known; it is durable, but not much used on account of the great difficulty of working it.

We shall now proceed to consider the manipulation of cast-iron in forming it into the various shapes required in the construction of machinery.

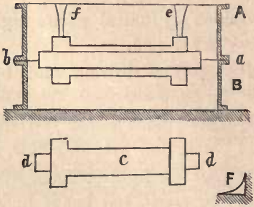
PATTERN-MAKING.—In the ordinary method of making castings, such as are of moderate size, green sand, or rather a mixture of green sand, loam, &c., is used, the impression of the body to be cast being imprinted upon it by a representation or model in wood or other material of the object to be produced.

The model or "pattern," as it is technically called, must be made somewhat larger than the proposed casting is intended to be, in order to allow for the contraction of the metal in cooling down from the molten state. The amount of contraction commonly allowed is,—

For cast-iron one-tenth of an inch per lineal foot.

For brass one-eighth of an inch per lineal foot.

Fig. 50.



A simple example will render the mode of making patterns and thence forming the mould and casting easily comprehensible. Let it be supposed that a distance piece of cast-iron is required in the form of a pipe with slight flanges.

The pattern will appear as shown at *c* in Fig. 50, being made of the shape of the required casting, with the proper allowance for contraction. Instead, however, of being made hollow, there is attached to each end of the, pattern a projection *d*, corresponding in shape and size to the hollow through the distance piece; these projections are called "core prints," and their use will presently be explained. In preparing patterns great care is to be taken that they may be accurate and of sound, well-seasoned wood, in order that when put into contact with the damp sand they may not warp, or twist, or split. A certain amount of protection against damp is afforded by the use of a good varnish, which also materially affects the readiness with which the pattern leaves or parts from the sand. Large patterns are usually painted, but for small ones the following varnish will be found very useful :—Take a convenient quantity of good shellac and dissolve it by means of a gentle heat in a sufficient amount of methylated spirit; this may be then coloured with "vegetable black;" the varnish will then be fit for use; it should be applied coat after coat as each one dries, rubbing down each coat with glass paper until the grain of the wood ceases to be discernible and the pattern presents an uniformly smooth surface. This varnish is perfectly waterproof and very durable.

In forming the pattern care must also be used that there be no sharp or well-defined internal angles left, as at such the casting will be weak from the shrinking of the metal; hence, where these arise they should be filled in with rounded fillets, as shown at F, Fig. 50. If the fillets are large they may be made of wood, but if small, of some composition such as Burgundy pitch, rosin, &c. Glueing should be avoided as much as possible in pattern-making, the connection of the different parts being made by means of nails and screws wherever practicable, but where glue must be used it should be properly prepared. The best glue should be taken and broken into small pieces and then allowed to soak in cold water for from 24 hours to 48 hours, after which it is put in a glue-pot and dissolved by heat in the usual manner, the heat not being allowed to exceed 212 degrees. The glue may be strained through coarse muslin if there be many impurities in it. The pattern being completed, it is ready for the foundry. The hollow within the casting is formed by a "core" of sand running through the mould, and in cases where the cores are of special shapes the pattern-maker must supply core-boxes in which they may be pressed into form. These, however, are not required when the cores are cylindrical, as such cores are roughly turned, of different diameters, and in lengths from which portions may be cut off as required. The pattern and core boxes being finished pass into the hands of the moulder.

Moulding and Founding.—The apparatus used to hold and support the sand in which the impressions are made from patterns to give form to the castings are called flasks, and consist of boxes without either top or bottom, made so as to fit accurately together.

A and *B* in Fig. 50 represent two flasks fitted together, and kept in their proper position by pins or pegs, *a*, *b*, fixed in legs on the top flask, and passing into holes in legs on the bottom flask. In the first place, one flask is taken and rammed full of sand, which is made smooth and level on the surface, then in the centre of it is scooped out a cavity, in which the pattern is buried to half its depth, or to some other distance, according to its shape, but always so that it may, when required, be removed from the sand without adhesion, which tends to cause breakage of the mould. Then on the surface of the sand is sprinkled coal-dust or other material, which will prevent other sand from adhering to that already rammed down; this is called "parting" sand, because it ensures the parting of the mould when required. The flask *A* being undermost, the flask *B* is fitted on to it, and filled up with sand, which is carefully rammed down so as to lie close all round the pattern and form an exact matrix to it. The flasks are then turned over; *A* being now on the top, is removed, emptied, and refitted on *B*, then filled and rammed down with sand, certain pegs, *e*, *f*, being placed in it to allow of the metal being poured into the mould and to let the steam and gas evolved by the heat escape. The flask *A* is now again lifted off from *B*, and the pattern, after being lightly tapped with a hammer, is taken out of the sand; the mould is then, if broken anywhere, mended and smoothed by the moulder with suitable trowels, after which the core is placed in its proper position, being supported at the ends by the indentations made by the core prints.

The cores, if heavy, are made on iron rods, and if very long are supported at intervals by broad-headed nails, which, of course, remain in the casting; they are made of sand, with straw or cow-dung to bind them, after which they are dried in a core-stove to render them firm.

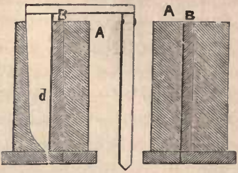
The core replaced, the top flask is again put on the lower one and firmly fixed to it, and the pieces *e* and *f* having been removed, the molten metal is poured in, and, spreading round the core, it fills the mould, assuming the required shape. When the casting is sufficiently set the mould is opened, and the "heads" filling the places of *e* and *f* knocked off, and on cooling the rough skin of sand which, under the influence of the heat of the iron, vitrifies on to the casting, is, when necessary, rubbed down with a piece of hard coke.

Precaution must be taken that the sand be not too damp, else there is danger of the liquid metal being blown about the foundry by the steam formed, and ample room should be allowed for the escape of gases and vapours. On the other hand, if the sand be too dry, or having too much baked sand amongst it, the surface of the mould will be apt to peel off, and the casting will accordingly be scaly.

Moulding in loam is effected without a pattern, and is the method generally used for large castings of bodies symmetrically described by the revolution of surfaces, such as cylinders, &c.

Let it be required to mould a large cylinder in loam. Upon a cast-iron ring of suitable size build a well of loose bricks *A A*, around which place a layer of kneaded loam; then, at a proper distance from the centre, with a scraper *d*, carried on a central revolving spindle, strike the surface of the loam to correspond with the inside of the cylinder. Then thoroughly paint the surface of the loam in order to ensure its parting. Next put on another layer of loam and strike it to the radius of the outside of the cylinder. Outside the cast-iron ring above-mentioned place another, and adjust it to the former by set screws. Having painted the second layer of loam, which represents the thickness of the metal in the cylinder, surround it by loam supported by brickwork where necessary. Now lift up the outer ring clear of the inner ring, and break away the layer *B B*, representing the thickness of metal; mend and complete the mould, and dry with a fire in the centre. The cylinder being cast, the metal runs into the space previously occupied by the layer of loam *d*. The casting is done as usual, but as soon as it has sufficiently set to bear its own weight the brickwork within it should be loosened to allow of the free contraction of the metal.

Fig. 51.



Large cylinders, columns, and long castings generally are much stronger if cast in a vertical position than in a horizontal, but all small castings should be run with a good head to consolidate the metal of the casting, and so to prevent its being honeycombed.

Before leaving the foundry castings are trimmed or dressed, by having any ribs, seams, or feathers chipped off; but it is not advisable to take off more of the sand-skin than is requisite for rough castings intended for purposes where they will be subject to exposure.

It is well for those inspecting castings from the foundry, if any blow-holes are suspected, to put them over a forge fire for some minutes, as it may sometimes occur that such holes are filled up by the founder with lead, which, while concealing the fault, does not obviate its injurious character.

For hardening and softening of iron see chapter "On Materials."

Forging and Welding.—Wrought-iron is reduced to the shapes required for the purposes of manufacture by beating or rolling it when hot; thus masses are passed through heavy rollers to form plates and bars, or wrought under tilt and sledge hammers, either alone or with moulds to shape them. These moulds are called "swages" and "swage-blocks." Malleable iron at nearly a white heat, and steel at a low red heat, may be shaped into almost any required form by the smith, but by a process which is more tedious and costly than that of founding cast-iron; hence the wrought metal is not used for usually-formed elements unless great strength or tenacity is more an object than economy. To render forgings thoroughly good, elastic, and homogeneous, the hammering should be continued lightly until they are nearly cold; thus will the density of the iron be increased, and its toughness proportionately so.

In working cast-steel under the hammer, it must always be borne in mind that a low, cherry-red heat is sufficient, as, if the steel be made too hot, it will literally crumble under the blows and be useless; but some of the inferior steels will bear a much higher temperature without injury.

The process of welding pieces of iron together is sufficiently simple. The two portions to be welded together are raised to a bright white heat, and then, having been dipped in a flux consisting of white sand, or white sand and salt, or borax calcined with some essential hydrocarbon oil, they are laid together and hammered until they become firmly united. The hammering should begin in the centre of the sections to be united, and gradually proceed outwards, so as to drive out any particles of scale or slag instead of closing it in the weld or "shut," as it is commonly termed.

The best flux is that which will the most readily dissolve the iron scale,—which is sure to form even from momentary contact with the atmospheric air,—and reduce it to the most liquid condition. Until lately no method was known of detecting the presence of a flaw or imperfection in a weld lying deep in the metal, but it has been discovered that by passing a magnetic needle, under certain circumstances, over a weld in a piece of iron, it will indicate the soundness or otherwise of the shut, and, if any defect exists, show the position and extent of such defect. The welding of iron into steel has always been regarded as a work of some difficulty, on account of the different temperatures at which the metals are worked, as the welding heat of iron is sufficient to burn steel, and the heat of steel is not high enough to allow of the welding of iron.

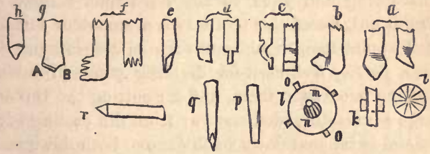
In addition to forming iron by rolling, hammering, and pressing, the only other manipulations commonly performed on *hot* iron are cutting and punching, but even this latter is but seldom done. Iron railway bars are cut to suitable lengths, while hot, by circular saws.

CHAPTER XV.

ON THE WORKING OF METALS COLD.

In the last chapter the mode of forming iron when hot has been explained, both for cast and wrought or malleable iron, and now we shall proceed to describe those processes which are resorted to in finishing the metal when cold, such processes comprising turning, planing, shaping, slotting, filing, chipping, &c.

Fig. 52.



The tools generally used are shown in Fig. 52. *a* represents side and top view of a *point tool* for turning, planing, or shaping metal. This tool is used for taking the first cuts; it may be regarded as forming a superficies geometrically, as it makes a number of cuts in straight lines side by side, being moved at right angles to the line of cut after every stroke when planing. This tool turns out true work, but, from being rigid and unyielding, will not give way to any hard places, hence sometimes leaves a somewhat rough surface. In cutting cast-iron the metal, being brittle, falls away in chips or as dust, and no lubricant is required to cool the tool; but when wrought-iron is being operated upon, the shavings, longer or shorter, according to circumstances, by rubbing on the tool soon heat it; hence it is usual to keep wrought-iron or steel moist by the constant dripping from a suitable can of a ley of soft-soap and water on to it at the point where the tool is acting. When this tool is used in a lathe the line cut by it is a very fine screw, or helix.

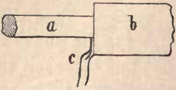
b is a point tool for inside work, such as for boring out small cylinders and hollow work generally.

c shows a plan and side view of a *spring tool*, which is used to finish work off with a smooth surface; its edge is broad, and slightly rounded at the corners, in order to prevent its digging into the work at those points. From the thinness of its extremity and its bowed form, it will spring and yield to any hard spot, instead of tearing it out, hence this tool leaves a smoother surface than the point tool, though not such an accurate one.

d is a *parting tool*, used for dividing pieces of metal, for cutting grooves in them, and for cutting the threads of large square-threaded screws; from the cutting edge the metal is tapered down in thickness, both downward and backward, in order that it may clear the cut, and not become jammed in the metal on which it is used.

e is a *side tool*, for taking heavy cuts when the dimensions are to be much reduced; its action is shown reducing a cylindrical piece supposed to be in a lathe at Fig. 53. *a* is the reduced part, and *b* the part being reduced by the tool *c*.

Fig. 53.



To return to Fig. 52, *f* shows *screw tools* for cutting small screws, both external and internal; the cutting edges are inclined so as to give the proper angle to the thread of the screw.

g is a *machine drill*, for use in the lathe or drilling machine; the half of the cutting edge *A* is facing and that *B* on the other side. Hand drills, which do not continuously revolve in one direction, are ground alike on both sides, and act rather by scraping the metal away than by cutting it; but the edges turning, first one, then the other way, must be thus ground.

h is another form of drill, on which the edge is formed by cutting away half of the conical extremity, as shown.

i is a drill formed of a cylindrical bar, having the end of it cut up into edges, so as to cut away the material against which it is pressed; but this kind of tool is best suited for enlarging holes already drilled, as otherwise there is some difficulty in clearing out the chips.

k shows a small cutter, or *boring bit*, fixed in a slot in a bar; this bar passes through a hole already made, and the cutter either "trues" it or enlarges it, as the case may be.

l shows a *boring head* carried on a shaft called a *boring bar;* it is furnished with two or more cutters, or boring bits, *o*, *o*. *m* is a screw working in a nut in the head, and laying in a slot or groove in the bar *n*, and by it the head is caused to move along the bar, so as to carry the tool forward as the work progresses. This head and bar are used for boring large cylinders. *p* and *q* respectively show a *chipping chisel* with a broad edge, and one with a point of a diamond shape. *r* is a *centre punch*, used for marking centres and other guide points in setting out work.

The edges of cutting tools require to be carefully formed, according to the nature of the work for which they are intended, and, as a general rule, it may be taken that the harder and rougher the work the more obtuse should be the angle of the cutting edge. Thus, we see, in heavy shears for cutting thick iron the edge of the shears is, very nearly, bounded by a right angle.

Most machine tools, after being hardened, are tempered down to a pale straw yellow colour; but drills and chisels require a lower temperature.

External screws are sometimes made in *dies*, and internal with *taps* or *hobs*, but in this method the threads are formed partly by cutting and partly by squeezing up the metal into shape—hence the screws thus produced are inferior to those which are cut by screwed tools.

In addition to those tools already mentioned may be named *punches*, which are merely hardened steel cylinders, that are driven by force through metal which is required to be perforated. *Bow-saws*, for metal; *rotary-cutters*, which are made of all descriptions and sections, having cutting-teeth both on their peripheries and sides, according to the purposes for which they are designed; *hammers*, of various descriptions; and

Files.—These are numerous in form and size, and also vary widely in their coarseness of cut. Those on which the cutting edges are continuous from side to side, without intersections, are termed *floats*, and those which have small points cut upon them over their surfaces are *rasps*. The commonest descriptions of files have their teeth cut by first making a number of serrations from side to side, and parallel with each other, at an angle of somewhat less than 90° to the side of the file, close together, and from end to end, and subsequently crossing these with similar cuts in an opposite direction, so as to form a number of fine cutting or scratching points all over the surface of the file. The hardening of files must be conducted with care, in order to prevent their warping or twisting in the process. File-making is a special manufacture, and used to be done entirely by hand; but of late years file-cutting machinery has been introduced. The coarseness of files is indicated by distinctive names, as *rough*, *second-cut*, *bastard*, *smooth*, and *dead-smooth*. If any of the sides of the file be left uncut, in order to prevent it from injuring any work on which it may be used, that is called a *safe-edge*.

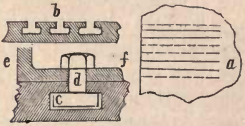
The different shapes of files are divided—first, according to their plan view, into *parallel* and *taper* files; then, according to their sections, into *flat*, *square*, *round*, *crossing*, *three-square*, *half-round*, &c.

To become an adept in the use of the file requires considerable practice, and there are some men who never will make good fitters. As the file is passed to and fro over the work, the constantly varying leverage of the two hands tends to cause the file to rock, and so round off the edges of the work, thus producing a surface which, instead of being a true plane, approaches the form of a cylinder or spheroid. In order to avoid this defect the pressure of the hands must be accommodated to the motion of the file. In order also that the files may not wear out unnecessarily quickly there should be no pressure upon them during the back stroke, when it would be liable to break the points off the teeth.

To get a surface as true as it can be made the final tool used is the *scraper*. The surface is applied to a true plane, called a surface-plate, which has been previously smeared over with ruddle or other colouring matter; this, of course, marks the highest points on the surface to be made true, and those points are scraped down, and the process repeated until the marking becomes uniform all over the surface under treatment.

In this brief description of the tools it must not be supposed that we intend to present anything approaching to an exhaustive account of those to be found in the workshop, as such a course would not only occupy an inconvenient amount of space, but would also be of no practical use, as the workman knowing the general types described above, can readily modify their forms to suit any particular purpose which may arise. In like manner we shall omit detailed descriptions of the machinery used in the shop—descriptions which, to those unaccustomed to such apparatus, are tedious, and often unsatisfactory, and merely set forth some of the modes of applying them, illustrating our remarks with a few necessary details.

Fig. 54.



Fixing or Chucking Work.—On every machine used in the manipulation of masses of matter to be operated upon by cutting tools there must be fitted apparatus supplying the means of firmly fixing the work, and holding it while it is being operated upon; and although this part has different names in different classes of machines, yet, in all of them its action depends upon similar, or almost identical, principles. This part, in the lathe, and in boring and screwing machines, is termed the *chuck;* in *drilling*, *slotting*, and *shaping machines*, the *table;* and in *planing machines*, sometimes the *bed*. A portion of one of these chucks or tables is shown in *Fig.* 54, *a* being a plan and *b* a section, or end view. It will be seen that it is made with a number of undercut grooves, so arranged that the heads of bolts may be slipped into the grooves at the ends, and slid along to any required position, to hold the work firmly against the table by clips or by brackets called "*dogs;*" *c* shows an enlarged section of one groove having in it a bolt *d*, which is retained by the head; on this bolt is a nut *f*, which firmly holds down the bracket or dog *e*.

When work is brought into the machine shop the first thing to be done is, with great care, to mark the centres of those parts that have to be turned, and to line out with accuracy all other guiding marks, so that there may be no difficulty in the chucking, which must be done so as to hold the piece of metal immoveable, except in obedience to the movements of the chuck or table, as the slightest yielding will most likely spoil the work and break the cutting tool as well, the latter being, of course, of no consequence compared with the former.

Where the action of the machine is reciprocating, and the cutting tool is intermittent in its operation on the work, the lateral movement is generally given to it after the stroke, this movement being called the *feed*. The back motion should be quick, in order to prevent the waste of time as much as possible. In machines where the action of the tool is continuous, as in the lathe, and drilling and boring machines, the feed should also be continuous.

In self-acting machines of the first class the feed is commonly given by a reciprocating pall or detent, which passes over a ratchet or spur wheel freely in one direction, but moves it when driven the opposite way; this latter motion is given to it during the return stroke, after taking a cut. The amount or rapidity of feed can be varied by means of altering the effective leverage of the arms by which the detent is moved, and the direction of the feed can be controlled by causing the detent (which is usually double, or of a T shape) to act above or below the arm that carries it, as may be required.

In machines where the cutting action is continuous the feed may be given by an arrangement of tangent-screw and worm-wheel, or by a screw acting on a nut, which, by opening and shutting, engages and disengages with the screw, or by spur-wheels or rack and pinion, or by all combined.

In cutting large screws the pitch is regulated by introducing spur-wheels of suitable sizes between the *mandril* of the lathe carrying the cylinder on which the screw is to be cut and the screw which gives the feed to the tool; the wheels are called *change-wheels*, and the screw, the leading screw. These should be constructed with the greatest care, as the accuracy of the screws made is dependent upon the correctness of their forms and excellence of construction.

The velocities at which the various machines are driven is regulated by means of speed pulleys and spur-wheels, so as, without interfering with the prime mover, to adjust the rate of cut so as to suit the size of the work and the hardness of the material wrought. A surface velocity of from twelve to twenty feet per minute is thought by many mechanics to suit the different kinds of metal; of course, the cut being slower for the hard substances than for the soft.

POLISHING.—Some elements, after being finished as far as can be done by the machinist and the fitter, require a finer surface, which can only be imparted by processes of grinding and polishing.

Grinding, as for tools and cutlery generally, is effected by revolving grindstones, followed, if necessary, by polishing, and in nearly all cases requiring the final adjustment of the cutting edge on an oil-stone, more especially for cutting soft materials. In polishing a variety of materials are used, such as powdered emery, finely-ground glass, diamond powder, crocus martis (sesquioxide of iron), putty powder (peroxide of tin), bath brick, &c. A very good—indeed, the best—crocus martis may be made as follows:—Taking equivalent weights of sulphate of iron and carbonate of soda, and having dissolved them in distilled water separately, and filtered the solutions through bibulous or white blotting paper, mix them and stir together; let the mixture stand for an hour, after which decant the supernatant liquor, and place the deposited precipitate upon filter paper, and thoroughly wash it until the water which passes through the filter is clear, and gives no precipitate with solution of acetate of lead; then put the precipitate into a crucible with a loosely-fitting lid, and raise it to a low red heat to drive off the carbonic acid; the resulting substance, being freely exposed to the air, will become pure sesquioxide of iron in an impalpable powder. Crocus prepared thus, and carefully preserved, can have no grit in it, and, therefore, cannot scratch the work upon which it is used.

A revolving wheel, or moving table of some sort, must be used in the application of polishing powders, and the material may be either wood or metal, but it must be remembered always that the "*lap*," or wheel, must be softer than the body to be ground or polished. The reason of this is, that the particles of grinding or polishing powder may be able to imbed themselves in the softer material, and being there held, will act upon the harder.

Where metal is used for the substance of the lap we have found a mixture of one part antimony to nine and a half parts of lead give very good results, especially in working on hard steel, where not even a microscopical fault would be tolerated.

Such nicety in working may seem, at first sight, to be unnecessary, but there are purposes for which it is requisite, one of which presents itself in the flattening by steel rollers of the gold-covered silver-wire which is used for the manufacture of gold-lace embroidery. This wire is thus prepared:—First, a layer of one ounce of gold is laid on to an ingot of silver, weighing nineteen ounces; the ingot thus plated is beaten and drawn out to a fine wire, the gold coating drawing out uniformly with the silver core, and when the wire has been drawn down sufficiently fine, it is pressed flat between hard polished steel rollers; the flattened wire only measures about one-thirty-second of an inch in width, and, in the course of further manufacture, is wound round silk, from which the embroidery above alluded to is made.

Before concluding our remarks upon the working of metals cold, a few observations on the perforating of sheet metals must be offered. In the ordinary practice, the greater portion of metal intended for rivetting is perforated by punching, a process that unduly weakens the plates operated upon, as they are stretched on the under surface by the sudden and violent action of the punches, and the pieces forced out of them also are not cylindrical, thus showing an unequal straining of the material. This, of course, does not occur when the metal is cut away as it is in drilling, hence, wherever feasible, the latter process should be adopted; but in many cases it is too tedious and too costly to be adopted for purposes of an ordinary character.

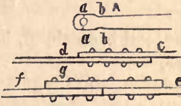
CHAPTER XVI.

ON JOINTS, BEARINGS, AND PACKINGS.

In any structure or machine its strength is measured by the weakest part, for it is evident that a machine will not be capable of sustaining a greater effort than the greatest which can be borne by its weakest part, hence it is important, in order to use all the strength of a machine, to make it as nearly as possible equally strong throughout. Where weakness is most likely to occur is in the joints, if they be not very carefully proportioned.

Joints.—In ordinary rivetted joints the number of rivets used must present sufficient sectional area to carry the strain from one element to the other, and the same remark applies to bolts. The nature of the strain on the rivet or bolt is shearing force, because the plates tending to slide one upon the other would rupture the bolts by cutting or shearing them asunder. In rigid joints the friction of the plates upon each other, due to the force with which they are pressed together by the rivets, has been shown in some experiments to take up all the strain, but this is not calculated upon in practice. The safe shearing stress which may be put upon wrought-iron is estimated at from three to four tons per square inch of sectional area.

Fig. 56.



Let *A* represent the end of a link to be sustained by a bolt passing through the hole in its extremity, the weakest part of the body of this link will be represented by the sectional area at *b*, *b*; the head should be so proportioned that the sum of the two sectional areas *a* and *a* on each side of the bolt-hole shall be equal to the sectional area *b*, *b*, and this area *a* must be continued round the hole from one side to the other.

Let the diameter of the link be d at *b*, *b*, and the thickness of the head t, D being the diameter of the bolt, all in inches. If the head be forked, as in some steam-engine connecting-rods, $t =$ the sum of the thickness of the two arms, $w =$ thickness of metal at *a*, and $B =$ total breadth of the head of the link, the area of the section at *b*, *b*,

$$= 0{\cdot}785\ d^2$$

and the area of the two sections at *a* and *a*

$$= 2 \,.\, t \,.\, w$$

but as these must be equal, it is evident

$$2\ t \,.\, w = 0{\cdot}785 \,.\, d^2$$

$$w = \frac{0{\cdot}392\ d^2}{t}$$

The total breadth, B, however, equals $2\ w + D$, wherefore,

$$B = \frac{0{\cdot}785 \,.\, d^2}{t} + D$$

D, however, has yet to be determined. The bolt may be supported at one end or at both; in the former case it will have to carry the whole strain on one section, in the latter on two sections.

Let the strain be carried by one section only, then if $S =$ the strain, and 3 tons be the safe shearing strength of the metal—

$$S = 0{\cdot}785 \,.\, D^2 \,.\, \times 3$$

$$D = \sqrt{\frac{S}{2{\cdot}255}}$$

but if the strain be carried by two sections, then we shall have

$$S = 0{\cdot}785 \,.\, D^2 \times 2 \times 3$$

$$D = \sqrt{\frac{S}{4{\cdot}71}}$$

As an example let us take the forked connecting-rod of a steam-engine; in this case the bolt will evidently carry the strain upon two sections. Let the strain on the link be 14 tons, then the diameter of the bolt or pin will be

$$D = \sqrt{\frac{14}{4{\cdot}71}} = 1{\cdot}73 \text{ inches (say), } 1\tfrac{3}{4} \text{ inches.}$$

The minimum diameter of the body of the link will be about 2¼ inches; hence, if 2 inches be the sum of the thickness of the two arms of the forked end of the connecting-rod, then

$$B = \frac{0{\cdot}785 \times \overline{2{\cdot}25}^{\,2}}{2} + 1{\cdot}73 = 3{\cdot}71 \text{ inches (say), } 3\tfrac{3}{4}$$

inches.

In the classes of rigid joints shown at *c d* and *e f*, a number of rivets or bolts are used. In the former case the joint is lapped, as the strain is transmitted direct from one part to the other. Let S = strain in tons, d = diameter of rivets in inches, n = number of rivets, and 4 tons safe strain per square inch, then

$$S = 0{\cdot}785 \,.\, d^2 \times n \times 4$$

hence,

$$n = \frac{S}{0{\cdot}785\, d^2 \times 4} = \frac{S}{3{\cdot}14\, d^2}$$

In the second joint, which is butted, the strain is transmitted first from *e* to the cover *g*, and thence to *f*, therefore the above number of rivets must be put in on each side of the line of juncture, the total number of rivets in this case being,

$$n = \frac{S}{0{\cdot}392\, d^2 \times 4} = \frac{S}{1{\cdot}57\, d^2}$$

If there be two cover plates, one on each side of the plates to be joined, then will the rivets carry the strain on two sections, hence half the number of rivets will be required.

It has been determined experimentally that the relative strengths for solid and rivetted work of boiler plate is,

Solid plate	100
Single-rivetted joint. . . .	56
Double ,, ,, . . .	70

The bolts and nuts must be also so proportioned that the head shall not strip off, nor the nut under a less strain than that which will tear the bolt asunder.

The strain, in passing from the body of a bolt to its head, tends to shear off the annular portion of metal by which the overhanging part of the head is formed; the surface to be sheared will be, if h = height of head,

$$= d \times 3{\cdot}1416 \times h$$

and the area of the bolt is

$$= d^2 \times 0{\cdot}785$$

taking the relative resistances of the metals to tensile and shearing strain as 5 to 4, we have,

$$d \times 3{\cdot}1416 \times h \times 4 = d^2 \times 0{\cdot}785 \times 5$$

$$h = \frac{5\,d}{16}$$

but the heads are very seldom made less than one half the diameter, and most commonly equal to the diameter.

In the case of nuts it is to be considered that there is not the same continuity of hold that there is in the solid metal, hence they are made with a minimum length equal to twice that given by the above formula, hence for nuts we have,

$$h = \frac{5\,d}{8}$$

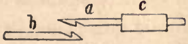
Sometimes joints are made by joint tubes having right and left handed threads cut in them, so that by turning the joint tubes, the bars are tightened up or slackened as circumstances may require.

When joints are made by means of keys, wedges, or cotters, the area of the cotter must be determined similarly to that of the bolt, which is done by replacing $0{\cdot}785\ d^2$ in the foregoing formulæ, by $B \times W$, where B is the breadth, and W the thickness of the cotter in inches.

In joints where the pressure is entirely compressive, the bearing area must be made sufficiently large to prevent any spreading, or great and unnecessary wear on the surfaces in contact. These connections often occur in the toggle joints of Stanhope and certain other presses.

In bars, such as long pump rods, which require to be occasionally disconnected, a species of scarf joint is much used, as shown in Fig. 55. The scarfed ends *a*, *b*, being placed together, the box *c* is slid over them to hold them in position. The strength of the necks of the rods must be duly proportioned.

Fig. 55.



The proper diameters of rivets to join two plates of given thicknesses together, as determined by long experience, are stated in the following table:—

Thickness of Plate. Inches.	Diameter of Rivets. Inches.	Thickness of Plate. Inches.	Diameter of Rivets. Inches.
1/4	1/2	5/8	3/4
5/16	5/8	11/16	7/8
3/8	5/8	3/4	7/8
7/16	5/8	13/16	7/8
1/2	3/4	7/8	1
9/16	3/4	15/16	1
		1	1

The diameter of the nut may be made about 1·75 diameters of the bolt, or in extreme cases twice the diameter of the bolt.

In making the joints of pipes under pressure and cylinder covers, &c., the first step is to arrange to have a sufficient number of bolts to carry the strain. A bolt of good sound malleable iron, one inch in diameter, should safely support a tensile strain equal to 10,000 lbs.; hence if p = total pressure on joint in pounds, d = diameter of bolt in inches, w = number of bolts, then

$$n = \frac{p}{10000 \times d^2}$$

$$d = \sqrt{\frac{p}{10000 \times n}}$$

thus if there be a joint in a steam pipe, of which the diameter is four inches, and the pressure per inch is 80 lbs., then the total pressure on the joint will be

$$= 0·785 \times 16 \times 80 = 1004·8 \text{ lbs.}$$

hence the minimum diameter of bolts to secure this joint must be

$$d = \sqrt{\frac{1004{\cdot}8}{10000 \times 4}} = 0{\cdot}025 \text{ inch, or 3-16 bolts.}$$

Bolts so small as this, however, would not be used in practice.

To take another example, let the joints of an air vessel be under a pressure due to a head of water equal to 200 feet, and let the diameter of the air vessel be 7 feet, there being 44 bolts in the joint, giving a distance of about 6 inches between the bolts :—

The pressure per square inch will be

$$= 200 \times 0{\cdot}434 = 86{\cdot}8 \text{ lbs. per square inch};$$

the area of the vessel at the joint in square inches—

$$= 49 \times 0{\cdot}785 \times 144 = 5541 \text{ square inches};$$

hence the load on the bolts

$$= 5541 \times 86{\cdot}8 = 480{,}958{\cdot}8 \text{ lbs.}$$

For simplicity, this may be called 481,000 lbs., then the diameter of the bolts required will be

$$d = \sqrt{\frac{481000}{10000 \times 44}} = 1{\cdot}09 \text{ inch (say), } 1\tfrac{1}{8} \text{ inch}$$

diameter.

In respect to bolts, as in all other matters of construction, it is found that when we have to deal with small quantities and light strains, it is not practicable to keep the dimensions down nearly so low as is shown to be safe by calculation, and, moreover, all elements must be sufficiently massive to withstand accidental blows and concussions.

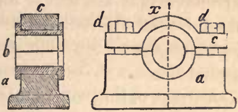
In all descriptions of joints, the parts to be joined together should be made true so as to fit, otherwise an undue strain will be thrown upon the bolts, or perhaps a side or twisting stress. Of course in steam and water joints it is necessary, generally, to interpose some material to render the joint tight, for this purpose canvas covered with a mixture of red and white lead together in about equal parts may be used, the lead being moistened, if necessary, with boiled oil to make it spread.

In all cases where the main nuts of a joint cannot be jammed down hard upon the parts which they hold, as with the nuts on bearing caps, cross-heads of piston and connecting rods, a second thinner nut is used which is called a guide or check nut; by screwing the latter tight upon the main nut both are effectually secured from moving. In some instances also, guards made of thin iron to fit the nuts are used, which, by closely encircling them, prevent their turning.

BEARINGS.—The bearings of machinery being those parts in which naturally the greatest amount of wear takes place, it is very important that much care should be given to proportioning their dimensions, and to the selection of materials from which to manufacture them. The requirements to be satisfied are to have the greatest steadiness of working, with a minimum wear and minimum friction, so as to require the least quantity of unguent for lubrication.

Fig. 57 shows a side elevation of the ordinary kind of bearing for revolving shafts and elements having an oscillating motion, and a vertical section of the same taken on the dotted line *x*........... *a* is the lower part, which is called the plummer-block, usually of cast-iron; *b* indicates the bearings or brasses, made each in the form of a semi-cylinder, of gun-metal or bearing metal; *c* is the cap of the plummer-block, by which the brasses are kept in position, the cap being secured by the bolts and nuts *d, d.* In light work sometimes the whole bearing is made of brass. For wrought-iron shafts the length of bearing should be 1·75 times the diameter of the journal of the shaft, which is that part which lies in the brasses. If a sufficient length of bearing be not given, especially in machines that are liable to much vibration, the journals will work about in the bearings, and the whole machine soon becomes shaky. This may frequently be noticed with some ill-contrived marine-engines, where, apparently in order to save room, the bearings have been made much too short.

Fig. 57.



In the construction of bearings and journals, the former should be bored and the latter turned as truly as possible, after which the fitting of them accurately together may be completed by scraping. In this process ruddle or other colouring matter is rubbed on the shaft, which is then slightly worked on the bearings to show the most prominent parts; the operator then reduces these parts with a scraper, and the process is repeated until a satisfactory result is obtained.

As the bearings wear away they are brought together by tightening the nuts *d*, *d*, and where there is a decided tendency to wear oval, as in the bearings of a steam-engine, the plummer-blocks should be so arranged that the thrust and pull act relatively in the direction of the dotted line *x*......., that is to say, at right angles to the diameter on which the brasses are separated.

A great variety of metals and alloys have been tried for bearings in order to obtain the most durable combination available; brass, gun-metal, hard white metal, steel and glass, have each had their trial, but almost universally brass and gun-metal are used for the bearings for wrought-iron shafts, and if kept well lubricated the results are tolerably satisfactory.

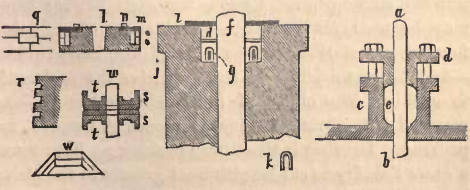
If an unguent could be found sufficiently permanent not to be squeezed out of the bearings, then the nature of the material would not much affect the friction, as the rubbing surfaces would in fact be of the unguent, and not of the metals upon which it is spread, then the hardest material would be the best that could be used for the bearings, as that would wear the slowest.

There is some trouble about the efficient lubrication of bearings, both in regard to the kind of unguent used and the mode of applying it so as always to keep the bearing sufficiently oiled or greased and yet not waste the substance used for that purpose. The unguent should be sufficiently cohesive not to be readily forced out from between the shaft and bearing, yet it should not be of a gummy or clogging nature, in which case it would cause the bearing to become hot. In every case vegetable oil is far preferable to mineral, no matter how pure the latter, for it is apt to decompose into certain compounds injurious to the surfaces of the metals with which it is in contact.

A great variety of contrivances have been applied for the regulation of the supply of oil to machine bearings, some being on the same principle as a common lamp, sucking up the oil by a cotton wick, and allowing it to fall drop by drop through a hole in the plummer-block on to the journal of the shaft, while others have acted as pumps, making one stroke for every revolution of the shaft. This latter is an improvement, inasmuch as the oil is not supplied to the shaft when at rest, during which time it would be merely running away to waste. To attempt to describe the varieties of these apparatus would occupy more space than they are worth, notwithstanding the importance of the subject, but we may mention that an oil vessel has been introduced, and in use for some time, which seems to work satisfactorily. It is called the needle lubricator.

Packings.—The object of packing is to allow moving parts to work in contact without permitting the passage between them of certain liquids and gases. In Fig. 58 different methods of packing are illustrated. *a b* represents a cylindrical rod, such as a piston or slide rod, which is required to work steam and air tight through a plate. Upon this plate is formed a box or gland

Fig. 58.



called a stuffing-box, *c*. This box, which is cylindrical, is somewhat larger in its internal diameter than the rod which works through it. *d* is a flanged cylinder bored out to fit the rod closely but yet not tightly, as the rod has to slide to and fro within it; the outer surface of this cylindrical piece is accurately turned to fit into the box *c*, which is bored out to receive it. The mode of using the stuffing-box is thus:—Into the cavity *e* around the rod is pretty tightly packed a plait of untwisted rope or gaskin, which has previously been been well saturated with Russia tallow, or some other unguent of equal efficiency; then the part *d* is placed upon this packing and tightened down upon it by means of the screws and nuts shown; by this pressure the packing is caused to lay close against the rod, so as to prevent the passage of air or steam by it, whilst, being freely lubricated, it allows the rod to move with but little friction. As the packing wears away, the nuts are screwed down so as to keep the joint air-tight until there is not sufficient of the material left in the box, when it must be opened, emptied, and re-filled. In small glands the bolts are frequently dispensed with, the part *d* of the gland having a thread cut on it so as to screw down into the stuffing-box. Various materials besides hemp may be used for stuffing,—metal rings of a conical form, shown at *W*, have been applied, also india-rubber,—but for steam joints we certainly give the preference to gaskin. The object of introducing other packing material is to obviate the inconvenience of frequent repacking. In using india-rubber packing we have found a great liability to cut longitudinal grooves in the piston rod. The length of the glands is regulated by the circumstances of the particular case, according to the amount of pressure to be resisted and the nature of the material used for stuffing; if it be made longer than is necessary undue friction is created.

For hydraulic machinery, leather packing is commonly used. *f* is the ram of a hydrostatic press working in the cylinder *j*. In the upper part of the cylinder is turned a recess in which is placed a leather collar of an inverted *U* section, having between its sides a copper ring to prevent its collapse; this collar, shown in place at *g*, is illustrated in section more clearly at *k*; upon it is placed a thin annulus of metal, and over that some hemp or tow, as seen at *h*, the whole being kept in position by the plate *i*, which is fastened down by screws. From the form of the leather collar, it follows that, upon pressure being put upon it, water entering between its arms or sides will press them asunder and keep them firmly against the cylinder on the one side and the ram on the other, thus making a water-tight joint; these leathers, if of good quality, will wear for a considerable time without renewal, according to the work done by the press.

In the early steam-engines the pistons were universally packed with gaskin, but now metallic packing rings or segments are in general use. *l* shows the body of a piston in section; it has a groove around it in which the packing-rings *o o*, of cast-iron, are fitted, being held in position by a junk-ring, *m*, fastened to the piston by bolts, *n*. These rings are sometimes kept in contact with the surface of the steam cylinder by their own elasticity, being turned somewhat larger than it, and cut so as to admit of their being forced into it, otherwise they are made in segments and forced out by springs placed behind them or by the action of steam from the cylinder upon them. When one cut ring alone is used, the line through which it is cut should be interrupted by a tongue-piece, shown in the partial elevation, *q*. In some instances pistons running at high speed have been fitted with numerous small rings put each into a separate groove, as shown in the part section, *r*.

Pistons for pumps and hydraulic engines are packed by having cup leathers on them, as shown in section at *s*, *s*, held between two plates, *t*, *t*, bolted together on the rod *w*. The pressure of the water or other liquids on the edges of these cup leathers also assists in keeping them close against the pump-barrel or cylinder.

CHAPTER XVII.

FOUNDATIONS AND FRAMING.

However well and carefully the proportions and relative strengths of the working parts of a machine may be calculated and set out, yet it is evident that if the parts supporting these elements be not sufficiently strong and rigid to resist the vibration produced by motion, the combination will not be durable; hence a rigid framework and firm foundation should in all cases be secured.

The nature of the strains upon framing, and the vibrations occurring, will necessarily depend upon the construction of the machine and the object which it effects; thus while some engines produce scarcely any extraneous vibration at all, others will tend to wrench and twist their frames in every direction; and again, another class of apparatus may tend to tear up its foundations bodily. The characters of the various vibrations which arise in machinery do not seem to have received consideration in any systematic treatise, hence we propose in the present to enter somewhat at length into the matter.

Revolving masses, if perfectly balanced and moving on true centres at unvarying velocities, would produce no vibration whatever; but these are conditions which cannot, in practice, be satisfied, and the result is that tremors are produced by revolving bodies on account of unavoidable inequalities in balance or bearing. If an element in rotation be not balanced about its centre of motion, it is evident that the centrifugal force of the unbalanced portion will be ever tending to draw the bearings into an oval or elongated form; but the direction in which this force acts will be constantly varying as the element revolves, hence a general tremor will be created. The only way in which to meet this is by a general rigidity and massiveness of the bearings and framework to which they are fixed; but when the masses in revolution are very large, they should be counterbalanced in all cases where it is practicable.

Oscillating and reciprocating masses cause a vibratory impulse every time a change in the direction of the motion occurs, the effects of which may be modified in some instances by the use of springs, or equivalent means, as, for example, in the ordinary steam-engines, in "cushioning" the steam.

In addition to these two descriptions of vibration common to all kinds of machinery, there are others of various kinds peculiar to special machines, and, if occurring with much violence, productive of very deleterious effects. To discuss every sort of shock and vibration that presents itself would be beyond our scope, hence some examples of engines and machines will be selected, from the consideration of the strains on which a general knowledge of the practical way of dealing with shocks and vibrations may be gained.

CORNISH PUMPING-ENGINES.—These engines are single-acting, the general principle on which they work being the lifting of a weight, called the preponderating weight, by steam, which, in its descent, forces the water to the place where it is required. It is evident that the steam acting to press the piston downwards, must exert an equal pressure upwards, tending to lift the cylinder instead of the preponderating weight; therefore, the former must be securely held or "anchored" down to the foundation upon which it is placed, and this foundation must be sufficiently heavy to resist the tendency to raise the cylinder. To give some idea of the quantity of masonry necessary for the "cylinder load" of a large engine, the following example will suffice:—Let the diameter of the pump be 50 inches, the height to which the water has to be raised being 100 feet, then the total pressure on the pump-plunger will be

$$= 0{\cdot}7854 \times 2500 \times 0{\cdot}434 \times 100 = 85{,}216 \text{ lbs.}$$

adding to this 5 per cent. for friction, we get for the preponderating weight, approximately,

$$85{,}216 + 4260 = 89{,}476 \text{ lbs.}$$

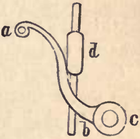
This, then, will be the upward pull upon the foundations of the cylinder, and if we presume that for safety the load is made double of this amount, it will practically become equal to 180,000 lbs. If this mass of matter be made of masonry equal in specific weight to flint or granite, the bulk of it required will be

$$\frac{180000}{150} = 1200 \text{ cubic feet,}$$

which will be equal to a mass 10 feet square and 12 feet high.

Another matter to be considered is the making provision to receive the blow of the preponderating weight if it should fall or "run out" suddenly, through the pump losing its water from injury to the valves or a main-pipe bursting. For this purpose the box holding the weights is cast with brackets or snugs on it, which come upon spring-beams made of laminæ of timber somewhat after the fashion of a coach-spring, or they may be received by buffers of india-rubber or other elastic material.

Fig. 59.



The valves of the Cornish engine are actuated by tappets striking on handles or horns connected with them, and to prevent concussion the handles must be of such form that the tappets will first touch them in a tangential direction, as shown in the elevation of an equilibrium valve-handle in Fig. 59. *a b* is the curved handle which moves upon an axis *c*; the tappet *d* is just coming in contact with the handle to depress it. If the curves of these handles be properly set out, and the tappets suited to them, the valve-gear of the engine will work almost without sound, so slight will be the actual blow on the handles. In the earlier engines provision had to be made against the concussions produced by the main pump-valves, but improvements in those elements have obviated this necessity.

Rotative Beam-engines.—In the Cornish engine, towards the end of each stroke the speed slackens, so as gradually to bring the parts of the machine to rest; but in the rotative beam-engine the change of direction of motion is more sudden, and, therefore, gives rise to more continuous, or, rather, more repeated vibrations, though not comparatively so intense. Very commonly these vibrations are sustained by a sole or foundation plate of cast or wrought iron, resting upon a solid mass of masonry or concrete. The centre frame or columns supporting the main-beam have evidently to bear twice the total pressure on the piston, acting alternately in tension and compression, hence care must be taken that the holding-down bolts be strong enough, and that the nuts on them be screwed down tightly, as, if any play is allowed, the whole engine will be violently shaken at each change of motion, and ultimately the bolts broken. It is worth remembering that wrought-iron and steel, under the influence of repeated concussions, change their texture and from fibrous become crystalline, losing their tenacity and exhibiting much brittleness.

Concussions of this sort also occur in the main-bearings and connecting-rod heads when their brasses wear loose, if they be not kept properly tightened up to counteract the effects of such wear.

The effect of the alternate tensile and compressive strain on the centre frame or columns of the engine, will be to produce a transverse strain on the sole or bed plate, putting it under the conditions of a girder supported at both ends and loaded in the centre, but differing from that inasmuch as an ordinary girder always has the description of strain on any particular part constant; thus, generally, the top flange is compressed and the bottom one extended, but in the case under consideration each flange suffers alternately extension and compression. The load put upon the sole-plate by the action of the engine may be thus determined:—Let $p =$ the maximum effective pressure of steam per square inch in the cylinder, $a =$ the area of the steam-piston, $l =$

length of the working-beam in feet, D = distance of centre pin of connecting-rod from main gudgeon of beam, W = load, then

$$W = \frac{p \times a \times l}{D}$$

and if the piston-rod and connecting-rod are at equal distances from the main gudgeon, $l = 2\ D$, hence,

$$W = p \times a \times 2 = 2\ p\ .\ a\ .$$

If d = depth of frame or sole in feet, the strain in pounds on either flange will be

$$= \frac{2\ .\ p\ .\ a\ .\ l}{4\ d} = \frac{p\ .\ a\ .\ l}{2\ .\ d}$$

For example, let the diameter of the cylinder be 25 inches, then its area is

$$a = 0{\cdot}7854 \times 625 = 490{\cdot}8 \text{ square inches};$$

let the initial pressure be 40 lbs. per square inch in the cylinder, then the direct strain on either flange of the beam will be, the length of the beam being = 9 feet, and depth of frame 9 inches—

$$= \frac{40 \times 490{\cdot}8 \times 9}{2 \times 0{\cdot}75} = 117{,}792 \text{ lbs.};$$

if the frame be of cast-iron, then taking the working strength at 3000 lbs. the area of each flange should be

$$\frac{117{,}792}{3000} = 39{\cdot}26 \text{ square inches};$$

or if of wrought-iron, having a safe resistance of 8000 lbs. per square inch,

$$\frac{117{,}792}{8000} = 14{\cdot}72 \text{ square inches};$$

The reason of the much greater area required in the cast-iron frame is accounted for by the low tensile strength of that metal, and as the strains on the flanges alternate, the section with unequal flanges is not suitable. If the sole-plate be bolted down to a bed of concrete it will be very materially strengthened.

In referring to these foundations a convenient opportunity occurs to mention the mortars and cements used in making them.

Hydraulic Mortars are composed of silica and caustic lime in general, and their peculiar property of hardening under water may be attributed to their forming hydrated silicate of lime; when clay and magnesia are added double silicates of greater consistency and strength are produced. The silica should always be in such a state that it is easily converted into a gelatinous paste by the addition of an acid, and it should be prepared by calcining it at a bright red heat with an alkaline earth, after which it will dissolve in acids. Sand of the quartzose kind, when mixed with lime in the ordinary way, will not make a hydraulic mortar, but, after being burnt with lime, becomes suitable for building under water.

Those limestones which contain about 10 per cent. of clay, when strongly burnt form good hydraulic mortars; but if the proportion of clay be double or treble of this quantity it requires to be well ground before it will set.

Marls containing 30 per cent. of clay make excellent mortar without the addition of any other ingredient; when the proportion of clay is greater it must not be subjected to any great or prolonged heat.

As a general rule, all those limestones which burn to a buff colour make hydraulic mortars.

Parker's Cement contains 45 per cent. of clay and 55 per cent. of carbonate of lime; it is manufactured from reniform limestones found in nodules in beds of clay; the analysis of the cement shows 55 parts of lime, 38 of alumina, and 7 of oxide of iron.

Concrete.—A very good and durable concrete is made of six parts gravel and well-sifted sand to one part of chalk lime, or barrow lime. Neither sand nor gravel alone will make a good concrete. In putting concrete down it should be shot from as great a height as possible in order to consolidate it; and, where it has heavy weights to bear, the stratum should not be less than five or six feet deep.

Puzzolana.—Artificial puzzolana may thus be prepared:—Reduce coarse red bricks to powder, and mix them with lime which has been slaked for some time, in the proportion of two measures of brickdust to one of lime paste, with the addition of as much water as is necessary to incorporate them throughly.

Common lime, sand, and brickdust, in equal proportions, have been found to make a good hydraulic mortar.

The Roman and Portland cements are also much used, the latter being, when properly prepared, probably the strongest cement there is.

If the strains on a foundation are all compressive or of a downward tendency, the sole-plate only requires to take sufficient hold of it to obviate the general tremor of the machine; but if the strains are of a lifting or upward nature then the holding-down bolts must be carried completely through the concrete or masonry forming the foundation, and fastened to anchor-plates at the bottom of it, in order that the *weight* of the mass may act in steadying the superstructure. In some cases it may be found convenient to make the bed-plate in the form of a trough or box, and weight it by filling it with concrete, in order to give steadiness to the engine the steadiness increasing as the weight of the base.

In the GRASS-HOPPER, or half-beam engine, the maximum load on the sole-plate will be at a point under the main-shaft, which in these engines is between the cylinder and rocking post which supports the end of the beam. Let P = total pressure on piston, l = length of beam in feet, and d = distance of connecting-rod pin from main gudgeon of beam, then the maximum weight on the sole

$$= P \times \frac{l}{d}$$

The case is very similar to that of the beam-engine.

VERTICAL, INCLINED, AND HORIZONTAL ENGINES.—In these engines the vibration and shocks caused by the reciprocating nature of the movement are taken as direct tensile and compressive strain by the framing to which the main-shaft plummer-blocks are attached, hence the calculation of the area of such framework become simple.

In a vertical engine let the steam cylinder be 16 inches in diameter and the initial effective pressure of the steam 40 pounds per square inch, then the total pressure will be

$$= 0{\cdot}785 \times 256 \times 40 = 8040 \text{ lbs.}$$

If the framework be of cast-iron it will be weakest in tension, hence the least area to withstand this strain would be

$$\frac{8040}{2000} = 4{\cdot}0 \text{ square inches.}$$

Very frequently, instead of using a common crank with engines of these classes, solid discs or crank-wheels are used, carrying crank-pins, and these certainly work very smoothly and uniformly.

A horizontal engine, well arranged, and placed on a sound foundation, will work as equably as any kind ordinarily made, and the reason is obvious; in the first place, there is no massive beam to cause vibration by its oscillations, and, in addition to this, the parts of the horizontal engine are usually lighter than those of a beam-engine.

MARINE ENGINES.—Marine engines are, from the peculiar circumstances under which they are placed, much more liable than land engines to vibration and concussions. It is, of course, impossible to get a solid foundation for the machinery, as the ribs of the vessels are in themselves yielding; hence, all that can be done is to make the engine framing as rigid and solid as possible; then almost all the vibration which passes to the ships' frames will be due to the concussion of the paddle-floats or propeller and to the "way" on the ship. Feathering paddle-wheels, of which the floats enter the water edgewise, cause less concussion than those with radial boards.

LOCOMOTIVE ENGINES.—The vibratory movements of the locomotive engine, although due to causes similar to those producing the tremors of other horizontal engines, are yet peculiar to the former class, on account of its high velocity and the want of a solid foundation. The action of the steam on the cylinder covers causes the frame of the engine to vibrate laterally and longitudinally, and the unbalanced revolving masses give rise to vertical vibrations, producing a galloping movement of the engine frame. Some years back an engine was slung in chains, and a pencil being attached to the buffer-beam, the machinery was started; upon a piece of paper being placed under the pencil an ellipse was drawn upon it by the vibratory, or rather, compound oscillatory movement of the suspended engine.

MACHINES GENERALLY.—In machines generally are found the same kinds of vibrations as those already referred to as belonging to steam-engines, but that class, having percussive movements, are, of course, liable to more violent concussions than others. In such cases materials which, from their inelasticity, will deaden vibration, should be interposed in the joints through which the percussive action passes. Felt is useful, also lead, if laterally prevented from spreading under the force of the blows. In such machines as steam-hammers the momentum of the blow, or that portion which is not expended on the work, should be, in great measure, taken up by the inertia of the anvil block, which block may be bedded upon ashes kept together by well made ground or piling. In some peculiar cases vibrations may be taken up by springs, and in others caused to counteract each other.

CHAPTER XVIII.

THE ADAPTATION OF MACHINERY TO SPECIAL PURPOSES.

HAVING examined the laws by which the action of the various mechanical elements are controlled and their parts proportioned to the strains they are intended to sustain, the mode of combining them for special purposes requires careful and studious consideration. In all machinery in ordinary use the engineer who desires to construct more of a similar character may derive some assistance from examining that already made; but when a new machine is required differing in its details and purpose from any to which reference can be made, the ingenuity of the constructor is called into action.

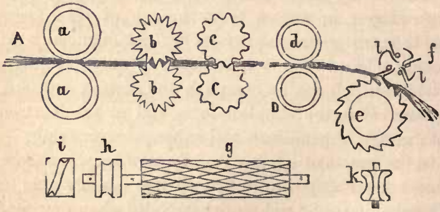
Those whose practice lies amongst inventors soon ascertain that, in the majority of cases, the inventor knows *what* he wants to do, but the consulting engineer has the task of showing *how* to do it; it is, therefore, evident that he should have a thorough knowledge of combinations of mechanical elements and of the limits of their application.

To define these limits is not a very easy task, so wide is the sphere of those purposes to which mechanical arrangements are readily applicable; but, although it is possible to contrive machinery capable of superseding hand labour in almost every branch of manufacture, yet, in many cases, the results are not financially satisfactory, wherefore it is necessary not only to contrive a machine which shall accomplish the desired end, but to construct it in the simplest form and at the least cost, both in first expenditure and subsequent working.

In the practical application of a new machine there is almost invariably some more or less considerable time expended in trials, and more especially when new modes of manufacture are attempted; as an instance, we may refer to P. H. Devignes' flax and hemp machinery. This was originally designed to supply, in a compact form, a machine to clear the fibrous portions of flax, hemp, and other similar substances, of the accompanying pithy and siliceous matters. After many tentative experiments a satisfactory result was attained, the machinery being constructed at Messrs. Ledger & Co.'s factory, at Deptford. Before describing the apparatus it is desirable to consider the operations to be effected. As supplied, the fibrous substance is surrounded externally by a siliceous coating, while internally it is in contact with pith, or "boom;" hence, both these materials must be removed in order to obtain the fibre in a clean condition. The pith is of a short, non-fibrous nature, but soft and yielding, and the siliceous coating of the stems is hard, brittle, and adherent. The first, evidently, would be removable by crushing and rubbing, the latter by attrition and beating.

In Fig. 60 are shown the details of the machine. The lower series of rollers revolve in fixed bearings, but the upper series is fitted with bearings which are

Fig. 60.



capable of sliding in vertical slots, and they are kept in contact with the lower rollers or materials operated upon by spiral springs pressing upon the bearings of the upper rollers, and contained in the vertical slots. The first operation the hemp undergoes is a flattening or crushing, by the simple pressure of the plain cylindrical rollers *a a*, the raw material being fed in at the end *A* of the machine. The next pair of rollers *b b* is grooved in a vandyked form, as shown in the section, and serves to break the boom into short pieces; the pair *c c* carry undulations, the effect of which crushes the boom, and causes the greater portion of it to fall out at the bottom of the machine. The last pair of rollers *d D* are formed with surfaces like rasps, as shown in the plan view *g*. The upper roller, besides revolving, has a longitudinal motion, so that the one roller rubbing upon the other breaks up the siliceous coating of the flax and hemp, whilst the revolution of the rollers passes the fibre onwards towards the exit from the machine. The axis of the roller *d* carries a grooved pulley *h*, in which gears a vibrating piece *k* actuated by a cam *i*, having on its periphery a spiral groove, and being fixed on the axis of the upper roller of the pair *c c*. The fibre, after passing through the four pairs of rollers above mentioned, falls upon the step-roller *e*, on which it is beaten by the revolving blades *f*, thus clearing it of the remaining siliceous coating.

The first point to be determined in this machine was the relative sizes of the rollers, to ensure the fibre passing through without being broken or entangled. The material stretched as the woody and siliceous matters were removed from it, hence the rollers evidently require to be of a progressively-increasing perimeter. The first pair *a a* being three inches in diameter, the following pairs require to be one-twentieth of an inch greater in perimeter each than the previous pair. If the increase be less than this the material does not clear the machine, if greater the fibre is broken.

In the first machines made some difficulty was caused by the fibres wrapping round the beaters *f*, which drew them up by creating a draught; this was at first attempted to be counteracted by a supplementary fan, which, however, proved a failure; the addition, however, of the guards *l l* prevented the wrapping of the fibres, as the beaters giving back on coming in contact with the steps of the wheel *e*, as soon as they pass those steps are brought back by their springs into a radial position, at the same time causing a slight draught of air in closing against the guards *l l*, which is sufficient to blow the fibrous material off the beaters.

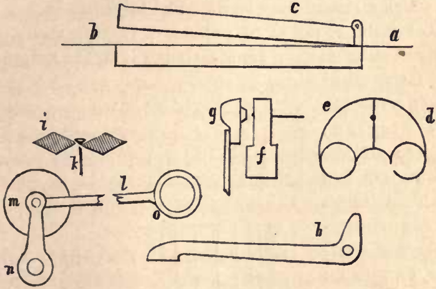
The rollers were made of cast-iron, hollow, and with wrought-iron axles, and the *V* and semicircular grooves cut by rotary cutters, the work being fixed on the bed of a planing machine, through which the feed was given. The vibrating piece *k* was made of hard gun-metal, and showed itself rather liable to rapid wear. This cam arrangement was not so well designed as it might have been; thus, the cam *h* might have had a spiral groove cut in its periphery, and a roller on a fixed stud or "dead centre" working in such groove would have produced the required movement, and with fewer parts and less wear than was entailed by the plan adopted.

This contrivance serves to illustrate the nature of the obstacles to be dealt with in the treatment of textile fabrics, of which the elasticity is altered as it passes through the machine, this variation requiring adjustments which can only be determined by actual experiment, occupying considerable time and requiring careful attention. The machine, in its completed state, weighs about 7 cwt., whereas the old machines each weighed about 1½ tons.

As another example of special machinery we may cite the pin-making machines designed by Mr. Thomas Ruler. The wire of which the pins is made is coiled on a reel, from which it is drawn into the different parts of the apparatus.

In Fig 61 the principal details of the apparatus are shown. The wire *a b* is first taken by the pincers *C* and drawn forward a slight distance, when it is grasped by the dies *d e* actuated by face cams, then a blow from the snap *g*, which is carried on a spring, half forms the head of the pin; the dies *d e* then release the pin wire, and the pincers *C* bring it a little farther forward, and a second blow from the snap *g* finishes the head of the pin, which is then cut off by the shears *h*. The pin then falls into a groove formed by two rectangular bars, shown in section at *i*; these bars are inclined at an angle of about 45 degrees to the horizon, and the pins slide down them to the pointing-mill shown at *m*. In order to give the pins points of a conoidal form, the mill is placed upon vertical rocking-posts moving on an axis *n*, and caused to vibrate by links *l* actuated by eccentrics *o*. The different motions in these machines for moving, heading, and cutting the wire are actuated by cams. The pins are turned out at a rate of about

Fig. 61.

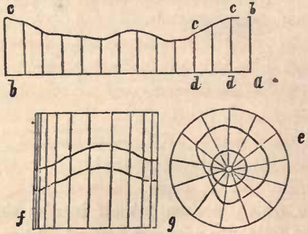


400 per minute, and of lengths from one-eighth of an inch upwards.

Calculating and registering machines have presented and still present problems of which the solution is often exceedingly difficult—hence calculating apparatus have not come much into use, and are now chiefly used in the preparation of tables.

We will now explain the laws by which variable kinds of motion for any purpose whatever within the scope of mechanics are ruled, and from the knowledge of which elements may be designed to produce them.

Fig. 62.



Let it be required to produce a varying rectilineal reciprocating motion from an edge cam, the nature of the movement being shown in the diagram, Fig. 62. Make *a b* a right line equal in length to the circumference of a circle *e*, on which it is proposed to set out the required cam; draw the ordinates *a b*, *d c*, &c. of such a length as to represent at *c* the position of the element in contact with the cam; that is to say, the various distances of the point of contact from the centre on which the cam revolves, corresponding to proportional angular distances travelled. Thus the line *a b* being divided into sixteen equal parts, the periphery of the circle *e* must also be divided into a like number of equal parts, and radii drawn from these divisions to the centre, then any convenient radius being taken, the length *a c* is marked off on it, and on the following ones the lengths *d c*, until the first one is again reached, the length of which will correspond with *b c*. The actual distance traversed by the element actuated by the cam at any point in the revolution will be found by deducting the radial length for such point from the length *a c*. If it be desired to use a cam such as that shown at *f*, the groove is set out by dividing the periphery as in *e*, and marking off the lengths *d c* on the surface parallel to the axis of revolution of *f*, and from a line *f g* passing round the cam, &c. at right angles to its axis. A very brief consideration will suffice to show that the varieties of cams which can be thus set out are infinite, hence elements of this description are very largely used in machinery having peculiar movements.

In order to understand the nature of movements produced by any mechanical element, it is convenient to conceive another movement combined with that due to the element itself. Thus if a card be supposed to move at right angles to the direction in which the action of the cam is exerted upon a piece carrying a pencil, then will a line be drawn on such card, the proportions of which and its conformation will be determined by the shape of the cam and its velocity in relation to that of the card. In the above case the lines *c*, *c*, *c*, &c. would be drawn. If, however, the card revolved instead of moving rectilineally, the form of the curved line would be compounded of that shown and the circle described by the paper or card under the pencil.

If the student of engineering science desires to be able at any time without delay to determine what class of element is most suitable for any particular purpose, he will find that a previous knowledge of the diagrams drawn by the elements most commonly used in machinery will materially assist him, and frequently save long and vexatious delays in arriving at a satisfactory result.

The cam as shown above has no distinctive diagram, but with some of the elements the diagrams, however varied, are ruled by fixed laws. If in an ordinary crank movement a pencil be attached to the sliding block at the end of the connecting rod, and a piece of paper travel under it at right angles to the direction of the motion of the block, and at such a velocity that during one revolution of the crank the paper will have passed through a space equal to the circumference of the circle described by the centre of the crank pin, then will the curve described be almost a true cycloid, the irregularities in it being due to the varying angle of the connecting rod; this, however, being slight, and the more so where long connecting rods are used, may be neglected.

The ordinate corresponding to any angular position of the crank will be for the first quadrant from one end of the stroke—

$$= r \left\{1 - v\right\}$$

where $r =$ radius of crank and $v =$ versed sine of the angle described by the crank since the commencement of the stroke; for the second quadrant the ordinate becomes

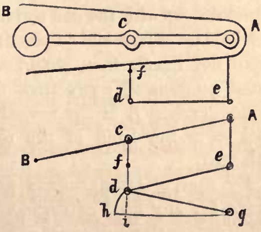
$$= r \left\{2 - v\right\}$$

If a pencil is attached to the connecting rod at any point between the crank pin and sliding block, and a paper be held at rest under it, then in one revolution of the crank an egg-shaped oval will be described on the paper, having its longest diameter in the direction of and equal to the stroke or throw of the crank. This figure becomes a circle at the point of junction with the crank pin, and a right line where the connecting rod joins the sliding block, and is flatter as it is nearer to the latter, its length being constant, and its narrow end presented towards the sliding block. If motion be imparted to the paper as before, the result will be a somewhat similar curve developed upon the oval.

As the eccentric is identical in principle with the crank, the diagrams described by it will of course be the same as those above referred to.

There are many contrivances of which the object is to restrain the movement of some particular element of the machine in a right line. These combinations are called parallel motions. The simplest method of obtaining the required end is by the use of guide bars placed parallel to each other, and having between them a guide block, or roller, to which the part of the machinery to be kept moving in a right line is connected; this is very commonly used for horizontal, inclined, and vertical steam-engines.

Fig. 63.



In beam-engines, and some other machinery, the parallel motions are usually formed by a combination of jointed rods, of such proportions that a certain point shall move in a right line, or so nearly so as to be practically satisfactory. Let *A*, *B*, Fig. 63, represent half the beam of an engine, *A* being one end-pin, *B* the main pin, or gudgeon, by which the beam is carried, and *c* a pin mid-way between *A* and *B*; let the bars *A e*, *c d*, be equal and parallel, and *e d*, equal *A c*. There is also another bar, *d g*, shown in the second view, in which the beam is in the position it attains when the piston is at the top of its stroke, but in the first hidden by the bar *d e*, to which it is equal, and consequently also to *c B*. The end *g* works on a dead-centre fixed to the framing of the engine.

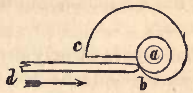
In this arrangement there are two points which will preserve a rectilineal movement; first, the point *e*, to which the head of the piston rod is usually attached. The rod *d g*, in revolving about the centre *g*, describes the arc *h d*, causing the position of the point *d* to shift laterally through a distance, *h i*, and carry with it the end *d* of the bar *e d;* but, at the same time, the latter bar has revolved about *d* in such a manner as to cause the end *e* to describe (in respect to *d*) an arc equal to *h d*, shifting the end *e* as much towards the centre, *B*, as the motion of *d g* shifted it in the opposite direction; hence the motion of the end *e* of the rod *e f* is restricted to a right line.

B c being equal to *d g*, and having the same angular velocity, it is evident that by its movement the end *c* of *c d* will be moved in an opposite direction to, but in an equal degree with the end *d*, hence the centre of the bar *c d* will move in a right line. If the distances *d g*, *c B*, were not equal, then would the rectilineally-moving point be situated away from the centre of *c d*. This point, marked *f*, is the second one above referred to, and to it the head of the air-pump rod is usually attached.

By similar arrangements parallel motions may be made for any kind of engine, but those consisting of links are much more expensive than those formed with guide-bars, and they are also apt to be not quite so accurate.

In Fig. 64 is shown an element termed a snail. This is a species of cam revolving on the axis *a;* its periphery is a curve of gradually increasing radius, being smallest at *b*, and greatest at *c*. *d* is a bar held against the periphery of the snail by suitable means and guided so as only to be capable of moving in a right-line, as indicated by the arrow. As the snail revolves the bar *d* will be forced farther from the centre *a*, the distance through which it moves for a given angular movement of the snail being determined by the form of the curve bounding the latter, which may be set out in a manner similar to that described for setting out cams.

Fig. 64.



In arranging the different parts of a machine those elements should be selected which consist of the fewest parts, and will occupy the least room—the former, for economy of prime cost and subsequent repairs, the latter for compactness. Where the velocity-ratios of shafts are required to be exact and perfectly constant, belts should not be relied upon, although they are good enough for transmitting power to workshop machinery, but toothed gearing, or some other of an equally positive and certain character, should be used, such as the worm-wheel and tangent-screw, or helical wheel, according to the relative positions of the driving and driven shafts.

In setting out spur-gearing for purposes requiring nicety of movement, great care should be observed in the formation of the teeth, as, without properly-shaped teeth, wheels will not run well together; and, on the other hand, where the form of tooth is correctly set out and accurately cut, there need be no shaking or jarring at all. In France for many years spur-gearing has been used for the transmission of motion in some delicate machinery employed in the manufacture of textile fabrics, and the only noise to be heard from them is the "whirring" due to the currents of air set in motion by the revolution of the wheels moving at a high velocity.

As has been already stated, the teeth of wheels running together should be of an epicycloidal form, but in a wheel and rack arrangement the teeth should be of a cycloidal shape, and those of chain wheels involute on the faces.

CHAPTER XIX.

PHYSICAL SCIENCE CONSIDERED IN RELATION TO MECHANICS.

In the construction of machinery for ordinary purposes, the mechanical engineer does not require the aid of a knowledge of physical science, except in those branches to which we have already referred; but in general practice it very frequently happens that the engineer is called upon to design or report on apparatus in which chemical and electrical forces are applied, hence it is necessary that he should possess some knowledge of these forces, otherwise he will be liable to grave mistakes. In the present chapter, therefore, we propose giving a sketch of physical science, necessarily brief, but sufficient to impart a general idea of the action of the cosmical forces.

CHEMISTRY.—Chemical affinity is that force by which bodies of dissimilar natures attract each other so as to form compounds, and by the overcoming of which combinations are separated again into their constituent elements. The building up of a compound substance from its elements is termed *synthesis*, separating it into its component parts *analysis*, and when the presence of a body causes certain chemical effects to be produced upon other substances while itself is unaffected, the action thus produced is called *catalysis*. Animal membranes have a property by which, when in contact with certain substances, they will allow some to pass through them but not others, hence thus is a method afforded for the separation of matters which has been named *dialysis*.

The mode of combination is ruled by certain fixed laws; that is to say, bodies do not combine in uncertain or chance quantities, but in ascertained definite proportions which are invariable. Thus water consists of oxygen and hydrogen; it being assumed (according to the old notation, which will be adhered to herein) that one equivalent of water contains one atom of oxygen and one atom of hydrogen, water will be represented by the equation

$$\text{Water} = H + O = H\,O$$

the numbers which represent the combining proportions of these gases are $H = 1$ and $O = 8$, hence the equivalent of water becomes $= 9$. It does not always happen that the number of the different atoms are equal, but the relative proportions of the different elements always give either the equivalent numbers or multiples of them; these numbers are called the atomic weights. The red rust of iron consists of two atoms of iron and three of oxygen, the composition being thus written (*Fe* being the symbol for iron)—

$$\text{Oxide of Iron} = Fe_2\ O_3$$

the small figures representing the number of atoms. The atomic weight of iron is 28, hence oxygen being 8, that of rust or sesquioxide of iron will be

$$28 \times 2 + 8 \times 3 = 80$$

Hydrogen gas, the lightest of all the elements, is usually taken as unity, the atomic weights of the other elements being given in relation to that of hydrogen. Some modern writers have adopted a view that atomic volumes should be equal, and consequently have doubled the equivalents of certain bodies, but, as stated above, we intend to use the old notation.

The elements are divided into two principal classes, *metalloids* and *metals*, and these again are subdivided into other classes according to their different properties, but upon these secondary divisions it is not necessary here to dilate.

The following table shows the atomic weight of the metalloids and their symbols:—

	At Wt.	Sym.		At Wt.	Sym.
Hydrogen. . .	1 —	H	Chlorine . . .	36 —	Cl
Oxygen . . .	8 —	O	Iodine	127 —	I
Nitrogen . . .	14 —	N	Bromine . . .	80 —	Br
Carbon. . . .	6 —	C	Fluorine . . .	19 —	Fl
Sulphur . . .	16 —	S	Boron	11 —	Bo
Selenium . . .	79 —	Se	Silicon	21 —	Si
Phosphorus . .	32 —	P			

The second class, the metals, comprises a great number of elements, but many of them are rare and costly, hence are not used to any extent in the arts; the equivalents and symbols of such as occur more commonly are given below :—

	At Wt.	Sym.		At Wt.	Sym.
Potassium	40	K	Aluminum	13·7	Al
Sodium	23	Na	Manganese	27·6	Mn
Lithium	6·5	Li	Iron	28·0	Fe
Barium	68·5	Ba	Chromium	26·7	Cr
Strontium	43·8	Sr	Nickel	29·6	Ni
Calcium	20	Ca	Cobalt	29·5	Co
Magnesium	12	Mg	Zinc	32·6	Zn
Bismuth	213	Bi	Copper	31·7	Cu
Lead	103·7	Pb	Tin	58	Sn
Antimony	129	Sb	Silver	108	Ag
Gold	197	Au	Mercury	100	Hg
Platinum	98·7	Pt	Arsenic	75	As

Oxygen in combining with other elements forms either oxides or acids; the former acting as bases to the latter, the two kinds of bodies uniting to form salts,—thus one atom of oxygen with one of potassium forms oxide of potassium, or potash (potassa), which is a powerful alkali or antacid. Three atoms of oxygen with one of sulphur forms sulphuric acid, which will combine readily with the potash and form the salt known as sulphate of potash, the composition of which is

$$K\,O + S\,O_3 = K\,.\,S\,O_4$$

This is a typical salt of one class, being that formed from oxyacids, or acids in which oxygen is the ascescent principle.

Hydrogen also in combination with certain bodies forms acids; thus one atom of this element with one of chlorine forms hydrochloric or muriatic acid, and this acid may be combined with potash, forming a salt typical of another class.

$$K\,O + K\,.\,Cl = K\,.\,Cl + H\,O$$

here the chlorine and potassium combine to form chloride of potassium, and the oxygen and hydrogen unite as water. Salts of this class are called *haloid* salts, from the similarity of their constitution to that of sea salt.

Unfortunately the rapid development of chemical science has been attended with an evil which is great to beginners; this is a constant tendency on the part of experimentalists and theoretical chemists to alter the nomenclature to suit the results of their researches or the requirements of the theories built thereon, and thus an amount of confusion is unnecessarily imported into the matter which might well be avoided, for although the professional chemist is of course always informed of alterations and acquainted with the systems adopted by different physicists, yet others whose profession requires a knowledge of the science cannot afford time to study every new proposition or doctrine put forth, hence cannot conveniently avail themselves of the discoveries of certain experimentalists because the language adopted by them is unusual.

A few examples may here be inserted to illustrate the terminations and prefixes used in the nomenclature of chemical compounds.

Different terminations and prefixes in some cases show the quantities of oxygen in a body; nitrogen is capable of combining with oxygen in five different proportions, which are named as follows:—

Nitrous oxide . . = $N.\ O.$
Nitric oxide . . = $N.\ O_2$
Hyponitrous acid = $N.\ O_3$
Nitrous acid . . = $N.\ O_4$
Nitric acid . . . = $N.\ O_5$

Thus the termination "*ous*" indicates the presence of less oxygen than the terminal "*ic*," and prefix "*hypo*" also shows a still lower proportion of the acidified, but "*hyper*" would indicate more oxygen.

Salts formed from acids ending in "*ic*" have names ending in "*ate*," those from acids having the terminal "*ous*" end in "*ite*."

Thus sulphuric acid and oxide of iron form sulphate of iron, the composition being,

$$Fe.\ O + S\ .\ O_3 + aqua,$$

the last (*aqua*) indicating water, which is incidentally present in the proportion of seven equivalents. Sulphurous acid and soda form sulphite of soda,

$$Na.\ O + S\ O_2 + aqua.$$

The water present is termed water of crystallization, being necessary for the substance to retain its characteristic crystalline form. The prefixes to the acids remain the same when applied to the salts.

The acids of hydrogen give terminations "*ide*" or "*uret*" to their salts; thus from hydrochloric acid and oxide of zinc we get chloride of zinc, and from hydrosulphuric acid and oxide of iron we have the sulphide or sulphuret of iron.

The oxides have prefixes according to the qualities of oxygen in them; thus, "*proto*" signifies atom, to atom; "*bis*," two oxygen; "*sesqui*," two metal to three oxygen; "*per*," the highest oxide. These prefixes also attach to the salts of the bases to which they refer; thus we have protosulphate of iron from protoxide of iron, and sesquisulphate or persulphate from sesquioxide or peroxide.

When Greek prefixes are used, they signify that the number of atoms of metal predominates over that of the oxygen, thus deutoxide would indicate two atoms of oxygen to one of metal.

Bodies may be separated from each other according to their solubilities, and in mineral chemistry it is by this method principally that analyses are conducted. If to a solution of acetate of lead some sulphate of soda be added, the two bases will change places with each other, sulphate of lead will form and fall to the bottom of the solution, while the acetate of soda will remain in solution, and may be filtered off from the precipitate.

If a body is to be analysed, the first step is to dissolve it in water, or if necessary in acid, then the elements must be precipitated in various forms, according to circumstances, and from the weights of such precipitates and their known constitution, the amounts of the various elements present may be readily computed.

In organic chemistry a different course has to be pursued, as it is not so much the ultimate elements as the proximate constituents which serve as a means of judging of the nature of any given substance; thus nearly all organic matters are mainly composed of two, three, or all of the elements, oxygen, hydrogen, carbon, and nitrogen, hence it is more frequently the relative amounts of the gluten, sugar, starch, &c., which are required to be determined than those of the ultimate elements. These may be separated by using different solvents, or menstrua, such as water, alcohol, ether, &c., to dissolve out the various components. The following catalogue shows the behaviour of some of the commonly occurring substances with re-agents, and may serve as a guide in qualitative analyses, that is to say, in analyses where the nature only, not the *quantity*, of substances present is to be determined:—

Potassa with bichloride of platinum yields on evaporation yellow crystals.

Potassa with tartaric acid, a granular crystalline precipitate.

Soda with antimoniate of potash yields a crystalline precipitate.

Lithia boiled with phosphate of soda and ammonia gives a slightly soluble precipitate.

Baryta with carbonates of alkalies gives white precipitate, also with sulphates and oxalic acid, and a yellow precipitate with chromate of potash.

Lime with sulphuric acid and water, no precipitate, but with alcohol a precipitate.

Magnesia with potash a flocculent precipitate dissolved by adding chloride of ammonium.

——— with oxalate of ammonia yields white precipitate.

Alumina with potash or ammonia yields a bulky white precipitate.

Zinc with potash and ammonia, a white gelatinous precipitate,—with sulphuretted hydrogen, a white precipitate, except in acid solutions.

Iron Protoxide with potash or ammonia, flocculent precipitate turning brown.

——— with phosphate of soda, white precipitate turning green.

——— with ferrocyanide and ferricyanide of potassium, a blue precipitate.

——— with alcaline carbonates, white precipitate.

Iron Peroxide with potash and ammonia, reddish brown precipitate.

Iron Peroxide with alkaline carbonates, light brown precipitate.

——— with ferrocyanide of potassium, blue precipitate.

Lead with iodide of potassium, or chromate of potash, a yellow precipitate.

—— with sulphuric acid, a white one.

Silver with phosphate of soda, a yellow precipitate—ferrocyanide of potass, white—ferricyanide of potass, brown,—persulphate of iron, white.

Mercury with potash, a yellow precipitate,—iodide of potassium, red,—and with chloride of tin, grey.

Copper with carbonate of potash, greenish-blue precipitate,—ferrocyanide of potassium, brown,—and ferricyanide of potassium, yellowish-green.

Amongst the proximate constituents of organic matter—

Æther dissolves fatty matters, caoutchouc and sulphur.

Alcohol dissolves many organic crystalline matters, such as vegetable alkalies, &c.

Water dissolves sugar, gum, starch, and other bodies insoluble in alcohol and æther.

Benzole and *Chloroform* resemble æther in their action.

We have not space, nor indeed is it necessary for our present purpose, to give a more detailed account of the methods of detecting and extracting bodies, but we shall now set forth the general properties of some elementary substances and their compounds.

Hydrogen has the least atomic weight, and is also specifically the lightest of the elements, the weight of a given bulk of atmospheric air being 1000, that of the same bulk of hydrogen would be 68. Its heating power during combustion is very great, but its flame is colourless, and gives no light of any intensity. In combination with certain of the metalloids it forms acids. The distinctive test of an acid is that it will turn infusion of litmus red, and when thus changed an alkali will restore the original blue color; but there are certain substances which will combine with bases after the manner of acids, which do not exhibit this property.

With sulphur, selenium, and phosphorus hydrogen forms sulphuretted seleniuretted, and phosphuretted hydrogen, the latter burning on exposure to the air. The first is a very valuable analytical test for classifying the metals. With chlorine, iodine, bromine, and fluorine the hydracids are formed, which, in conjunction with bases, yield haloid salts. Hydrogen combines with oxygen in two proportions, protoxide or water, and binoxide of hydrogen, which latter does not occur in nature.

With nitrogen hydrogen combines in proportion of three atoms to one, producing that well known body *ammonia.* This product is formed in many ways, as by the decomposition of animal matter by heat or putrescence, and by the action of powerful alkaline substances on its salts. If ammonia and hydrochloric acid are brought together chloride of ammonium is formed (ammonium is a hypothetical metal having the formula NH_4) thus,

$$NH_3 + H\,.\,Cl = NH_4\,Cl.$$

if this body be acted upon by caustic lime there results ammonia, chloride of calcium (lime is oxide of calcium), and water,

$$NH_4\,Cl + Ca.\,O = NH_3 + Ca\,Cl. + H\,O$$

the ammonia escapes in a gaseous state, and the water remains in mechanical combination with the chloride of calcium, which is a powerful absorbent, and when dried by a strong heat is used to dry gases in various chemical processes.

We may here cite one practical effect of this reaction; when it occurs through the addition of lime as a deodorizer to sewage matter, the latter is rendered of no value as manure, because the ammonia in it is expelled, and therefore its constituent nitrogen, which is one of the most valuable elements of manure.

Ammonia is strongly alkaline; it affects some of the metals, dissolving oxide of copper pretty freely, and combining rapidly with the acids; its salts are mostly volatile under the influence of heat. One volume of water will absorb 600 volumes of ammoniacal gas.

Hydrogen will not support combustion or animal life, and it is rapidly condensed by contact with spongy platinum, spontaneously burning,—the product of its combustion is water.

Hydrogen is easily obtained by the decomposition of water by some substance which takes away its oxygen, leaving the hydrogen free. Metallic zinc is commonly used for the purpose, but as the coating of oxide of zinc covering its metallic surface soon stops its action, it is necessary to add sulphuric acid to dissolve it. The action is represented by the equation,

$$Zn + S\,O_3 + H\,O = Zn\,O\,.\,S\,.\,O_3 + H$$

Hydrogen, in combination with carbon, forms a great variety of bodies known as hydro-carbons, which are much used for lighting and heating purposes; coal gas, paraffine, and naphtha are familiar examples. The hydrogen greatly increases the heating power, and carbon that of illumination. A unit of heat being that amount which will raise one pound of water in temperature one degree Fahr., the theoretical heating powers of hydrogen and carbon are—

Calorific value of hydrogen per pound, 62,081 units
,, ,, carbon ,, 14,505 ,,

Oxygen is incombustible, but a supporter of combustion and animal life. It combines with all the metalloids to form acids, and with the metals to form oxides; its specific gravity (air being 1,000) is 1,100. Oxides combine with acids and form salts, and there are two modes of regarding such combination: the first merely assumes the simple combination of the two bodies, thus

$$Zn\,.\,O + S\,O_3 = Zn\,.\,O\,.\,S\,.\,O_3 = \text{sulphate of zinc;}$$

the second is somewhat more complex, but yet ingenious, as explanatory of the changes occurring both in mineral and organic chemistry. It is based on the assumption that the salts of the oxygen acids are similar in structure to those of the hydrogen acids. Instead of considering, say, sulphuric acid as existing as $S\,O_3$ the elements of a molecule of water are introduced, creating a salt radical combined with hydrogen, thus,

$$S\,O_3 + H\,O = S\,O^4\,H$$

which may be termed sulphate of hydrogen; then other sulphates are produced by the substitution of metals for the hydrogen—

$S\ O_4 + H$ becomes, by substituting, Zn, — $S\ O_4\ Zn$

or sulphate of zinc, and similarly other salts are obtained; thus the combination of the acid or radical with the base is shown fully by the equation,

$$S\ O_4\ H + Zn\ O = S\ O_4\ Zn + H\ O$$

the displaced hydrogen combining with the oxygen of the base and forming water. The ordinary atmospheric air consists mainly of oxygen largely diluted with nitrogen gas, the composition of 100 measures of air being

79 measures of nitrogen,
21 „ oxygen.

There is usually a little carbonic acid present, and also aqueous vapour in variable proportions; thus, at a temperature of 42 degrees, it is 0·01, and at 80 degrees, 0·035 of the bulk of air. Air is about 800 times lighter than water. Oxygen may be obtained by heating chlorate of potash, when it will freely be given off, leaving chloride of potassium behind, thus

$$K\ O\ .\ Cl\ O_5 = K\ .\ Cl + O_6$$

The gas is evolved at a much lower temperature if oxide of manganese be added, which acts catalytically, its own composition being unaltered.

Combustion, putrefaction, rusting, &c., are processes of oxidation, and reduction is a process of deoxidation. (See Chap. xiii.)

Nitrogen, in a pure state, is an inert gas, incapable of supporting life or combustion, although, at a very high temperature, it may be burnt; but its combustion does not generate sufficient caloric to maintain the temperature at which it burns. Its specific gravity is 970, and it may readily be obtained by depriving atmospheric air of its oxygen by burning phosphorus in it, or by passing it slowly over spongy iron at a red heat. This latter method is used for commercially obtaining nitrogen, when required for preserving perishable matters, a purpose to which it is admirably adapted from its perfect inertness.

Nitrogen, in combination with other elements, forms substances capable of producing violent and sudden chemical action; thus nitric acid, $N\ O_5$, is a most powerful re-agent, and exerts an instant destructive action on organic matter, and there is scarcely any explosive material which does not contain this elementary gas; it is found in gunpowder, gun-cotton, nitro-glycerine, &c.

The nitrates have a very great power of oxidation, and have been employed to oxidize the carbon in cast-iron in the process of manufacturing steel.

Carbon is the only solid amongst the four elements which mainly constitute organic matter. It possesses the property of absorbing gases so as probably to bring them by catalytic action into combination, hence it is useful to destroy the foul gases from putrescent matter, or rather to recombine them in an innocuous form, and also as a filter for purifying and decolorising water and other liquids. It exists in many different forms, such as soot, charcoal, coke, bone-black, plumbago, and diamond. Charcoal may also be prepared from sugar, which consists of carbon, with hydrogen and oxygen in the proportions of water; by removing this water the carbon is left. Sulphuric acid has a stronger affinity for water than has the carbon, hence if it be added to a saturated solution of sugar, the latter will be decomposed and the carbon eliminated, thus

$$C . H . O + S O_3 = S O_3 H O + C = S O_4 H + C$$

by washing and drying, pure carbon will thus be obtained in a finely divided (atomic) state.

Carbon combines with oxygen in burning, producing carbonic oxide and carbonic acid gases, having the formula CO and CO_2; the latter unites readily with bases, but is displaced with effervescence by the stronger acids.

Sulphur, Selenium, and Phosphorus are three elements which may be classed together as pyrogens, from the readiness with which they ignite, forming sulphuric, selenic, and phosphoric acids. Selenium bears a great resemblance to sulphur, but it is of very rare occurrence, hence is not used in the arts.

Sulphuric and phosphoric acids act as oxidizers, the former being a powerful and stable acid; it may be distilled from sulphate of iron, or prepared by the combustion of sulphur, which produces sulphurous acid SO_2, that may be oxidized into sulphuric acid by the subsequent action of nitric acid. Phosphoric acid may be similarly produced; but either of the more highly oxidized acids may be obtained direct by combustion in pure oxygen.

Chlorine, Iodine, Bromine, and Fluorine are four bodies of similar character; between the three first, which have been more studied than the last, there are very striking analogies.

These bodies combine with hydrogen to form hydracids of the type $x\ H$, where x represents any of the above elements; they also combine with oxygen to form oxy-acids in different proportions. Chlorine, which is gaseous, will support combustion to a certain extent; it has a very pungent odour, and is destructive to life. It is a powerful bleaching agent, acting indirectly by combining with the hydrogen of aqueous molecules present, thus producing nascent oxygen, which removes colouring matter; its specific gravity is 2,500. Chlorine is obtained by the action of hydrochloric acid on black oxide of manganese, assisted by heat, thus

$$Mn\,.\,O_2 + 2\,H\,.\,Cl = 2\,H\,O + Mn\,.\,Cl + Cl$$

Iodine is a solid, having a specific gravity—5,000 (water being 1,000), and bromine is a liquid of specific gravity, 3,000. Both these elements are very volatile, and are found in company with chlorine.

Boron and Silicon occur in nature in combination with oxygen, as boracic and silicic acids, and with many bases they form amorphous salts, as glass, slag, glaze, &c., wherefore they may be called hyalogens.

The foregoing thirteen bodies are termed non-metallic elements or metalloids, in contradistinction to the metals. They are bad conductors of heat and electricity. When substances are decomposed by galvanism, they always separate at the positive (zinc) pole, hence are called electro-negative bodies; almost all of these combine with hydrogen, forming acids, and with oxygen, forming oxy-acids. The conditions in which they exist are—

7 Metalloids, solid: *C. S. P. Se. I. B. Sv*
1 „ liquid: *Br.*
5 „ gaseous: *O. H. N. Cl. Fl.*

They form four families, or groups, founded on their resemblance to each other—

1st Group—Organogens, animal and plant producers, *O. H. N. C.*
2nd ,, —Pyrogens, fire producers, *S. Se. P.*
3rd ,, —Halogens, salt producers, *Cl. I. Br. Fl.*
4th ,, —Hyalogens, glass producers, *Bo. Si.*

Having briefly shown the behaviour of metalloids with metals, it will not be necessary to treat of the latter individually, we shall, therefore, merely consider them generally.

METALS.—The following are the general properties of the metals in contradistinction to the metalloids. All the metals have a peculiar *lustre*, are *opaque*, and are the best *conductors* of heat and electricity. Most of the metals will *crystallize* on being slowly cooled from a molten state; generally the crystals are cubical. All the metals are *fusible*, and some may be *volatilized.*

All metals will combine with *oxygen*, *sulphur*, and *chlorine*, and with each other they form alloys. Most of the metals form basic oxides with oxygen, and which are usually insoluble in water. The sulphurets of the light metals are soluble in water, and those of the heavy metals insoluble. Most of the chlorides may be crystallized, and are solnble in water. Generally the oxy-salts of metals may be crystallized, sometimes with, and sometimes without, the accession of water, but they have different degrees of solubility in water.

The metals principally occur native in five forms, 1st, *Pure*—Gold, Platinum, Silver, Bismuth, Mercury, Arsenic. 2nd, *as Sulphurets*—Lead, Antimony, Copper, Silver, Mercury, Arsenic, Iron, Zinc. 3rd, *as Arseniurets*—Cobalt, Nickel, Silver, Iron. 4th, *as Oxides*—Manganese, Tin, Iron, Chromium, Zinc, Uranium, Copper. 5th, *as Salts*—Potassium, Sodium, Barium, Strontium, Calcium, Magnesium, Aluminum, Zinc, Iron, Lead, Copper. The following arrangement shows the order of affinities of elements, commencing with the most negative and finishing with the most positive :—

Oxygen
Fluorine
Chlorine
Bromine
Iodine
Sulphur
Selenium
Phosphorus
Nitrogen
Carbon
Boron
Silicon
Arsenic
Antimony
Tin
Hydrogen
Platinum and Gold
Silver
Mercury
Copper
Lead and Bismuth
Nickel and Cobalt
Zinc
Iron
Manganese
Chromium
Aluminum
Calcium and Magnesium
Barium and Strontium
Sodium
Potassium

The negative elements, forming preferably *acids*, are the first, as far as carbon. The next to nickel are undecided, and the remainder are positive, forming preferably bases. In chemistry generally the law holds good that the more dissimilar bodies are to each other the more eagerly will they combine with each other; thus in the above series potassium and oxygen have a much stronger affinity for each other than manganese has for sulphur, but there are many circumstances under which bodies are brought together that tend to cause the scale of affinities to fluctuate.

If any two solutions be mixed together and they contain elements that by exchanging places will form an *insoluble* compound, such a reaction will almost invariably occur; thus if to a solution of acetate of lead another containing sulphate of soda be added, a reaction shown by the following equation will take place,—

$$Na.\ S\ O^4 + Pb.\ O.\ \bar{A} = Na.\ O.\ \bar{A} + Pb\ S\ O_4$$

($\bar{A}$ is the symbol of acetic acid). The sulphate of lead being insoluble falls to the bottom of the solution as a dense white precipitate and may be separated by pouring the solution on to a filter of bibulous or blotting paper; the acetate of soda will pass through in the solution, leaving the sulphate of lead on the filter. By elective affinity also bodies may frequently be displaced from their compounds. Chemical changes are wrought in some instances by invisible means; thus the actinic or chemical rays emanating from the sun and other sources will produce certain reactions, such as are exhibited in photography. These rays act independently of those that are luminous, and in fact the most vigorous of them when refracted by a prism fall outside of the luminous spectrum.

The next series of physical phenomena which requires our attention is that due to ELECRICITY. The word electricity is derived from the Greek ελεκτρον (amber), from its effects first being noticed as arising from friction on amber. It has been very common to speak of electricity as a fluid, and even two kinds, positive and negative, have by some physicists been assumed to exist, others considering the negatively electrical state of a body to be due to a deficiency of electricity, that is to say, caused by the body being less electrical than it is in its normal condition.

Electricity has been classed as static and dynamic, the former being obtained by friction of vitreous matters, the latter by chemical action; also the first has great *intensity*, whereas in the latter *quantity* predominates. It is necessary to explain these terms as a correct understanding of their application is indispensable to a knowledge of electricity. Intensity refers to the quantity accumulated *on a given surface*, whereas the quantity is shown by the chemical effects it is capable of producing; the former is capable of giving violent shocks, and shattering non-conducting bodies, but the latter, although the quantity passing may be much greater, will not produce effects so evident to the senses. It is not to be supposed, however, that intense effects cannot be produced by electricity chemically developed, for the intensity can be regulated, as will presently be shown.

It appears to us that the doctrine of the existence of an electric fluid is not satisfactory, and that the phenomena arising from it are more conveniently considered as resulting from vibratory motions, somewhat akin to those supposed to cause the phenomena of heat.

Frictional electricity is usually obtained from a machine consisting of a glass plate or cylinder mounted on insulators (non-conductors), and caused to revolve in contact with a rubber of wash-leather, on which is smeared an amalgam or alloy of mercury, to increase the friction; the electricity is collected by metal points connected with a metallic ball, cylinder, or other *prime conductor*, which is insulated, and from which the electricity may be led by suitable conductors, and applied to any required purpose, or it may pass off, if any body be brought within striking distance of the prime conductor, when the force will bridge over the intervening space, exhibiting a flash or spark, as the case may be.

Dynamic, or galvanic, or voltaic electricity is formed by the action of acids, &c., upon metals; thus, if two plates, one of copper and the other of zinc, be immersed, but not in contact with each other, in an acid solution, then upon making a connection between them by a conductor outside the liquid, a current of electricity will pass along the conductor, and at the same time the zinc will be attacked and partially dissolved by the acid, whereas the copper will remain intact. The latter will form the *positive*, and the former the *negative* pole of the battery or cell. The course taken by the electrical current is from the zinc through the acid solution to the copper, whence it passes back through the conductor from the copper to the zinc.

In the frictional machine the electricity is lowered in the cushion or rubber, and increased in the prime conductor, hence the positive pole is on the latter, the negative on the former part in this case.

In the battery, although the zinc is the negative pole, the metal is positive, compared with copper, as the current passes first from it through the acid solution to the copper. The quantity of electricity generated by the same materials will vary as the size of the plates of metal, but the intensity as the number of cells which are used. In combining a number of cells to form a battery, the zinc of one cell is connected to the copper of the next, and so forth, the poles being located in the terminal cells. It is evident that by enlarging the plates the surface for the chemical action is increased, so that more electricity is developed, but as it is developed on a larger surface, the intensity remains constant; but if the number of cells be increased, the electricity passes from one plate on to the next, where more is developed, thus causing more electricity to exist on the same surface, hence the intensity is increased, but not the quantity.

We will now direct our attention, in the first place specially, to frictional electricity. Insulated bodies oppositely electrified attract, but those similarly electrified repel each other. The insulation of bodies is accomplished by supporting them on glass, or some other material which, being a non-conductor, will not allow the electricity to pass so as to restore equilibrium. When two bodies by friction become electrified, such as glass and leather, then one body becomes positively charged, the other negatively; and if both are in electrical communication with the earth, the surcharge will pass to the earth from the positive body, and return to the negative: the earth may be regarded as the reservoir of electricity. The behaviour of electrified substances towards each other is ruled by the following laws:—

1. The attractive and repellent forces vary inversely as the squares of the distances.

2. At equal distances these forces vary as the quantities of electricity contained by the two bodies.

The intensity of charge is in some cases the same all over the surface of an electrified body, but this is not always the case, depending upon the form of the body; it will be uniform, for instance, on a sphere, but if an ellipsoid, with one end elongated into a point, be charged, the greatest intensity will be found at the point, naturally by its repulsion seeking the most distant parts. The electricity will also pass off into the air from a point, showing a light in the dark. The electrical equilibrium may also be disturbed by *induction;* thus, if a body, such as a cylinder, have one end presented to a positively electrified mass, that end will be negatively electrified, and the more distant one positively. In all these cases the bodies experimented upon are supposed to be insulated. On the removal of the cylinder from the positively electrified body its electrical equilibrium is restored, provided it has not been held near enough for any portion of electricity to pass into it. If a wheel, carrying on its periphery points placed tangentially, and suspended so as to admit of rotation, be electrified, it will revolve rapidly, as if driven by a reaction current; and similarly a charged point being applied to a flame, will deflect it. In order to produce greater effects than can conveniently be obtained from the sparks passing from prime conductors, it is accumulated on a metallic surface, commonly consisting of metallic foil lining a glass jar, or bottle, which is also coated externally with metallic foil, the two coatings being separated by the glass of which the jar is made. On positively charging the internal lining from a frictional machine, the external coating becomes negatively charged, and the jar may then be discharged by making electrical connection between the two coatings, and any substances placed in the circuit of such connection will be subjected to the electric shock. If necessary, a number of these jars may be combined into a battery, by connecting all the internal linings together, and also all the external, then the whole series of jars may be discharged simultaneously through one conductor. By means of an electrical spark non-conducting bodies may be perforated, and also chemical effects may be produced; thus, by its means, the combination of gases may be brought about; hydrogen and oxygen, when a spark is passed through them, combine with violently explosive effects.

Frictional electricity is not used in the arts to any extent, as it is inconvenient to procure it, whilst that derived from chemical means is always obtained with great facility, being, of course, of the same character. Dynamic electricity will, therefore, now be more fully considered.

The forms of galvanic batteries are multifarious, but the fundamental principle being the same throughout, it is not necessary to catalogue them all, though some are worthy of a special notice. In the ordinary cell one surface of the plate of copper and one of the zinc are in action; but in Wollaston's battery the copper plate is curved into a U shape, so as to surround the zinc, then both the surfaces of the latter will be brought into action. The batteries may be charged with water acidulated with nitric acid. As the zinc of commerce is never pure, it will always occur that local currents are set up in it, causing rapid destruction; hence the zinc should be *amalgamated*, then it will only be consumed when the battery is in action and the circuit complete. Amalgamation consists in rubbing mercury on the zinc, which absorbs it, thus forming a protective coating. The theory of the action of the galvanic battery is as follows:—

1. In the combination of oxygen with an oxidizable body, the former takes the positive and the latter the negative electricity.
2. When an acid combines with a base, the former takes the positive, the latter the negative electricity.
3. When an acid acts chemically on a metal, the former is electrified positively and the latter negatively.
4. In decompositions the electrical effects are the inverse of those above mentioned.
5. In double decompositions the electrical equilibrium is not disturbed.

The quantity of electricity disengaged by chemical action is something enormous; in fact M. Becquerel found that the oxidation of sufficient hydrogen to yield one millegramme of water evolved sufficient electricity to charge a metallic surface of one square metre so highly as to discharge a spark through a distance of one centimetre, and similar results have been arrived at by Faraday, Pelletier, and Buff. Grove's battery consists of an external vessel of glass or earthenware, partly filled with water acidulated with sulphuric acid, containing a zinc cylinder open at both ends and all down one side; inside this is a porous vessel of pipe-clay, containing ordinary nitric acid, in which is immersed a piece of platinum.

Bunsen's battery is similar in form to the last, but in the porous tube, instead of the platinum, solid carbon is used.

The calorific effects of dynamic electricity are controlled by the following laws:—

1. The quantity of heat varies as the square of the quantity of electricity passing in a given time.
2. This quantity of heat varies as the resistance of the conductor to the passage of the electricity.
3. Whatever be the length of the conductor, if its diameter is constant, and will pass the same quantity of electricity, the elevation of temperature will be the same throughout its length.
4. For a given quantity of electricity, the elevation of temperature at different points of the conductor varies inversely as the fourth power of the diameter.

In chemical actions Faraday has found that if the same quantity of electricity acts successively on a series of solutions, the weights of the elements separated are in proportion to their chemical equivalents.

If a piece of wire be insulated by covering it with silk or other non-conducting material, and then coiled round a bar of soft iron, the latter will become magnetic whenever an electric current is passing through the coil of wire, but the magnetism ceases directly the current is discontinued. The effect of a current on a permanent magnet freely suspended, such as a mariner's compass needle, if the current be caused to travel through a wire laying north and south, is to make the needle for the time being point east and west, returning to its normal position on the cessation of the current. On this effect is based the construction of the electric telegraph now most commonly used.

If two conducting circuits are in proximity to each other, but not in electrical contact, on passing a current of electricity through one, an induced current flows through the other, but is only momentary, occurring only on the completing and at the breaking of the primary circuit. The following are the laws of induction:—

1. The distance being the same, a continuous constant current does not induce a current in a neighbouring circuit.
2. An inducing current creates an induced current in a direction opposite to its own when the current commences.
3. Both currents are in the same direction when the inducing current is ending.
4. A diminishing current gives rise to a direct induced current.
5. An increasing current induces a current in an inverse direction.

By means of passing a current through a short primary insulated coil in the vicinity (say on the same reel) of a long secondary coil, arrangements being made for incessantly breaking the contact, a secondary current of greatly-increased intensity is obtained, from which very remarkable effects may be obtained. An apparatus of this description is known as Ruhmkorff's Coil, or more commonly as an induction coil.

Currents of electricity are also induced by causing the armature of a permanent magnet to revolve rapidly in proximity to the magnet, and these currents may be collected by suitable coils of insulated wire surrounding the armatures.

Electricity may be evolved by variations of temperature under some circumstances.

It would be inappropriate to conclude this brief notice of the physical forces without considering the very important doctrines referring to the *correlation and mutual convertibility* of the physical forces.

It has been experimentally ascertained that the various physical forces are mutually convertible; that is to say, the force producing one particular set of phenomena may be changed into a force exhibiting a different class of phenomena; the following example will suffice to indicate the nature of this correlation:—

The combustion of fuel in the furnace of a steam-boiler is an instance of *chemical action* which produces *heat*, which heat, by expanding the aqueous molecules in the boiler, gives rise to stored or potential force, and this force may, through the intervention of a steam-engine, be converted into mechanical power and overcome the force of gravity, or, being expended in creating friction, may be reconverted into heat. The same work may be employed to develop electricity from a frictional machine or from a magneto-electrical machine, and this electricity may be caused to incite *chemical* *action;* thus, commencing with chemical force, after a variety of changes, it is finally again reached.

Similar transformations may be accomplished in other ways; thus, *electricity* may be used, through the agency of electro-magnets, to do *mechanical work* of any description, or to generate *heat* direct by its action on certain substances, or to incite *chemical action.*

Commencing with *heat,* it may be converted into *mechanical* effect, or will *incite electricity* or *chemical action.*

It is now desirable to point out generally in what ways a knowledge of physical science is requisite or advantageous to the mechanical engineer. It will be admitted that it is expedient for any one engaged in designing machinery for a manufacturer to be acquainted with not only the nature of the work to be done, but also with the nature of the materials and character of the processes employed in connection with the apparatus. Where acids are present the apparatus must be of such materials as will resist their action; thus, sulphuric and nitric acid, with some others, rapidly corrode the common metals, and require platinum or glass to resist their deteriorating tendency, while, for fluoric acid, silver or lead is requisite, glass being destroyed by it.

To conduct successfully novel metallurgical operations, and for the comprehending of existing methods, a knowledge of chemistry is required.

The sciences of electricity and magnetism involve those principles on which depends the action of telegraphic instruments and of electro-magnetic prime-movers, and, in addition, affords us the means of measuring and recording the efficiency of all kinds of machinery.

While strongly urging the desirability of the mechanical engineer acquainting himself with the general principles and fundamental laws of all branches of natural philosophy, it is not to be imagined that we wish him to be a thorough practical chemist and electrician, as this would be almost beyond his reach, as the time that can be spared to obtain a comprehension of such laws is not sufficient to master the details of the sciences to which they refer, nor is it necessary that he should be able actually to practise the various manipulations, although he may know how they are done by seeing and reading, without having the manual dexterity necessary for their performance, and which can only be acquired after continued practice during a long period of time. But even where there is no actual chemical process to be carried on in the machinery, as with sewerage works, &c., it is desirable to be conversant with the nature of the materials passing through, and of the changes to which they are liable; and very frequently, in all kinds of manufactures, an engineer who is also a scientific man may be able to see and suggest improvements which would not present themselves to any one who did not combine the two kinds of knowledge.

In concluding this chapter it cannot be too forcibly impressed upon the mind of the student that there are many intervals of time actually wasted which would serve well, if properly applied, for obtaining scraps of knowledge on subjects near the boundaries of strictly engineering science which subsequently may prove of immeasurable value. By seizing these opportunities, and gathering together, one by one, certain physical facts, they are each more enduringly marked in the memory, so as to be more distinctly remembered individually, than when a great number of facts are taken in quick succession, as in this case it not unfrequently happens that before one matter is well appreciated another is commenced upon, and thus, in the mental effort to retain the two, both are confused together. It is a notable fact that "a little well learnt is much better than a great deal half learnt," as the former use is useful, as far as it goes, and the latter is no at all.

By storing the mind with information little by little, and at times when the facts which come under notice may be considered and digested, it is found that, after a time, these elements coalesce into a complete knowledge of the science to which they refer, and the student becomes acquainted with it in a manner almost unknown to himself.

CHAPTER XX.

ELECTRICAL AND CHEMICAL MACHINERY.

For many years different designs for electro-motive engines have from time to time been brought out, but hitherto this class of machinery has not come much into use, for although the actual efficiency of an electrical engine may be made to approach more nearly to that determined by theory than is the case with the useful effect of an ordinary steam-engine, yet from the greater expense of the materials used in the electrical than in the steam engine, the amount of work obtained for *a given price* is greater, when the latter is employed, than when the former motor is used.

A current of electricity of unit strength will decompose 0·02 grains of water per second, or 0·0103 pounds per hour, and to produce a current of this strength requires the consumption in each cell of

0·0728 grains zinc per second,
0·0374 pounds zinc per hour.

The quantity of zinc necessary to decompose one pound of water per hour would be, according to the above figures,

$$\frac{0{\cdot}0374}{0{\cdot}0103} = 3{\cdot}63 \text{ pounds of zinc,}$$

and the quantity of water which would be evaporated into steam by oxidizing the hydrogen thus set free would be, the quantity of hydrogen being 0·111 lbs.,

$$= 64{\cdot}2 \times 0{\cdot}1\dot{1} = 7{\cdot}13 \text{ lbs.}$$

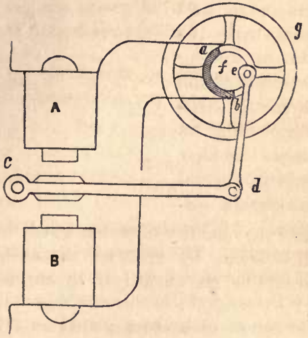
or the units of heat developed by one pound of zinc will be in this way,

$$\frac{966 \times 7{\cdot}13}{3{\cdot}63} = 1896{\cdot}3$$

which is equal to less than two pounds of water evaporated per pound of zinc consumed. Although the force obtained by electrical influence is not thus applied, this calculation will yet serve to give some idea of the quantity of heat evolved from the zinc in the process of oxidation.

A simple form of electro-motive engine is shown in Fig. 65; it may be found useful where a small power is required to be occasionally at work, and where, therefore, a steam-engine would not be required, and constant attention to it would be inconvenient. *A* and *B* are two electro-magnets, made of soft iron, and surrounded by coils of insulated wire, through which currents of electricity may be passed at pleasure. *c d* is a vibrating piece, moving on a fixed centre *c*. To the end *d* is attached a connecting-rod *d e*, of which the upper end is connected with a crank *e f*, fixed to a shaft *f*, carrying a fly-wheel *g*, from which motion and power may be transmitted to the machinery to be worked by the engine.

Fig. 65.

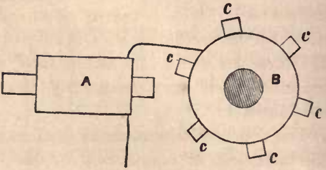


When either magnet is in action, that is to say, whilst a current is flowing round either, that one will attract the vibrating link *c d*, and cause the shaft *f* to revolve, one magnet acting to produce an up-stroke, and the other a down-stroke. In order that the strokes may be successively and regularly made, there is fixed on the shaft *f* a small wheel called a *rheo-motor*, which changes the current from one magnet to the other as may be required; thus, when the top of the stroke is reached, the conductor to the magnet *A* passes on to the non-conducting part *a b* of the rheo-motor, and the conductor to

B falls on the conducting part, the contrary change occurring at the bottom of the stroke.

The electro-magnets must be placed near the fixed centre *c*, as, although the magnetic force may be intense, its power rapidly diminishes as the distance between the magnet and armature increases, varying inversely as the square of the distance. Fig. 66 shows another form of electro-magnetic engine. *A* is the electro-magnet, *B* the wheel to be caused to revolve. The latter carries on its periphery a number of armatures, *c c*, &c , which are successively attracted by the magnet; in this machine the electrical contact is broken as each armature comes opposite the magnet, and made again shortly before the next armature comes before it, and so forth. A number of magnets may be arranged if required round the wheel *B*. This kind of engine works more uniformly than that last described. The mode of constructing the rheo-motor is self-evident, and this engine may be commended for its general simplicity, there being but one moving part in it.

Fig. 66.



By far the most extensive application of electricity to useful purposes is to be seen in the all-encircling system of telegraphs, which has now been improved almost to perfection; in the laying of the Atlantic Cable, the greatest question yet raised in connection with electrical intercommunication, found its solution; the difficulties peculiar to the special undertaking had but to be thoroughly understood, and once surmounted, to render the future establishment of ocean telegraphs an ordinary matter of business, and great honour is due to those who, undaunted by repeated misadventure, boldly persisted in their undertaking, and persevered until rewarded with success in a matter which many thought impossible of achievement.

Electrical telegraphs may be divided into two principal classes:—1, those which communicate by signs indicated by the oscillation of a needle or magnetised bar; 2, those in which the signs are made by electro-magnets; but very frequently the two methods are combined.

The action of telegraphs of the first class depends upon the behaviour of magnetised needles when currents of electricity are passing through wires in their vicinity. The common magnetic needle points north and south, its position being induced by an earth current of electricity running east and west. The properties of a freely-suspended magnetic needle are, first, they will assume a position according to neighbouring currents; second, they may be affected by magnets or pieces of iron. Similar poles repel each other, and opposite poles exert mutual attraction; if the north pole of a permanent magnet be brought near a magnetic needle, it will repel the north pole of the latter, and attract the south.

If a current of electricity be passed through a wire lying parallel to a needle, the latter will deflect to a position more or less at right angles to the course of the current. The direction in which the needle will vibrate is determined by the course of the current and the position of the conductor through which the electrical current is passing; the distance through which the oscillation takes place will depend upon the relative strengths of the artificial and the earth currents, hence in any given apparatus the direction of oscillation may be controlled at pleasure, by causing the current to flow in the course corresponding to the vibration required. On breaking the circuit so as to stop the current, the magnetic needle resumes its normal position.

If two magnetic needles of exactly the same magnetic power be attached together, so as to be suspended on the same axis, parallel to each other, but with their poles in reverse positions, then the directive effort of the earth current on one will be exactly counteracted by the effort on the other, and the system will be indifferent to the earth current, which, be it remembered, passes *under* them. If a current be passed through a wire lying *between* the needles, they will obey it, as one needle being *above*, and the other *below*, the current, the directive effort on both will be the same. Any position once taken up by the two needles will be retained until another current comes into action, or some other force is applied.

This arrangement of needles, on account of its indifference to the natural currents which regulate the normal positions of single magnetised bars placed under their influence, is termed an *astatic system*, and is exceedingly delicate in its action, being affected by very slight currents.

As a galvanometer, two needles may be similarly fixed, but *not exactly* of equal power, then the earth current will affect them, but the resistance to motion from the normal position will be very feeble, and easily overcome by weak artificial currents.

Usually in telegraphs the electricity is conducted through wires, which, of course, oppose a certain resistance to the passage of the current, hence it is necessary to indicate the laws which regulate such resistance.

A current of electricity of unit strength will decompose

0·0103 pounds of water per hour, and requires for its maintenance a consumption of 0·03744 pounds of zinc per hour. Hence, to find the strength of a current, divide the pounds of zinc consumed per hour by 0·03744, or,

Let S = strength of current
w = weight in pounds of zinc consumed per hour:

$$S = \frac{w}{0·03744} = 26·7 \times w$$

let the consumption of zinc be half a pound per hour, then the strength of the current caused by its oxidation is

$$S = 26·7 \times 0·5 = 13·35 \text{ units.}$$

The strength of the current varies directly as the electro-motive force of one cell and the number of cells, and inversely as the resistance of the circuit.

Let E = electro-motive force of one cell,
n = number of cells,
R = resistance of circuit, then

$$S = \frac{E\,n}{R}$$

The resistance of a conductor, however, is equal to its length divided by its sectional area and multiplied by a factor depending on the material.

Let l = length in feet of conductor,
a = sectional area in inches,
c = factor of resistance, then

$$R = c \, . \, \frac{l}{a}$$

or, if W = weight of conductor in pounds,

$$R = f \, . \, l \, W^2$$

For copper wire, at 50° Fahrenheit,

$$f = 128 \text{ to } 176$$

Let 10 feet of copper wire weigh one quarter of a pound, then

$$R = 128 \times \frac{100}{0{\cdot}25} = 3200$$

replacing R by its value in the formula, for strength of current we have

$$S = \frac{E \, . \, n \, . \, W}{f \, . \, l^2}$$

The second class of telegraphs indicates signals by means of mechanical action brought into play through electro-magnets; of this kind are printing and writing telegraphs, and also electrical bell-signals The action of the magnet may be merely to release a stop and so allow of the movement of clockwork driven by a spring or weight, or the attractive force of the magnet may produce the required effect. Generally on railways bell-signals are used in conjunction with the needle instruments.

In all cases the conducting wires of telegraphs must be insulated, as otherwise the current proceeding from the positive pole of the battery would return to the negative pole by the shortest route, and without passing through the instruments it is desired to actuate. Railway and similar wires are supported by earthen carriers attached to the posts, but subterranean and submarine cables consist of conductors insulated by coatings of caoutchouc or gutta percha, or some analogous compound,—the perfect insulation being a matter of the greatest importance, as defect in this matter must be attended with certain failure.

Electricity has been successfully applied in weaving, to obviate the necessity of making costly new cards for every pattern to be produced in the Jacquard loom. A number of electro-magnets are employed, being regulated in their action by a band having the required pattern painted on it, thus producing a surface partly conducting and partly insulating, which acts as a rheo-motor.

Several kinds of prime-movers have at different times been brought forward, somewhat similar to the steam-engine, but the elastic force of steam as the propelling agent is replaced by that of some other gas.

Oxygen and hydrogen gases will explode very forcibly when mixed in due proportion and ignited, hence by thus combining the gases in a cylinder fitted with a moveable piston, motion may be imparted to the latter. The modes of ignition adopted have been various. In the earlier engines an electric-spark was the agent, but in those more recently constructed, gas jets have been employed. Generally the ordinary carburetted hydrogen used for purposes of illumination is also employed for the propulsion of these engines.

In the Hugon engine, manufactured by Messrs. Vallance, of Greenwich, the gas, after being mixed with a due proportion of atmospheric air, is ignited by a gas jet at the end of the slide; in this method there is necessarily a communication between the interior of the cylinder and the outer air at the moment of explosion, hence a part of its expansive force must be lost. There are two igniting jets, one at each end of the cylinder, to cause the explosions to occur alternately above and below the piston. The cylinders of gas-engines are in proportion very much larger than those of steam-engines, hence this class of machine would not be admissible in situations where economy of space is an object, but they are not used for heavy work, rarely being made of more than about three-horse power.

Gas-engines have advantages which adapt them to light work, where they are not required to be constantly running, as when still they require no attention, and also there is no boiler to be looked to, and consequently no danger of destructive explosions occurring. As to their economy of working, we are not in a position to give any particulars.

Other gases have been proposed to be used in motive-power engines, such, for instance, as carbonic acid, which may be generated under pressure in a close vessel, and used similarly to steam. Carbonic acid for this purpose may be generated readily from an alkaline earthy carbonate, such as chalk or limestone, by the addition of a strong mineral acid, and, if it were required, the carbonic acid gas, after doing its work in the cylinder of the prime-mover, may again be taken up by an alkali. Such contrivances, however, must for the present be regarded rather as scientific curiosities than as of practical utility.

There are other numerous apparatus, any of which may occasionally be brought under the notice of the mechanical engineer in the course of practice; but to describe these in detail would occupy too much of our space, and would fail to be of sufficient general interest, and any of these contrivances may be readily understood when a knowledge of the general laws of chemistry and electricity is obtained.

Electric lights obtained from galvanic currents, and also from magneto-electric currents, have been applied for the illumination of lighthouses, but there is nothing in the arrangements which here require any particular notice; the light produced, although possessing much intensity, is, like all others, obscured by mists, aqueous vapour intercepting light rays as effectually as a solid body, as may be observed by noticing the depth of shadow thrown by the exhaust steam from a locomotive chimney.

CHAPTER XXI.

MISCELLANEOUS.

In the present chapter it is proposed to notice certain miscellaneous matters which, although worthy of notice, could not with propriety have been included under any of the foregoing heads.

Cast-iron Floor Plates.—The following rule will serve to determine the proper thickness of cast-iron floor plates to sustain a given load; it is based upon the laws of resistance to transverse strain already set forth:

Let t = thickness of plate in inches,
l = length of plate in inches,
w = load in pounds per square foot:

$$t = \frac{l \sqrt{w}}{380}$$

Let $l = 30$ inches, and $w = 64$ pounds:

$$t = \frac{30 \times \sqrt{64}}{380} = 0{\cdot}63 \text{ inches}$$

say five-eighths of an inch.

Dock Gates.—To find the thrust in pounds on the ribs of dock gates,

Let D = depth of water in feet,
L = length of one gate in feet,
d = distance between point at which gates meet and a right line joining their hinges,
P = thrust in pounds, then

$$P = \frac{D^2 \times L^2 \times 31{\cdot}2}{d}$$

Let the depth of water be 20 feet, the length of one gate 30 feet, and the distance $d = 3$ feet, then

$$P = \frac{400 \times 900 \times 31{\cdot}2}{3} = 3{,}744{,}000 \text{ pounds.}$$

Supposing the ribs to be of a rigid form, and of wrought-iron, and assuming 8,000 lbs. as the safe resistance to compression per square inch, the total area of the ribs in one gate in square inches will be

$$\frac{3{,}744{,}000}{8{,}000} = 468 \text{ square inches.}$$

To find the normal pressure on the surface of the gate we have

$$P = 32 \,.\, L \,.\, D^2 \,.$$

TRACTIVE POWER OF LOCOMOTIVES.

Let T = tractive force in pounds of a locomotive,
p = mean pressure in pounds per square inch on piston,
l = length of stroke in inches,
d = diameter of cylinder in inches,
D = ,, ,, driving-wheel in inches,

then,
$$T = \frac{p \,.\, l \,.\, d^2}{D}$$

Suppose a train weighing 110 tons requires to be propelled, the friction being on the average 11 pounds per ton, what will be the mean pressure, the dimensions of the locomotive being as follows :—

$l = 24$ inches, $d = 16$ inches $D, = 60$ inches ?

Transposing the above equation we have to find the value of p,—

$$p = \frac{T \,.\, D}{l \,.\, d^2}$$

From the weight of train and relative frictional resistance given above, we have, for the total traction required,

$$110 \times 11 = 1210 \text{ lbs.}$$

hence the pressure will be

$$p = \frac{1210 \times 60}{24 \times 256} = 11{\cdot}8 \text{ lbs. per square inch.}$$

This would apply to the train running on a level; if it be ascending an inclined plane higher tractive power will be required; thus the additional tractive force to take the train up an incline of 1 in 100 will be

$$\frac{110 \times 2240}{100} = 2464 \text{ lbs.}$$

the total tractive force in this case will be

$$2464 + 1210 = 3674 \text{ lbs.}$$

and the mean pressure per square inch,

$$p = \frac{3674 \times 60}{24 \times 256} = 35{\cdot}8 \text{ lbs. per square inch.}$$

SUPER-ELEVATION OF OUTER RAIL ON CURVES.—Railway trains in passing round curves, have a tendency, by virtue of the centrifugal force, to leave the metals; but to obviate this the outer rail is laid at a higher level than the inner. From the laws of centrifugal force, and of the inclined plane, we find a formula to show what super-elevation is necessary:—

Let S = super-elevation in inches,
G = gauge of rails in feet,
v = speed of train in miles per hour,
r = radius of curve in chains, then

$$S = \frac{G \,.\, v^2}{397{\cdot}5 \,.\, r}$$

Let the gauge be 7 feet, speed 50 miles per hour, and radius 10 chains,

$$S = \frac{7 \times 2500}{397{\cdot}5 \times 10} = 4{\cdot}4 \text{ inches.}$$

Of course the highest speed is taken in calculation, but from the super-elevation may be deducted that due to the conicality of the wheels' tires.

EQUILIBRATION CHAINS TO GAS-HOLDERS.—As a gas-holder rises out of the water in its tank, its pressure on the gas increases because the metal weighs heavier in air than in water; hence the chains carrying the equilibrating weights, when such are used, should be constructed to counterbalance this difference. The following formula gives the required weight of the chain:—

Let w = weight of one foot vertical of gas-holder in pounds,
G = specific gravity of the iron in gas-holder,
W = weight of one foot of chain in pounds,
n = number of chains:

$$W = \frac{w}{2\,G.n.}$$

For example, let $w = 2000$, $G = 7{\cdot}8$, $n = 4$, then

$$W = \frac{2000}{2 \times 7.8 \times 4} = 32{\cdot}05 \text{ pounds per foot of chain.}$$

PRESSURE DUE TO GAS-HOLDER.—Let p = pressure in inches of water, w = weight of gas-holder in pounds, d = diameter in feet, then

$$p = \frac{w}{4{\cdot}1\,d^2}$$

To find the weight of counterbalance to holder to produce a given pressure, let W = counterbalance in pounds, P = required pressure in inches of water:

$$W = w\left\{1 - \frac{P}{p}\right\}$$

WEIGHT OF GAS.—To find the weight of gas the following formula will suffice :—

Let G = specific gravity (air = 1), v = volume in cubic feet, w = weight required :

$$w = 0{\cdot}0766\, v \,.\, G\,.$$

STEAM CRANES.—It is required to ascertain what weight a given steam-crane is capable of lifting. In the first place, the velocity ratio of the main drum to the steam piston must be determined. The piston velocity will, of course, be determined by multiplying the stroke in feet by the number of strokes per minute, there being two strokes of the piston to each revolution of the crank shaft.

Let n = revolutions of crank shaft per minute,
l = length of stroke in feet,
S = speed of piston in feet per minute :

$$S = 2\, n \,.\, l\,.$$

Let N = number of revolutions of main drum per minute (found from n by calculating from the diameters of wheels in the gearing),
d = diameter of main drum in feet,
s = speed of main drum in feet:

$$s = 3{\cdot}1416 \,.\, N \,.\, d$$

The velocity ratio will be

$$= \frac{3{\cdot}1416 \,.\, N \,.\, d}{2 \,.\, n \,.\, l\,.}$$

The total pressure on the pistons, there being two of them, will be

$$= 2 \times 0{\cdot}785 \times D^2 \times p$$

where D = diameter of piston in inches,
p = pressure of steam in pounds per square inch.

If W = the load the crane is capable of lifting,

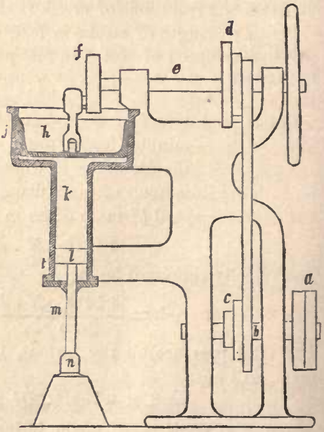
$$W = \frac{n \, . \, l \, . \, D^2 \, . \, p}{N \, . \, d}$$

Let $n = 100$, $l = 1{\cdot}5$ feet, $D = 5$ inches, $p =$ (mean pressure) 30 lbs., $N = 5$, $d = 2$ feet, then

$$W = \frac{100 \times 1{\cdot}5 \times 25 \times 30}{5 \times 2} = 11{,}250 \text{ lbs.} = 5 \text{ tons},$$
1 qr., 22 lbs.

Pneumatic Hammer.—A hammer in which the power is transmitted through air is now considerably used; it has been introduced by Mr. F. H. Roberts, and seems admirably adapted for light work, such as stamping, planishing, coppersmiths' work, light forgings, rivetting, &c. This hammer consists of two cylinders of different diameters, arranged one over the other, and communicating with each other internally, as shown in Fig. 67 at j and k. The larger and uppermost cylinder has a piston or trunk-plunger h, worked by a

Fig. 67.



slotted crank-plate *f*. In the smaller cylinder is a piston *l*, attached to which by the rod *m* is the hammer-head *n*. On the up-stroke of the piston *h* a partial vacuum is formed in the cylinder *k*, causing the piston, *l*, and hammer, *n*, to rise, being again driven down on the descent of the larger piston. The relative strokes of the two pistons are usually made so as to be nearly in inverse proportion to their areas.

a shows the fast and loose pulleys for driving the hammer, being on the shaft *b*, carrying the cone or speed-pulleys *c*, whence the power is transmitted to the speed-pulleys *d* on the driving shaft *e*. In order to control the force of the blow, or stop the hammer altogether, a stop-cock is fitted to the large cylinder, by opening which the air flows in and out, as the piston *h* moves, without causing any movement of the hammer-head. A slide-valve *t* is also attached to the lower end of the small cylinder, to afford additional command over the force of the blow. These hammers, having heads weighing about 25 lbs., will give 250 blows per minute, and at that speed do their work very efficiently.

CHAPTER XXII.

ESTIMATION OF QUANTITIES.

WHEN any machine has been designed it may be necessary to calculate the weight of material which will be required for its construction, hence it is advisable here to insert rules whereby such weights may be readily ascertained from the dimensions of the different parts.

Wroguht-iron Work.—The weight of a mass of wrought-iron is equal to its content in cubic inches multiplied by 0·278 pounds or 0·000124 tons, or to its content in cubic feet multiplied by 490 pounds or 0·2143 tons.

Round Bars.—Multiply the square of the diameter in inches by the length in feet, and by 2·618 pounds or 0·00117 tons.

Elliptical Bars.—Multiply the conjugate diameter in inches by the transverse diameter in inches, by the length in feet, and by 2·618 pounds or 0·00117 tons.

Rectangular Bars.—Multiply the width in inches by thickness in inches and length in feet, and by 3·33 pounds or 0·00149 tons.

Plate-iron.—Multiply the surface in square feet by the thickness in inches, and by 40 pounds or 0·0178 tons.

Angle-iron.—Add together the breadths in inches, measured on the outside, from the sum subtract the thickness of the metal in inches, multiply the remainder by the thickness in inches and length in feet, and by 3·33 pounds or 0·00149 tons.

Bars of irregular section.—Multiply the sectional area in square inches by the length in feet, and by 3·33 pounds or 0·00149 tons.

Sphere.—Multiply the cube of the diameter in inches by 0·1454 pounds or 0·000065 tons.

Rivetted Work.—Allow 5 per cent. additional weight for heads of rivets.

Steel, Cast-iron, &c.—To ascertain the weights for other metals proceed as directed above, and then multiply the results by one of the following factors, corresponding to the metal to be used:—

If the material is	steel .	multiply by	1·008
,,	cast-iron	,,	0·915
,,	brass .	,,	1·084
,,	copper .	,,	1·150
,,	lead .	,,	1·477

If the pattern for a casting be made of dry pine the weight of the casting will be equal to that of the pattern multiplied by 11.

Timber Flooring.—Multiply the length in feet by the breadth in feet and thickness in inches, and by one of the following factors, according to the material:—

Elm . .	3·50	lbs.	or	0·00156	tons.
Yellow Fir .	3·42	,,	,,	0·00153	,,
White Fir .	2·97	,,	,,	0·00132	,,
Dry Oak . .	4·85	,,	,,	0·00216	,,

Timber Beams, Posts, &c.—Multiply the length in feet by the breadth and depth in inches, and by one of the following factors:—

Elm . .	0·292	lbs.	or	0·000130	tons.
Yellow Fir .	0·285	,,	,,	0·000127	,,
White Fir .	0·247	,,	,,	0·000110	,,
Dry Oak .	0·404	,,	,,	0·000180	,,

In the estimation of quantities and measuring of work the following numbers may also be frequently found serviceable:—

1 centimetre		0·3937 inches
1 metre		39·37 ,,
1 ,, ...		3·2808 feet
1 gramme		15·436 grains
1 kilogramme		2·2048 lbs.
1 link		7·92 inches
1 foot		1·5151 links
36 cubic ins. of wrought-iron weigh		10 lbs.
1 inch square bar 1 yard long weighs		10 ,,
¼ inch plate 1 foot square	,,	10 ,,
1 cubic inch wrought-iron	,,	0·278 lbs.
36 cubic inches of cast-iron	,,	9·96 ,,

1 inch square bar 1 yard long	,,	9·96 lbs.
¼ inch plate 1 foot square	,,	9·96 ,,
1 cubic inch of cast-iron .	,,	0·262 ,,
1 ,, ,, lead . .	,,	0·41 ,,
1 ,, ,, brass . .	,,	0·283 ,,
1 ,, ,, copper .	,,	0·317 ,,
1 ,, ,, steel . .	,,	0·283 ,,
1 cubic foot of elm . .	,,	42 ,,
1 ,, ,, yellow fir .	,,	41·1 ,,
1 ,, ,, white fir .	,,	35·6 ,,
1 ,, ,, dry oak .	,,	58·2 ,,
80 chains	.	1 mile
69·121 chains . . .	.	1 geog. degree
10 square chains . .	.	1 acre
640 acres	.	1 square mile
Circumference of a circle .	.	3·1416 × diameter
Area . ,, .	.	0·7854 × sq. diam.
Surface of a sphere . .	.	3·1416 × sq. diam.
Solidity of a sphere . .	.	0·5236 × cube diam
1 cubic foot pure water .	.	62·321 lbs.
1 imperial gallon . .	.	277·274 cubic ins.
1 ton of water . . .	.	35·84 cubic feet
1 mile	.	5280 feet
1 mile per hour . .	.	1·466 feet per scnd.

CONCLUSION.

In concluding this Treatise, which has been written with the view of supplying a work which shall furnish at once the data upon which the practice of mechanical engineering is based, and to serve as a convenient book of reference, it may not be unadvisable to offer a few remarks upon the conducting of such practice.

The first thing which the young engineer has to do is to use every endeavour and seize every opportunity to gain a thorough knowledge, practically and theoretically, of the materials and processes with which in after life he will be called upon to deal. Having such a knowledge (and this cannot be acquired except by years of patient, untiring, study and observation) he will be guarded from falling into such mistakes as that widespread one on which so many fortunes and lives have been wasted, "perpetual motion." Although this is the notable fallacy, the *ignis fatuis* which has led so many uneducated mechanicians astray, yet there are many others which, though not so important in their results, are sufficiently vexing, and cause a considerable waste of both time and money, besides bringing discredit upon those who are misled by them; but these smaller mistakes will not be committed by such as thoroughly understand their business and take sufficient care.

In order to carry out any work in the most satisfactory and, at the same time, most expeditious manner, the following course should be pursued:—*First*—Thoroughly examine and become acquainted with all that is required to be done, the mechanical forces to be brought into action, and the nature of the materials to be dealt with. *Second*—Give a full consideration to all the details of the work and the mode of combining them. *Third*—Having planned the work, do not readily alter such plans; that is to say, do not alter the plans unless some evident benefit is to be gained by so doing; and *Fourth*—Take means to ensure that the work shall be rigorously in accordance with the designs both as to form and materials used in manufacture.

THE END.

ERRATUM.

At p. 81, the diagram, showing the chemical changes during combustion, has been accidentally reversed. The reactions are as follows:—

The hydrogen of the fuel combines with oxygen of the air, forming water,—the carbon of the fuel combines with oxygen of the air, forming carbonic acid gas, and the nitrogen of the air remains free—as shown by the equation, where a hydro-carbon fuel is assumed:—

$$\overset{\text{Fuel.}}{C_{10}H} + \overset{\text{Air.}}{O_{21} + N_{79}} = \overset{\text{Products of Combustion.}}{HO + 10.CO_2 + 79N}$$

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