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John Tellwood.
Portland
Oregon.
Aug. 6. 1869.

STEAM ENGINE.

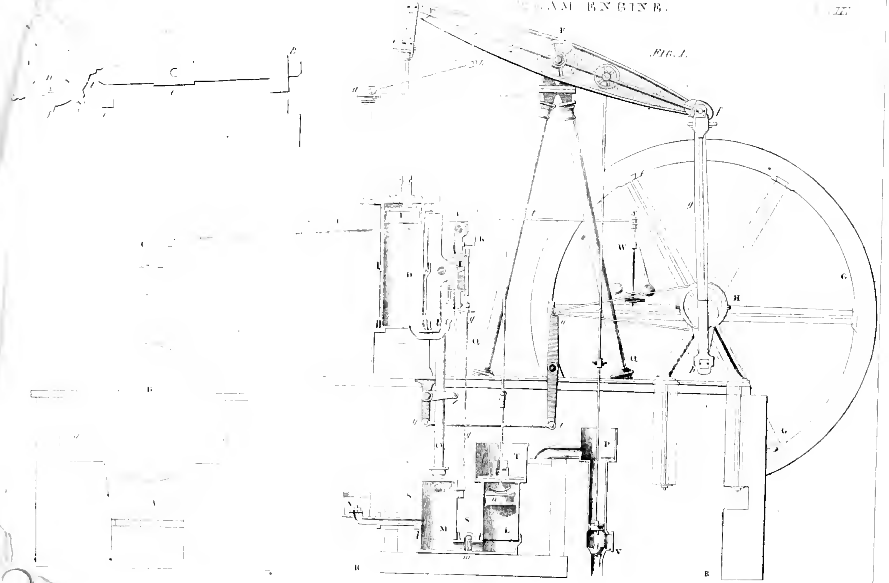

Fig. 1.

THE

USEFUL ARTS,

CONSIDERED IN CONNEXION

WITH THE

APPLICATIONS OF SCIENCE:

WITH NUMEROUS ENGRAVINGS.

BY JACOB BIGELOW, M.D.

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Animals, of the more perfect kinds, possess the power of shifting their place, at will, which power they exercise, both in transporting their own bodies, and in conveying other masses of matter. The chief obstacles, which oppose locomotion or change of place, are, gravity and friction, the last of which is, in most cases, a consequence of the first. Gravity confines all terrestrial bodies against the surface of the earth, with a force proportionate to the quantity of matter which composes them. Before they can be removed from one spot of this surface, to another, of equal height, they must either be lifted from the ground, against the force of gravity, or carried, horizontally, along the surface, resisting with a degree of friction, which increases with their weight. Most kinds of mechanism, both natural and artificial, which assist locomotion, are arrangements for obviating the effects of gravity and friction.

Motion of Animals.—Animals, that walk, obviate friction, by substituting points of their bodies, instead of large surfaces ; and upon these points they turn, as upon centres, for the length of each step, raising themselves wholly, or partly, from the ground, in successive arcs, instead of drawing themselves along the surface. The line of arcs, which the centre of gravity describes, is converted into an easy, or undulating line, by the compound action of the different joints. As the feet move in separate lines, the body has, also, a lateral, vibratory motion. A man, in walking, puts down one foot, before the other is raised, but not in running. Quadrupeds, in walking, have three feet upon the ground, for most of the time ; in trotting, only two. Animals, which walk against gravity, as the common fly, the tree toad, &c., support themselves by suction, using cavities on the under side of their feet, which they enlarge, at pleasure, till the pressure of the atmosphere causes them to adhere. In other respects, their locomotion is effected like that of other walking animals. Birds perform the motion of flying, by striking the air, with the broad surface of their wings, in a downward, and backward, direction, thus propelling the body upward, and forward. After each stroke, the wings are contracted, or slightly turned, to lessen their resistance to the atmosphere, then raised, and spread anew. The downward stroke, also, being more sudden than the upward, is more resisted by the atmosphere. The tail of birds serves as a rudder, to direct the course upward, or downward. When a bird sails in the air, without moving the wings, it is done, in some cases, by the velocity previously acquired, and an oblique direction of the wings, upward ; in others, by a gradual descent, with the wings slightly turned in an oblique direction, downward. Fishes, in swimming forward, are propelled chiefly by strokes of the tail, the extremity of which, being bent into an oblique position, propels the body forward, and laterally, at the same time. The lateral motion is corrected by the next stroke, in the opposite direction, while the forward course continues. The fins serve, partly, to assist in swimming, but, chiefly, to balance the body, or keep it upright ; for the centre of gravity being nearest the back, a fish turns over, when it is dead, or disabled.* Some other aquatic animals, as leeches, swim with a sinuous, or undulating, motion of the body, in which several parts, at once, are made to act obliquely, against the water. Serpents, in like manner, advance, by means of the winding, or serpentine, direction which they give to their bodies, and by which a succession of oblique forces is brought to act against the ground. Sir Everard Home is of opinion, that serpents use their ribs, in the manner of legs, and propel the body forwards, by bringing the plates, on the under surface of the body, to act, successively, like feet, against the ground.† Some worms and larvæ, of slow motion, extend a part of their body forwards, and draw up the rest to overtake it; some performing this motion, in a direct line, others, in curves.

When land animals swim in water, they are supported, because their whole weight, with the lungs expanded with air, is less than that of an equal bulk of water. The head, however, or a part of it, must be kept above water, to enable the animal to breathe; and to effect this, and also to make progress in the water, the limbs are exerted, in successive impulses, against the fluid. Quadrupeds and birds swim with less effort than man, because the weight of the head, which is carried above water, is, in them, a smaller proportional part of the whole, than it is in man.

Inertia.—In consequence of the action of gravity upon bodies, their inertia becomes a greater obstacle to locomotion than it would otherwise be. Every body tends, by its inertia, to preserve a state of rest, if it is still, and of uniform rectilinear motion, if it is not still. Changes, therefore, not only from rest to motion, but also changes

* The swimming bladder, which exists in most fishes, though not in all, is supposed to have an agency in adapting the specific gravity of the fish to the particular depth, in which it resides. The power of the animal to rise or sink, by altering the dimensions of this organ, has been, with some reason, disputed.

† Lectures on Comparative Anatomy, vol. i. p. 116, &c. Sir E Home deduces this fact from the anatomy of the animal, and from the movements which he perceived, in suffering a large coluber to crawl over his hand. The ribs appeared to be raised, spread, carried forward, depressed, and pushed backward, successively.

of direction, and changes of speed, are resisted by the force of inertia. Bodies moving upon the earth's surface are obliged, by their gravity, to accommodate their motions to the irregularities of this surface, and, consequently, to change, often, both their direction and velocity The inertia thus becomes a continual source of expenditure of power, although it would not be so, if bodies moved at a uniform rate, and in a straight course.

Aids to Locomotion.—All animals are provided, by Nature, with organs of locomotion best adapted to their structure and situation ; and it is probable that no animal, man not being excepted, can exert his strength more advantageously, by any other than the natural mode, in moving himself over the common surface of the ground.* Thus walking-cars, velocipedes, &c., although they may enable a man to increase his velocity in favorable situations, for a short time, yet they actually require an increased expenditure of power, for the purpose of transporting the machine made use of, in addition to the weight of the body. When, however, a great additional load is to be transported with the body, a man, or animal, may derive much assistance from mechanical arrangements.

Wheel Carriages.—For moving weights over the common ground, with its ordinary asperities and inequalities of substance and structure, no piece of inert mechanism is so favorably adapted, as the wheel-carriage. It was introduced into use, in very early ages, as affording a facility for the carrying of heavy loads, and, finally, for transporting man himself; not by his own powers, but by the strength of other animals, which he had subjugated to his use. Chariots were used in war, and wagons in agriculture, at a very remote period.

Wheels.—The mechanical action of wheels, applied to locomotive carriages, is twofold. They diminish friction, and, also, surmount obstacles, or inequalities, of the road, with more advantage than bodies of any other form, in their place, could do. The friction is diminished, by transferring it from the surface of the ground to the cen-

* This remark, of course, does not apply to situations in which friction is obviated, as upon water, ice, rail-roads, &c.

tre of the wheel, or rather to the place of contact, between the axletree and the box of the wheel. So that it is lessened, by the mechanical advantage of the lever, in the proportion, which the diameter of the axletree bears to the diameter of the wheel. The rubbing surfaces, also, being kept polished, and smeared with some unctuous substance, are in the best possible condition to resist friction.

In like manner, the common obstacles, that present themselves in the public roads, are surmounted by a wheel, with peculiar facility. As soon as the wheel strikes against a stone, or similar hard body, it is converted into a lever, for lifting the load over the resisting object. If an obstacle, eight or ten inches in height, were presented to the body of a carriage, unprovided with wheels, it would stop its progress, or subject it to such violence as would endanger its safety. But, by the action of a wheel, the load is lifted, and its centre of gravity passes over, in the direction of an easy arc, the obstacle furnishing the fulcrum, on which the lever acts.

Rollers.—Rollers, placed under a heavy body, diminish the friction in a greater degree than wheels, provided they are true spheres, or cylinders, without any axis, on which they are constrained to move. If the rollers be perfectly elastic, and, also, the plane upon which they move, there will be no sliding friction, whatever ; whereas the wheel always rubs at its axis. But an offset for this advantage is found in the circumstance, that the wheel maintains its relative place, in regard to the load, while the roller constantly falls behind, and is obliged to be taken up and replaced, at an expense of power. A cylindrical roller, likewise, occasions friction, whenever its path deviates, in the least, from a straight line.

Size of Wheels.—The mechanical advantages of a wheel are proportionate to its size ; and the larger it is, the more effectually does it diminish the ordinary resistances. A large wheel will surmount stones, and similar obstacles, better than a small one ; since the arm of the lever, on which the force acts, is longer, and the curve, described by the centre of the load, is the arc of a larger circle, and, of course, the ascent is more gradual and easy.*

A further advantage is derived from the circumstance, that, in passing over holes, ruts, or excavations, a large wheel sinks less than a small one, and, consequently, occasions less jolting, and expenditure of power. The wear, also, of small wheels, exceeds that of larger ones; for, if we suppose a wheel to be three feet in diameter, it will turn round twice, while a wheel, six feet in diameter, turns round once. Of course, its tire will come twice as often in contact with the ground, and its spokes will twice as often have to support the weight of the load. So, that, by calculation, it should last but half the length of time.

On these accounts, it would be advantageous to augment the diameter of wheels to a great extent, were it not for certain practical limits, which it is not found useful to exceed. One of these is found in the nature of the materials, which we are obliged to use, and which, if employed to make wheels of great size, at the same time preserving the requisite strength, would render them cumbersome, and too heavy for use.† Another reason, for regulating the size of wheels by a limited standard, arises from the relative size of the animals, commonly employed for draught. A wheel should seldom be of such dimensions, that its centre would exceed, in height, the breast of the horse, or other animal, by which it is drawn; because, if this were the case, the horse would draw obliquely downward, as well as forward, and expend a part of his strength in acting against the ground.

Line of Traction.—In practice, it is even found necessary, to place the point of draught, or centre of the wheels, lower than the middle of the horse's breast, for various reasons. 1. The shape of the animal's shoulders requires this direction. 2. The horse exerts a greater force, in proportion, as the line of draught passes near the fulcrum,

* If the plane, on which a carriage moves, and the line of draught be both horizontal, the advantage, for surmounting an immovable obstacle of a given height, is as the square root of the radius of the wheel.—See *Playfair's Outlines of Natural Philosophy*, vol. i. p. 103.

† See the article, *Limit of Bulk*, p. 48

which is in his hind feet. 3. If a horse draws obliquely upward, a part of his force is employed in lessening the pressure on the ground, and, to answer this purpose most effectually, it has been remarked, that the inclination of the traces, or shafts, ought to be the same with that of a road, upon which the carriage would just descend by its own weight.* According to Dr. Gregory, a power, which moves a sliding body along a horizontal plane, acts with the greatest advantage, as far as friction is concerned, when the line of direction makes an angle of about eighteen and a half degrees with the plane.† M. Deparcieux states, from experiments with carriages, that the angle, made by the trace with a horizontal line, should be one of fourteen or fifteen degrees. 4. Another reason, for inclining the line of draught, is, that a horse depresses his body, in proportion to the force he is obliged to exert, in order that he may bring his own weight to act more advantageously upon the load. M. Deparcieux has demonstrated, that animals draw through the medium of their weight, in all our common vehicles ; and this fact becomes obvious, when we consider, that if a horse had no weight, he would be unable to draw, but would simply be raised on his hind feet, by any exertion to advance, while in his harness.

In the foregoing considerations, it is necessary to recollect, that the conditions, which enable a horse to exert his greatest force, are not those which promote his greatest velocity, and that the means of increasing his speed are obtained, as in other cases, by the sacrifice of power.

When there are four wheels, the line of draught ought to be directed to a point between the two axletrees, or, rather, to a point directly under the centre of gravity of the load ; and such a line should always pass above the axle of the fore wheels.

Broad Wheels.—Much controversy has existed in regard to the comparative utility of wheels having a broad, or a narrow, circumference. The disadvantages of broad wheels are, that they are heavier than narrow ones, that

* Young's Natural Philosophy, vol. i. p. 216.

† Treatise on Mechanics, vol ii p. 18.

they are more expensive, and that they include in their path a greater number of stones, or projecting obstacles. Their advantages are, that they pass more easily over ruts and holes, and that, in soft and sandy roads, they sink to a smaller depth.* But the great benefit which results from broad wheels is of an indirect kind, and arises from the improvement of the roads, which takes place under their use. They tend to prevent deep and narrow ruts, and act as rollers, in levelling the surface.

Form of Wheels.—If roads were, in all cases, level and smooth, wheels should be made exactly cylindrical, or with all their spokes parallel to the same plane. But, since the unequal surface of most roads exposes carriages to frequent and sudden changes of position, it is found advantageous to make the wheels a little conical, or, as it is commonly termed, *dishing*, so that the spokes may all diverge, with their extremities from the carriage. In this case, whenever the carriage is thrown into an inclined position, and the centre of gravity shifted towards one wheel, the spokes on the under side of that wheel, become more nearly vertical, and are in a more advantageous position to sustain the pressure. This will be seen in Fig. 94, on the opposite page. In muddy roads, there is a convenience attending the dished wheel, in having its circumference further from the body of the carriage, than that of a straight wheel, upon the same hubb,† would be. Some disadvantages, at the same time, attend upon this form of the wheel, the principal of which is, the increase of friction which it occasions. A conical wheel, if left to itself, tends to travel in a circle, round a point, where the apex of the cone would be situated. If it is obliged to advance in a straight line, it has a degree of lateral motion and friction, which increases in proportion as it deviates from the cylindrical form. In common cases, a slight

* The latter advantage, however, is of a more equivocal kind than appears at first view; for although they sink less deeply, they displace more earth in sinking to the same depth. Still, however, the advantage, upon calculation, remains on the side of the broad wheel.

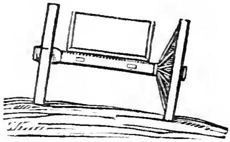
† This word, instead of *nave*, is so generally used in this country, that it would be a useless refinement to avoid it. The same is true of the word *factory* for manufactory, and also of many mechanical terms.

degree of the dishing form is best, but it should never be carried to such an extent, as to create much friction, or endanger the bending of the spokes.

In the annexed figure, (94,) A represents the cylindrical, and B the dished, form of the wheel.

Fig. 94.

A B



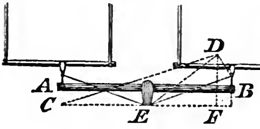
Axletrees.—When wheels are perfectly upright, the ends of the axles should be cylindrical; but, in dished wheels, they are made conical, and inclined downward, so as to make their under surface horizontal. In this case, the wheels spread most at top, and the lower spokes are most nearly vertical. The ends of the axletree are often inclined a little forward, which arrangement causes the wheels to run inward, and prevents them from pressing on the linch-pin. The friction, however, is increased. In some locomotive carriages, the axle is fixed to both wheels, and turns with them. This mode of connexion causes great strain and friction, whenever the path is in any other than a straight line, from the necessity, which is produced, that the wheels should keep pace with each other, in their revolutions.

Springs.—The effect of suspending a carriage on springs is, to equalize the motion, by causing every change to be more gradually communicated to it, and to obviate shocks, by converting percussion into pressure. Springs are not only useful for the convenience of passengers, but they also diminish the labor of draught; for, whenever a wheel strikes a stone, it rises against the pressure of the spring, in many cases, without materially disturbing the load; whereas, without the spring, the load, or a part of it, must rise with every jolt of the wheel, and will resist this change of place, with a degree of *inertia* proportionate to the weight and the suddenness of the percussion.

Hence, springs are highly useful, in baggage wagons, and other vehicles, used for heavy transportation.*

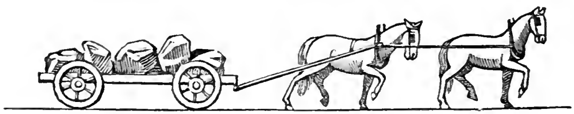
Attaching of Horses.—Horses draw most advantageously, when they are either single, or harnessed abreast of each other. When two horses draw side by side, they are equally near to the load, and have the same line of traction. If their traces are attached, as is frequently done, to hooks on the ends of a crossbar, which, in its turn, is connected to the carriage by a staple, projecting behind, a compensation will be thus made for any difference in the strength, or activity, of the animals. In Fig. 95, the cen-

Fig. 95.



tre, E, upon which the bar moves, is considerably behind the points of attachment, A and B. Hence, when one end falls back, so that the arm, AB, assumes the position, CD, the foremost horse will have the disadvantage of acting by a lever equal only to EF, while the other horse acts by a lever equal to EC. In the narrow streets of cities, a custom has arisen of harnessing draught horses before each other, in a single line, probably for the sake of room, and the convenience of the driver. But, in this situation, only the shaft horse has an advantageous line of draught. The remaining horses draw nearly in a horizontal line, and, of course, at a disadvantage. Besides this, the foremost horses, being attached to the ends of the shafts, do not act directly upon the load, but expend a part of their force

Fig. 96.



* See a paper by Mr. Gilbert, in Brande's Journal, vol. xix.

in vertical pressure, upon the back of the shaft horse, which is increased in drays, sleds, and all low carriages. This will be seen by inspecting Fig. 96, where it is obvious, that the line of draught of the first horse cannot become direct, without crippling down the shaft horse. The best mode of remedying this difficulty, would apparently be, to attach the traces of the forward horse to a strong hook, projecting downward from the end of each shaft, so as to bring the traces into the proper line of traction, by directing them more nearly towards the centre of the wheels. It is true, that the shaft horse derives a certain degree of mechanical advantage from vertical pressure, like that which would result from an increase of his weight. Yet this, although useful in short exertions, is not so, when continued through a day's fatigue.

HIGHWAYS.

Roads.—Roads, intended for the passage of wheel-carriages, are made more level, and of harder materials, than the rest of the ground. In roads, the travel on which does not authorize great expense, natural materials alone are employed, of which the best are hard gravel and very small stones. The surface of roads should be nearly flat, with gutters at the sides, to facilitate the running off of water. If the surface is made too convex, it throws the weight of the load unequally upon one wheel, and also that of the horses on one side, whenever the carriage takes the side of the road. Hence, drivers prefer to take the middle, or top, of the road, and, by pursuing the same track, occasion deep ruts. The prevention of ruts is best effected by flat and solid roads, and by the use of broad wheels. It would also be further effected, if a greater variety could be introduced in the width of carriages. Embankments at the sides, to keep the earth from sliding down, are best made, by piling sods upon each other, like bricks, with the grassy surface at right angles with the surface of the bank. But stone walls are preferable for this purpose, when the material can be readily obtained.

Pavements.—Pavements are stone coverings of the ground, chiefly employed in populous cities, and the most frequented roads. Among us, they are made of pebbles, of a roundish form, gathered from the sea-beach. They should consist of the hardest kinds of stone, such as granite, sienite, &c. If flat stones are used, they require to be artificially roughened, to give secure foothold to horses. In Milan, and some other places, tracks for wheels are made of smooth stones, while the rest of the way is paved with small, or rough, stones.*

The advantage of a good pavement consists, not only in its durability, but in the facility with which transportation on it is effected. Horses draw more easily on a pavement, than on a common road, because no part of their power is lost, in changing the form of the surface. The disadvantages of pavements consist in their noise, and in the wear which they occasion of the shoes of horses, and tires of wheels. They should never be made of pebbles so large as to produce much jolting, by the breadth of the interstices.†

Wooden Pavements, made of hexagonal blocks of wood, have been introduced in some of our cities. They have been found more free from dust and noise than other pavements. They are placed with the grain of the wood perpendicular to the ground, to prevent splintering, and give better foothold. The most hard and durable woods are best; but the cheaper kinds are more used, for economy.

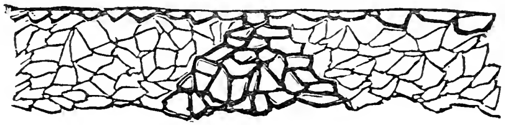
McAdam Roads.—The system of road-making, which takes its name from Mr. McAdam, combines the advantages of the pavement and gravel road. The McAdam roads are made entirely of hard stones, such as granite, flint, &c., broken up, with hammers, into small pieces, not exceeding an inch in diameter. These fragments are spread upon the ground, to the depth of from six to ten inches. At first, the roads thus made are heavy, and la-

* The streets of many of the ancient cities were paved, as those of Rome, Pompeii, &c. But the streets of London were not paved in the eleventh century, nor those of Paris in the twelfth.

† Mr Telford has constructed, in England, a kind of paved road, in which the foundation consists of a pavement of rough stones and fragments, having their points upward. These are covered with very small stone fragments, and gravel, for the depth of four inches, the whole of which, when rammed down and consolidated, forms a hard, smooth, and durable, road.

borious to pass ; but, in time, the stones become consolidated, and form a mass of great hardness, smoothness, and permanency. From the manner in which the stones overlap each other, each stone, at the surface, may be considered as the apex of a pyramid, so that it cannot be driven downward, without carrying before it a base of, perhaps, a foot square, as will be seen by Fig. 97. The

Fig. 97.



stones become partly pulverized, by the action of carriage wheels, and partly imbedded in the earth beneath them. The consolidation seems to be owing to the angular shape of the fragments, which prevents them from rolling in their beds, after the insterstices between them are filled. Mr. McAdam advises, that no other material should be added to the broken stones, apparently with a view to prevent the use of clay and chalk, which abound in England. It appears, however, that a little clean gravel, spread upon the stones, causes them to consolidate more quickly, and has the good effect of excluding the light street dirt, which, otherwise, never fails to become incorporated, in large quantities, among the stones.

BRIDGES.

The construction of small bridges is a simple process, while that of large ones is, under certain circumstances, extremely difficult, owing to the fact, that the strength of materials does not increase in proportion to their weight, and that there are limits, beyond which no structure of the kind could be carried, and withstand its own gravity. Bridges differ, in their construction, and in the materials of which they are composed. The principal varieties are the following.

1. *Wooden Bridges.*—These, when built over shal-

low and sluggish streams, are usually supported upon piles, driven into the mud, at short distances, or upon frames of timber. But, in deep and powerful currents, it is necessary to support them on strong stone piers, and abutments, built at as great a distance as practicable from each other. The bridge, between these piers, consists of a stiff frame of carpentry, so constructed, with reference to its material, that it may act as one piece, and may not bend, or break, with its own weight, and any additional load, to which it may be exposed. When this frame is straight, the upper part is *compressed*, by the weight of the whole, while the lower part is *extended*, like the tie-beam of a roof. But the strongest wooden bridges are made with curved ribs, which rise above the abutments, in the manner of an arch, and are not subjected to a longitudinal strain, by extension. These ribs are commonly connected and strengthened with diagonal braces, keys, bolts, and straps of iron. The flooring of the bridge may be either laid above them, or suspended, by trussing, underneath them. Wooden bridges are common in this country, and some of them are of large size. One of the most remarkable is the upper Schuylkill bridge, at Philadelphia, which consists of a single arch, the span of which is three hundred and forty feet.

2. *Stone Bridges.*—These, for the most part, consist of regular arches, built upon stone piers, constructed in the water, or upon abutments at the banks. Above the arches is made a level, or sloping, road. From the nature of the material, these are the most durable kind of bridges; and many are now standing, which were built by the ancient Romans. Several of the stone bridges across the Thames, at London, are distinguished for elegance and strength. The stone piers, on which bridges are supported, require to be of great solidity; especially, when exposed to rapid currents, or to floating ice. Piers are usually built with their greatest length in the direction of the stream, and with their extremities pointed or curved, so as to divide the water, and allow it to glide easily past them. In building piers, it is often necessary to exclude the water, by means of a *coffer-dam*. This is a temporary

enclosure, formed by a double wall of piles and planks, having their interval filled with clay. The interior space is made dry by pumping, and kept so, till the structure is finished.

3. *Cast Iron Bridges.*—These have been constructed in England out of blocks, or frames, of cast-iron, so shaped, as to fit into each other, and, collectively, to form ribs and arches. These bridges possess great strength, but are liable to be disturbed by the expansion and contraction of the metal with heat and cold.

4. *Suspension Bridges.*—In these, the flooring, or main body of the bridge, is supported, on strong iron chains, or rods, hanging in the form of an inverted arch, from one point of support to another. The points of support are the tops of strong pillars, or small towers, erected for the purpose. Over these pillars, the chain passes, and is attached, at each extremity of the bridge, to rocks, or massive frames of iron, firmly secured under ground. The great advantage of suspension bridges consists in their stability of equilibrium, in consequence of which, a smaller amount of materials is necessary for their construction, than for that of any other bridge. If a suspension bridge be shaken, or thrown out of equilibrium, it returns, by its weight, to its proper place; whereas the reverse happens in bridges which are built above the level of their supporters. One of the most remarkable suspension bridges, is that over the Menai strait, on the coast of Wales, the span of which, or rather the water-way, is five hundred feet, and the distance between the points of support, or centre of the piers, five hundred and sixty feet. It is suspended by four wrought-iron cables, which pass over rollers, on the tops of the pillars, and are fixed to iron frames, under ground, which are kept down by masonry.

5. *Floating Bridges.*—Upon deep and sluggish water, stationary rafts of timber are sometimes employed, extending from one shore to another, and covered with planks, so as to form a passable bridge. In military operations, temporary bridges are often formed by planks laid upon boats, pontoons, and other buoyant supporters.

RAIL-ROADS.

In the best constructed public roads, a great amount of power is expended, in overcoming the disadvantages which are inseparable from their construction, and the nature of their materials. The chief loss of power depends on the continual change of form, which carriages occasion in roads, by the crushing of stones, cutting of ruts, and other displacements of the material of which the road is made ; which processes serve to consume power, without forwarding the progress of the carriage.

The object of a rail-road is to furnish a hard, smooth, and unchanging, surface, for wheels to run upon. These surfaces, in most cases, consist of parallel rails of iron, raised a little above the general level of the ground, and having a gravelled road between the rails, so that the rail-road combines the advantages of good foothold for horses, where it is necessary to use them, and of smooth, hard, surfaces, for the wheels to roll upon. The wheels are made smooth and true, and guides, or flanges, to prevent them from slipping off, are affixed, either to the wheels, or to the rails,—most commonly, to the former.

Rail-roads are a modern invention, and their greatest improvements have been made within the present century. In comparing the effect of a rail-road with that of a common turnpike-road, a saving is made, according to Mr. Tredgold,* of seven eighths of the power ; one horse on a rail-road producing as much effect, as eight horses on a turnpike-road. In the effect produced by a given power, the rail-road is about a mean between the turnpike-road and a canal, when the rate is about three miles per hour ; but, when greater speed is desirable, the rail-road may equal the canal in effect, and even greatly surpass it. In the Winter season, when canals are liable to be frozen, rail-roads, if kept clear from snow and ice, may be always passable.

In the construction of rail-roads, it is desirable that they should be made as level as possible. For this purpose, the road is first *graded*, by digging down the more ele-

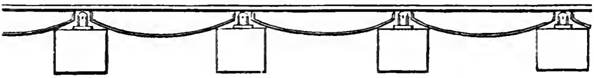
* Treatise on Rail-roads and Carriages, p. 3.

vated parts, and raising those which are depressed. Hills are usually passed through by *deep cuts;* and, in some instances, perforated by *tunnels*, or hollow passages. Vallies and marshes are raised by embankments of earth, and streams are crossed by wooden bridges, or by *viaducts* of stone, constructed with arches of regular masonry.

The earliest rail-roads appear to have been constructed of wood only. But, at the present day, iron is employed in all rails from which durability is expected. In some cities, tracks of hewn stone are laid for wheels, in the streets ; but these are seldom executed with sufficient accuracy, to deserve the name of rail-ways. Of the iron rail-road, there are three principal varieties. 1. The Edge rail. 2. The Tram road. 3. The Single rail.

Edge Rail-way.—In this species, which is now preferred to all others, and is, indeed, the only one now much in use, the rails are laid with the edge upward, and the carriage is retained upon them by a *flange*, or projecting edge, attached to the wheels, instead of the rail. These rails were originally made of cast-iron, about three feet long, and four or five inches deep in the middle, the outline being curved on the under side, to produce equality of strength. Fig. 98, represents a side-view of the old

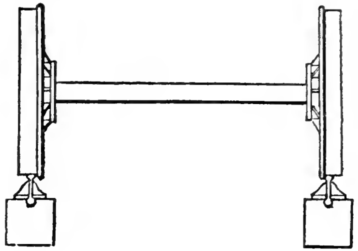
Fig. 98.



cast-iron rail-way. The ends of the rails are received in a piece of cast-iron, called a *chair*, and these chairs are affixed to large blocks of stone, or logs of wood, called sleepers, which are previously placed in the ground, upon a proper level. Fig. 99, on the next page, is a section, or end view, of the rail-road, together with the wheels of a carriage, and the flange which serves to guide them.

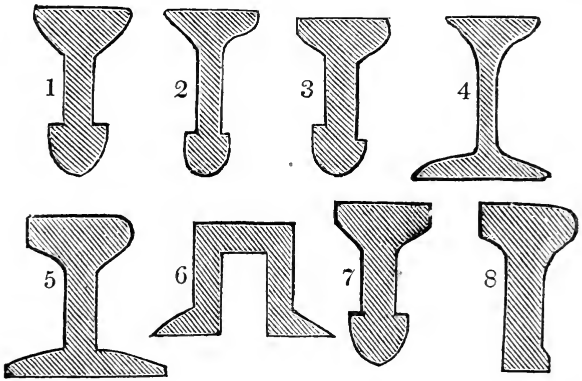
Rails are now almost universally made of wrought-iron. As this material is costly, when employed alone, it is sometimes used in thin bars, as a covering to wooden rails, particularly in this country, where timber is plenty, and iron

Fig. 99.



expensive.* But the most common rails are of solid iron, rolled out in lengths of several yards, the edges, especially the upper, being straight, and thicker than the other parts. Wrought-iron rails have the advantage of being longer, and, therefore, reducing the number of joints ; a circumstance which greatly increases the strength, as well as smoothness, of the road.

Mr. Trautwine has published, in the Franklin Journal, the following transverse sections of eight varieties of parallel rails, employed on different rail-roads in the United States. They are drawn to a scale of one fourth the full



* The durability of this combination of wood and iron, remains to be settled by longer experience. It must be greatly inferior to that of iron alone.

size, and accompanied by a statement of the weights, per lineal yard.

			Weights.
No. 1.	Columbia and Philadelphia,	per yard,	41¼ lbs.
" 2.	" "	"	33 "
" 3.	Germantown and Norristown,	"	39 "
" 4.	Camden and Amboy,	"	39¼ "
" 5.	Boston and Providence,	"	54 "
" 6.	Wilmington and Susquehanna,	"	40 "
" 7.	Alleghany Portage,	"	40 "
" 8.	Boston and Providence,	"	40 "

Tram-roads.—Tram-roads are flat rails, made usually of cast-iron, with an elevated edge, or flange, on one side, to guide the wheels of carriages in their path. Tram rails are weaker than edge rails, when made of the same amount of material, and it is sometimes necessary to strengthen them with ribs underneath. They are capable of being used for ordinary wheel carriages, but the introduction of wheels which are not perfectly smooth, is always injurious to the road. Tram-roads are more liable to be covered with dirt, than rails of other kinds, and are now little used.

Single Rail.—Carriages may be made to run upon a single rail, by elevating the rail from the ground, and suspending the load beneath it. In Mr. Palmer's rail-way, the rail is about three feet above the surface of the ground, and is supported by pillars, placed at distances of about nine feet from each other. The carriage consists of two receptacles, or boxes, suspended, one on each side of the rail, by an iron frame, and having two wheels placed one before the other. The rims of the wheels are concave, and fit the convex surface of the rail; and the centre of gravity of the carriage, whether loaded or empty, is so far below the upper edge of the rail, that the receptacles hang in equilibrium, and will bear a considerable inequality of load without inconvenience, owing to the change of fulcrum, allowed by the breadth of the rail, which is about four inches. The alleged advantages of the single rail are, that it is more free from lateral friction than the other kinds of rail-way, and that, being higher from the ground, it is less liable to be covered with dust and gravel; and, lastly, that it is more economical, the construction of one rail being less expensive than of two. It has not, however, been much introduced into use.

Passings, or Sidings.—When the amount of travel on a rail-road is very great, it becomes necessary that the road should be double, one set of tracks being provided for carriages moving in each direction. Where there is less travel, a single road is sufficient, if it be provided with double places, called *sidings*, for carriages to pass each other, at convenient distances. The siding, or passing place, is a short length of additional track, laid by the side of a line of rail-way, and connected with it, at each extremity, by suitable curves, the rails being constructed and disposed in such a manner, that the carriages can either proceed along the main line, or turn into the siding, as may be required.

To accomplish this, the portion of rails, forming the junction of the siding with the main line, is made movable, so as to join either track-way. This portion is termed a *switch*, and the points where one rail crosses another, are termed *crossing points*. These last are generally fixed or immovable; suitable grooves being left, on their surface, for the passage of the flanges of the carriage wheels on either track-way.

The *Turn-plate*, or *Turn-table*, is a contrivance for removing rail-way carriages from one line of rails to another. They are, generally, made for crossings at right angles with each other, but can be adapted to any angle that may be required. They consist of an iron framing, upon which iron gratings, or wood plankings, are laid, thereby forming a table, or platform, two pairs of rails being fixed on the surface of the same, crossing each other at right angles. This platform turns upon a centre pivot, which rests upon another iron frame, set on masonry, friction rollers being inserted between them, at the extreme edges of the table.

Curves.—The term curve is applied to a sudden bend, in a line of road, canal, or rail-way. Curves, upon railways of less than three fourths of a mile radius, should be avoided, as the centrifugal force, arising upon them, has a tendency to throw the train off the rails. They also pro duce an injurious amount of friction, which wastes power, and wears the flanges of the wheels.

When the rail-way crosses a public road, it is made to pass at a lower level than the common surface, and is protected from carriage wheels, by an elevated edging of wood, or stone ; bridges are preferred, whenever the situation permits them to be made. Rail-ways require to be free from dirt, which greatly increases the resistance. Mr. Palmer found, upon a tram-road, that it required nineteen per cent. more power to draw the same carriages when the rails were slightly covered with dust, than when they were swept clean. The edge rail, however, being convex on its upper surface, retains but little dust.

Propelling Power.—Horses were originally employed for drawing loads upon rail-ways, a horse being supposed capable of drawing eight times as much, as upon a common road. But *Locomotive* steam-engines are now generally employed upon rail-ways, of any considerable length. They were, at first, made to propel carriages, by means of a toothed wheel, which acted upon a rack attached to one of the rails ; but, at the present day, they are made to act by the friction, only, of the carriage wheels upon the plain rail. These engines are always made of high pressure, since those of low pressure are rendered too heavy, by the weight of the water necessary for condensation. Great improvements have lately been made in the construction of locomotive engines, in consequence of which, they have been enabled to attain the extraordinary speed of thirty or forty, and, in some short experiments, even of seventy, miles, per hour. (See *Steam Engine.*)*

Locomotive Engines differ considerably from other steam-engines, in their mode of construction ; and numer ous modifications are found necessary, to render the ma chine suitable for a rapid transit, the principal of which are the combination of the engine and boiler in one, and a contrivance for the rapid generation of steam.

* Franklin Journal, xix. page 407, New Series.

It became necessary, to form the boiler of much smaller dimensions, in proportion to its power, than was before customary, and to reduce the size of the cylinders. A greater degree of strength was also required, in securing the several parts of the framing together, in order to render the whole proof against the sudden shocks and strains, to which it is subjected.

Locomotives were in a very imperfect state, previous to the opening of the Liverpool and Manchester rail-way, having merely one flue, passing through the boiler, and returned again to the fire-box, at which end the chimney was situated. A greater velocity than eight miles an hour could never be attained by them, owing to the small extent of evaporating surface. They did not possess above one quarter the power of the present locomotives.

The directors of that rail-way, having, in the year 1829, offered a premium of five hundred pounds for the best locomotive engine, the first stimulus was given to the subject. The Rocket engine, by Mr. G. Stevenson, proved successful in obtaining this premium. In the boiler of this engine, tubes were introduced, for the first time, which greatly increased the evaporating powers of the engine; and, although locomotives have since been considerably modified, yet this has formed the basis of all the great improvements, which have taken place. A description of it will be given, under the head of *Steam Engine.*

Mr. Stevenson's engine weighed only four and a half tons, and the evaporating surface was three times the extent of that in the former engines, which weighed upwards of seven and a half tons. It attained a speed of twenty-nine miles an hour, and an average velocity of fourteen and a half miles an hour. It was soon after found, that, by constructing engines of greater size, with increased evaporating powers, ample amends would be made for the additional weight. Heavier engines were introduced on the Liverpool and Manchester rail-way; and the locomotives, in general use, at the present time, weigh from nine to thirteen tons. The power of a modern locomotive engine, having twelve-incn cylinders, and an eighteen-inch stroke of piston, is computed at about thirty-eight or forty horse power, at high velocities, and seventy or eighty horse power, at a slow rate of speed.

The rapid generation of steam, in these locomotives, is owing to the great number of tubes, and to their thinness, whereby a large surface of water receives its heat quickly, through a thin partition. An advantage is supposed to be derived from the final escape of the steam, which is discharged into the chimney.

Various improvements have been introduced into the locomotive engine, one of which consists in the use of six wheels, instead of four. In this country, many engines are constructed with six wheels, the first four of which are united by their axles, so as to form a kind of separate carriage, which is made to support one end of the locomotive. This carriage turns on a central bolt, like the fore axle of a wagon. It has the advantage, that the pressure is distributed more equally, and that the wheels accommodate themselves better, to curvatures of the road.

Stationary Engines are used to draw up loads where the ascent is too steep for locomotives to ascend. Where the declivity of the road is great, loaded carriages sometimes descend, by their own gravity, and, at the same time, draw up the empty ones, by means of pullies. To prevent carriages from acquiring too great a velocity, in descending, a crooked lever, called a *brake*, or *convoy*, is applied to the surface of the wheels, so as to retard them by its friction.* When loaded carriages are transferred from one part of the road to another, of greater elevation, they are either drawn up an inclined plane, with ropes, by horses, or stationary engines; or, in some cases, they may be lifted perpendicularly, by pullies. This method, however, is seldom practised.

* A retarding friction is produced, when necessary, in mountainous countries, upon common roads, by chaining one of the wheels, when the carriage goes down hill, so as to prevent its turning. The same effect is produced, in a safer manner, by placing a wooden shoe, like a runner, under one of the wheels.

CANALS.

Canals are artificial channels for water, cut for the purpose of admitting inland navigation. The great utility of canals, in facilitating transportation, has caused them to be constructed in all ages. The canals of the ancients were chiefly made on one level, so as to form merely artificial rivers, or creeks. Those of the moderns, by means of locks, are carried, indiscriminately, over ground which is depressed, or elevated. In level tracts of country, if the earth is of suitable character, canals are easily made. But, in loose and crumbling soils, in undulating, rocky, and mountainous, tracts, and in those which are intersected by large streams, their construction becomes expensive and difficult. To surmount these difficulties, loose soils are defended with firmer materials, vallies are passed by embankments, hills are penetrated by deep cuttings or tunnels, rivers are crossed with aqueducts, and declivities are ascended and descended by locks. In order that water may not be wanting in any part of the canal, a supply is ensured at the highest level, and this gradually passes off through the locks, to the lowest. The streams which furnish the water at this, and other, points, are called *feeders*.

Embankments.—Canals are dug with sloping sides, to prevent the banks from caving in. The boats being, in almost all cases, drawn by horses, a firm, uninterrupted, towing path is formed on one of the banks. The banks are liable, in time, to become indented and washed away, by the constant agitation of the water, occasioned by the passage of boats. To prevent this, they are sometimes secured, by driving close rows of stakes against the banks ; but, the only effectual protection is found in walling the banks with stone. When the canal crosses a section of country, the surface of which is lower than the intended surface of the water, the canal is raised to the proper level, by means of *embankments*. These are artificial banks, or dykes, made of such materials as will not be liable to leak, and of such form and strength, that they will not be broken by the pressure of the water. The surface of these banks is of a sloping form, and is secured by sodding, and, in some instances, by piles, or stone walls. Where the nature of the earth renders leakage probable, it is common to cover the bottom and sides of the canal with a lining of *puddle*, which is formed from loam, or clay, and gravel, worked up with water. For additional security, a trench is dug, in each bank, to a greater depth than the bottom of the canal, and filled with puddle.

It sometimes happens, that the embankments act as a dam, to prevent the land, on one side of the canal, from being properly drained. In this case, *culverts*, or subterranean passages, are constructed underneath the canal, but not communicating with it, to effect the necessary draining. Culverts are made of brick, or stone, and require to be strong and tight.

Aqueducts.—When a canal crosses a river, or a deep ravine, it is supported, at the proper level, by an *aqueduct.* This structure resembles a stone bridge, formed of strong piers and arches, of regular masonry, rendered as tight as possible, with hydraulic cement. Upon the top, a level channel for the water is formed. This is secured with strong and tight walls, on the sides, and lined within by a coating of clay. Room for the towing path must be preserved, on one of the sides. In England, aqueducts have sometimes been made of cast-iron.

Tunnels.—Tunnels are subterranean passages, most frequently cut through the base of hills, to afford a level water-course for canals. Tunnels are also made for the passage of rail-ways, and, in some cases, of highway-roads. When they are obliged to be cut through solid rock, which is done chiefly by blasting, their formation is difficult; but they require no artificial security for their subsequent protection. But tunnels, which are made in soft earth, require to be arched over, for their whole length, with stone, or brick; and, in loose, springy ground, the bottom, likewise, must be defended with an inverted arch. That tunnels may be properly ventilated, especially while digging, *shafts*, or vertical passages, are sunk, at proper distances, in which fires are kept burning, to create a current for discharging the foul air. One of the most remarkable tunnels is that at Worsley, on the Duke of Bridgewater's canal, which, with all its branches, is estimated at eighteen miles in length.

Gates and Weirs.—As all canals are liable to have their banks broken through, during violent rains and freshets, it is important to lessen the injury, which results from such accidents, by retaining as much of the water in the canal as possible. To effect this object, *safety-gates* and *stop-gates* are placed, at suitable distances from each other, on the canal, so that, by closing them, at any time, in case of accident, the escape of that part of the water, which is beyond them, may be prevented. These gates are sometimes attached to the sides, and sometimes lie upon the bottom.

Certain parts of the banks, called *Weirs*, are made lower than the rest, to discharge the superfluous water, and keep the surface at a proper level. To prevent them from being gullied, or worn away, by the attrition of the water, they are commonly made of stone, or, sometimes, of wood.

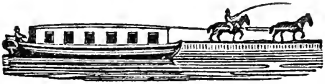
Locks.—When a canal changes from one level to another, of different elevation, the place, where the change of level occurs, is commanded by a *Lock*. Locks are tight, oblong enclosures, in the bed of the canal, furnished with gates, at each end, which separate the higher, from the lower, parts of the canal. When a boat passes up the canal, the lower gates are opened, and the boat glides into the lock; after which, the lower gates are shut. A sluice, communicating with the upper part of the canal, is then opened, and the lock rapidly fills with water, elevating the boat on its surface. When the lock is filled to the highest water level, the upper gates are opened, and the boat, being now on the level of the upper part of the canal, passes on its way. The reverse of this process is performed, when the boat is descending the canal.

Locks are made of stone, or brick, and, sometimes, of wood. The walls are sometimes erected upon an inverted arch, and also upon piles, if the soil is alluvial, or loose. They are laid with hydraulic cement, and rendered impervious to water. The gates are commonly double, resembling folding doors, turning upon *coin-posts*, which are next the walls. They meet each other, in most instances, at an obtuse angle, and the pressure of the water serves to keep their contact more firm. The hydrostatic pressure, in these cases, being in full force, in a direction perpendicular to the surface of the gates, has a different action from that of the pressure of gravity, applied to a roof, or similar structure, and gives to long gates a greater comparative disadvantage than to short ones. Cast-iron gates are sometimes used, in England, curved in the form of a horizontal arch, with their convex side opposed to the water. *Valves* are small sliding shutters, which admit a stream of water, for the purpose of gradually filling, or emptying, the lock, to prevent the shock of suddenly opening the gates.

In situations, where there is a scarcity of water, the waste, occasioned by frequently opening the gates, for the passage of boats, is too great for the amount supplied to the canal. In these cases, to economize the water, reservoirs are provided, at different heights, on each side of the lock. The water, in the upper parts of the lock, is discharged into these reservoirs, and only that in the lower parts is suffered to escape into the lower canal. Afterwards, the water in these reservoirs is used to fill again the lower parts of the lock, and thus, the same water is made use of, a second time.

In China, where inland navigation is much practised, it is said there are no locks, but boats are transferred, from one level to another, by means of inclined planes. This method is sometimes practised, in Europe, and it had a zealous advocate in the late Mr. Fulton. To effect this transfer most advantageously, two boats, passing in opposite directions, are connected together by a chain, passing over a pulley. One boat, in descending the plane, assists, by its weight, to draw the other upward. Sometimes, instead of inclined planes, perpendicular lifts have been proposed, by which the boats are hoisted directly, by pullies, from one level to another, or lowered, in the opposite direction, by the same means. The objection to all these modes exists in the strain, to which the boats are exposed, unsupported by the pressure of the water. Various expedients have been proposed, for altering the level of the water, and transferring boats, by means of large plungers, diving chests, &c.; but none of them, as yet, appear to have been approved in practice.*

Fig. 100.



Boats.—Canal boats are made narrow, for passing each other, and draw water proportioned to the depth of the canal. Their length is limited only by that of the locks. They are drawn by horses, on the tow-path, being kept, by the rudder, from coming in contact with the bank. No species of oars, poles, or paddle-wheels, is allowed, on account of the injury done to the bottoms and banks, by their use. It is said, however, that the steam-engine has, in some cases, been used, without injury to the canal, by causing the paddle-wheels to work in a water passage, or casing, which passes through the boat, above its bottom.

Size of Canals.—Canals differ greatly from each other, not only in their length, but their size, and the draught of water which they admit. One of the largest canals, as far as the volume of water is concerned, is the great Dutch canal, which connects the city of Amsterdam with the Helder, on the north coast of Holland. This canal is fifty miles in length, one hundred and twenty-four feet in width, at the surface of the water, thirty-six feet wide, at bottom, and about twenty-one feet deep. It is large enough to permit one frigate to pass another. The Caledonian canal extends from the Murray Frith, on the eastern coast of Scotland, to Loch Eil, on the western, and admits of the passage of large ships. It is one hundred and twenty feet wide, at the water surface, and fifty wide, at bottom. The depth of water is twenty feet. The distance, from sea to sea, is about fifty-nine miles, of which thirty-seven and a half is lake navigation, and

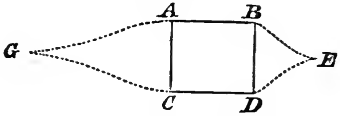
* Repertory of Arts, vols. i. ii. and xxiii.

twenty-one and a half is cut.* The canal of Languedoc, in France, is sixty-four leagues in length, and connects the Atlantic ocean with the Mediterranean sea. It is sixty-four feet wide, at the surface, and navigable for vessels of one hundred tons. The great New York, or Erie, canal is three hundred and sixty miles long, and extends from the Hudson river, at Albany, to Lake Erie, at Buffalo. It is forty feet wide, at the surface, twenty-eight feet wide, at bottom, and has four feet depth of water.

SAILING.

Form of a Ship.—The movement of bodies through water, if performed within certain limits of velocity, is attended with less resistance than that which takes place in most other modes of transportation. A body, however, of given size, will encounter a greater or less resistance from the water, according to its proportions, and the sort of surface which it opposes to the fluid. In calculating the proper form for a ship, it is necessary to consider the kinds of pressure, to which bodies, moving in fluids, are subject. If we suppose an oblong square box, or parallelopiped, as ABCD, in Fig. 101, to move through the

Fig. 101.



water, in the direction of its length, the pressure will be increased before, and diminished behind it, the surface of the water being elevated, at the anterior extremity, and depressed, at the posterior; an effect which increases, in a high ratio, as the velocity becomes greater. The principal part of the water, which is before the moving body, divides and passes off by the sides; but a certain quantity of what is called *dead water* is pushed along, in advance of the moving body, nearly in the same manner as if it were

* Supplement to the Encyclopedia Britannica, and Edinburgh Encyclopedia.

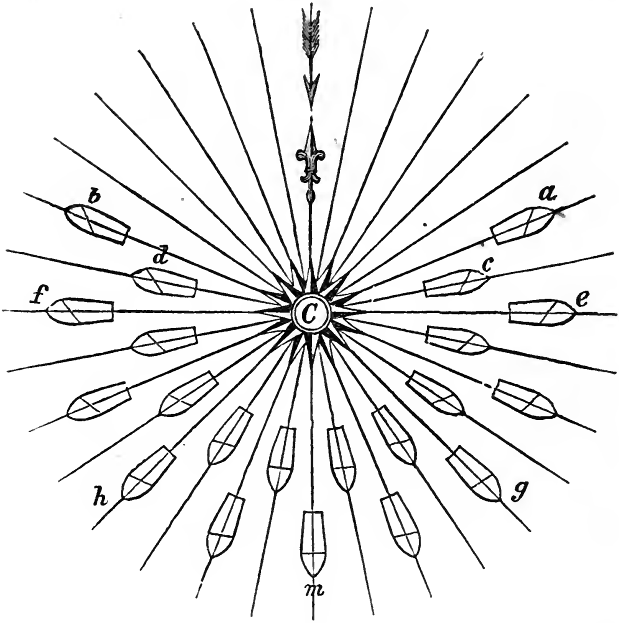
a part of the body itself. The shape of this dead water, at the surface, is found to be that of an irregular triangle, and hence it becomes advantageous to add to the moving body an extremity, or *bow*, having nearly the same shape as the dead water, and occupying its place, as in the dotted line, BED. On the other hand, there occurs, behind the moving body, a depression of surface, and a partially empty space, which is also of a triangular, or wedge, form, consisting of the room which the moving body has just left, and into which the water, upon each side, has not yet flowed. The cavity, which is thus formed, resists the progress of the body, by its *negative* pressure. Its effect is readily understood, when we consider, that, if the water before the moving body be raised one foot, while the water behind it is depressed one foot, the difference of pressure, upon the two extremities, will be equal to that resulting from two feet. On this account, it is advantageous to add to the moving body a tapering, or wedge-shaped, extremity, behind, capable of occupying this cavity, and nearly answering to it in shape, as represented by the dotted line, AGC. The consequence will be, that the water, which is advancing from both sides to fill up the vacuity, will meet the tapering sides of the vessel soon enough to obviate, or greatly diminish, the negative pressure. The form, produced by this general outline, varied by a proper curvature of the sides and bottom, corresponds nearly to that which is adopted in the construction of ships, and also to that pursued by Nature, in the structure of fishes. If a vessel be intended for a fast sailer, its proportionate length, and its sharpness, before and behind, must be increased, since both the positive and negative pressure, and the extent of the dead water and vacant space, will increase with the velocity.

Keel and Rudder.—The use of the keel, which is a projecting timber, extending the whole length of the ship's bottom, is to assist in confining the motion of the ship to its proper direction, and, by its lateral resistance, to diminish the disposition to roll, or vibrate, from side to side. The rudder, which is a perpendicular part attached, by braces, resembling hinges, to the stern-post of the vessel, serves to govern the ship's course, by altering the relative resistance of its two sides. Thus, while the ship is under way, if the rudder is turned to one side, it receives an impulse from the water on that side, causing the stern to turn towards the opposite side, where no such resistance exists, thus altering the direction of the keel, and the general course of the vessel.

Effect of the Wind.—When a ship sails in the same direction as the wind, she is said to be *scudding*, or sailing *before the wind*, and if she had but one sail, it would act with the greatest advantage, when perpendicular, or nearly so, to the wind.

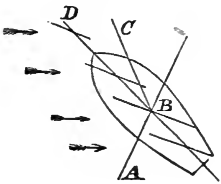
When a ship advances against the wind, and endeavors to proceed, in the nearest direction possible, to the point of compass from which the wind blows, she is said to be *close-hauled.* A large ship will sail against the wind with her keel at an angle of six points with the direction of the wind, and sloops, and smaller vessels, may sail much nearer. When a ship is neither sailing before the wind, nor close-hauled, she is said to be *sailing large.* In this case, her sails are set in an oblique position, between the direction of the wind, and that of the intended course ; as represented in the various plans of vessels in Fig. 102, on page 40, where the direction of the wind is represented by the arrow, and the position of the yards and sails, which is necessary for proceeding on the various points of compass, is shown by the transverse lines on each plan. The relation of the wind to the course of the vessel is determined by the number of points of the compass, between the course she is steering, and the course which she would be steering, if close-hauled. In Fig. 102, the ships, [*a* and *b*,] are close-hauled, and the ships, [*c* and *d*,] the former steering east by north, and the latter west by north, have the wind one point large. The ships, [*e* and *f*,] one steering east, and the other west, have the wind two points large. In this case, the wind is at right angles with the keel, and is said to be *upon the beam.* The ships, [*g* and *h*,] steering southeast, and southwest, have the wind six points large, or, as it is commonly termed, *upon the quarter*, and this is considered as a very favora-

Fig. 102.



ble manner of sailing, because all the sails coöperate to increase the ship's velocity; whereas, when the wind is directly aft, as in the vessel, [m,] it is partly intercepted by the after sails, and prevented from striking, with its full force, on those which are forward. The force of a wind which strikes obliquely upon the sails, supposing them flat surfaces, is resolvable into two forces, one of which tends to push the vessel ahead, and the other to push her sideways. If the form of the vessel, instead of being oblong, were circular, like a tub, she would move in the direction of the diagonal of a rectangle, representing these two forces, and her course would be at right angles with the position of the sail, or in the direction of the line AB, in Fig. 103. But, owing to the oblong shape of the vessel, and the influence of her keel, it requires about twelve times as much force to push her sideways, as to push her head foremost.* The oblique impulse, therefore, will carry her a great distance forward, in the time that she is drifting a short distance to the leeward, and it is this relative difference of progress, which enables a vessel to advance, even against the wind. The angular deviation of a ship's real course, from her apparent course, upon which her head is directed, is called the *leeway*. In the vessel, [Fig. 103,] with the wind blowing in the direction

Fig. 103.



of the arrows, and the sails set as represented, if the vessel were moving in a rail-way, or unchangeable channel, her course would be BD; but, in the water, she drifts so much to the leeward, that her real course is BC, and the angle, CBD, represents the amount of *leeway*.

Stability of a Ship.—The masts of a ship, when acted upon by the pressure of the wind against the sails, are so many levers, the tendency of which is, to overset her. To counteract this tendency, a sufficient weight of ballast, or cargo, is stowed in the bottom of the hold, to carry the centre of gravity into the lower part of the hull, so that this part will always preponderate, while the relative buoyancy of the upper part causes the vessel to right, as often as her position is disturbed. If the ballast is too light, or is stowed too high in the hold, the vessel is said to be *too crank*, and rolls more, and cannot carry so much sail, without danger of oversetting. On the other hand, if the ballast is too heavy, and placed too low, the vessel is said to be *too stiff*, and not only draws so much water as to impede her velocity, but is liable to have

* Robinson's Mechanical Philosophy, vol. iv. p. 620.

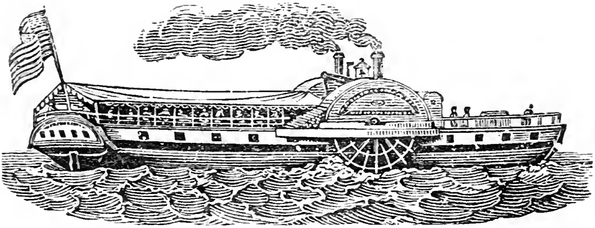
her masts endangered, by the shocks which result from the suddenness of her motions. In regard to shape, an increase of the width of a ship increases her stability, but, at the same time, detracts from her power as a fast sailer.

Steam Boats.—Experiments on the propulsion of vessels, by steam, were made in Europe, and this country, at different times, during the last century; but the first successful introduction of steam navigation, on a large scale, was made in America, by the late Mr. Fulton, about the year 1807. The application of the steam-engine to navigation, has given to vessels the advantage of greater speed and regularity, in the performance of their passages, without interruption from the changeable, and often adverse, operation of the elements. In the action of the steam-engine, as in that of rowing, a vessel is propelled by a succession of impulses, which act against the inertia of the water.

A power acting within a boat, whether of men, of horses, or of steam, may be applied to the water, in various ways. Some of the principal of these are the following. 1. A system of oars, or paddles, has been made to act with alternating strokes, rising out of water at the end of each stroke. 2. An alternating paddle has been contrived, which is continually immersed, and which folds up, like the foot of a water-fowl, during the backward stroke. 3. It has been proposed to drive a current of air, or a current of water, out at the stern of the vessel. 4. Spiral wheels and water-screws, or wheels with oblique vanes, like those of a windmill, have been made to turn under water, with their axes parallel to the keel of the vessel. 5. Oblique planes, acting with an alternate, instead of a revolving, stroke, were recommended by Bernoulli. 6. Paddle-wheels. These, from their simplicity, and advantageous mode of action, have, in common use, superseded all the rest. They consist of paddles, or float-boards, attached to the arms, or spokes, of a wheel, the axis of which is at right angles with the keel. Their common place is on the sides of the boat, as in Fig. 104, on the opposite page.

The outline of the float-boards, or paddles, is com-

Fig. 104.



monly rectangular, though Mr. Tredgold recommends that their outer extremity should be parabolic. The best position for the paddles is in a plane, passing through the axis of the wheels ; but with this position, they strike the water obliquely, in entering, and lift a considerable quantity, on quitting it ; both of which motions occasion loss of power. Attempts have been made to correct this disadvantage, by various mechanical arrangements, in which the paddles are made to enter and leave the water perpendicularly ; but want of simplicity, and objections of various other kinds, have prevented them from coming into use. It has been proposed to fix a series of paddles upon longitudinal chains, passing round wheels, and parallel to each side of the vessel. By this mode, a number of perpendicular paddles would act upon the water at once ; but it will be seen, that, as no more of these paddles can operate usefully, than are sufficient to put the water between them into motion, a part of the series will be less useful, than if it acted upon water at rest. In wheels of the common form, it is advantageous to have a double row of paddles, one outside the other, and so placed, that the paddles of one series shall be opposite the intervals of the other, and thus enter the water successively, and in different places.* This plan is the one most generally adopted, in American steam-boats. In Perkins's propelling wheel, the paddles are placed obliquely, in regard to the axis of the wheel, and the wheel itself is placed ob-

* For examinations of the different propelling powers, see the Edinburgh Encyclopedia, article 'Navigation Inland,' ascribed to Mr. Telford ; also, Tredgold on the Steam Engine, p. 309.

liquely, in regard to the keel of the boat. This arrange ment is such, that the paddles enter and leave the water obliquely, but, at the time of their greatest immersion, they are at right angles with the keel, and in the most favorable position for propelling the boat.

The average speed of a well-constructed steam-boat has been assumed at fourteen miles per hour, and the greatest speed at sixteen miles.*

Steam-boats have been considered as best adapted to the navigation of rivers, and straits, or sounds, where the water is comparatively smooth. In the open sea, the violence of the waves renders the action of the paddle-wheels irregular, and it was, for a long time, thought difficult for them to carry fuel sufficient to supply the engine, during long voyages. The steam-ship Savannah first crossed the Atlantic, in 1819, and was twenty-one days, from land

* Mr. W. S. Redfield, of New York, has addressed to Lieutenant Hosken, the commander of the Great Western steam-ship, a letter, in which he says: "There is, if I mistake not, some misapprehension prevailing, both in England and America, in regard to the ordinary, as well as maximum, speed of the best steam-vessels. This is mainly to be ascribed to three causes: 1st. The erroneous statements which often find their way into newspapers. 2d. To a mistaken estimate of the velocity of the tides and currents. And, 3d, to the erroneous popular estimate of navigating distances, which, on nearly all internal, or coasting, routes, in both countries, so far as my knowledge extends, are habitually overrated. This may explain, on one hand, the extravagant claims to velocity, which are sometimes stated of American steam-boats; and, on the other hand, may account for the strange incredulity, which has been manifested by Dr. Lardner, and others, not well acquainted with the structure and performances of American steam-boats. The acquaintance which I have had with the navigation of the Hudson, by steam, during the last thirteen years, enables me to speak with confidence on some of the points involved.

"The usual working speed of the best class of steam-boats, on the Hudson, may be estimated at fourteen statute miles per hour, *through still water of good depth.* That they are not unfrequently run at a lower speed, is freely admitted. But the maximum speed of these boats *is, and has been, for several years, equal to about sixteen miles per hour.* In regard to the "admitted four miles per hour tide up the Hudson," the admission is extremely erroneous. The average advantage to be realized, in a passage on flood-tide, from New York to Albany, is not more than one mile and a half per hour, or, at the most, say twelve miles, in a passage to Albany,—equal to about one twelfth of the distance, as performed under the most favorable circumstances" to land, during eighteen of which, only, she was able to use her engine.

Steam Ships.—The difficulties attendant on marine steam navigation, which, but a short time ago, were pronounced, by some distinguished authorities, to be insurmountable, have been completely overcome by the introduction, in 1838, of steam-ships of extraordinary size, propelled by engines of great power. The Great Western, which arrived at New York, from Bristol, in April, 1838, measured, for her extreme length, two hundred and thirty-six feet, and in width, between the outside of the paddle-cases, fifty-eight feet. The British Queen, which followed in the next year, is two hundred and seventy-five feet long, which is stated to be thirty-five feet longer than any ship in the British navy. She has two engines, of two hundred and fifty horse power each. It is now settled, that the passage of the Atlantic may be made, safely and successfully, by vessels of this size, and accomplished, under favorable circumstances, in less than a fortnight.

The success attending these experiments has led to the multiplication of ocean-steamers, which are intended to ply upon all the great tracks of commerce, in the civilized world. The communication between Europe and the United States, as well as that with the West and East Indies, and, indeed, with most of the important sea-ports on the globe, may be considered as hereafter to be performed, in half the time which was formerly required, and with far greater certainty, in regard to the times of arrival and departure.

Of the numerous steam-ships now building, or built, in Great Britain, to ply between that country and foreign ports, some are constructed entirely of iron. Some are of immense size, exceeding that of the British Queen, which has already been mentioned.

DIVING-BELL.

The diving-bell is an inverted vessel, containing air, and used for the purpose of enabling persons to descend, with safety, to great depths under water. It is made tight at the top and sides, but is entirely open at bottom. Its principle is the same with that of a gasometer, and may be familiarly illustrated, by immersing an inverted tumbler in a vessel of water. The air cannot escape from the inside of the vessel, being necessitated, by the order of specific gravities, to occupy the upper part of the cavity.

Diving-bells appear to have been first introduced, in the beginning of the sixteenth century. They were first known as objects of curiosity, only, but have been since applied to the recovery of valuable articles from wrecks, the blasting and mining of rocks, at the bottom of the sea, and the practice of submarine architecture. They may be made of almost any shape; but the common form has been that of a bell, or hollow cone, made of wooden staves, and strongly bound with hoops, having seats for the occupants, on the inside. It is suspended with ropes, from a vessel above, and is ballasted with heavy weights at bottom, which serve to sink it, and to prevent it from turning over. More recently, diving-bells have been made of cast-iron. The kind of bell used at Howth, near Dublin,* is an oblong iron chest, six feet long, four broad, and five high, thicker at bottom than at top, and weighing four tons. It has a seat at each end, and is capable of holding four persons. The upper part is pierced with eight or ten holes, in which are fixed the same number of strong convex glasses, which transmit the light. As the air in the bell becomes contaminated, by breathing, it is renewed, by letting down barrels, or small bells, of fresh air, which is transferred to the large bell; or else, by keeping up a constant supply, through a pipe, by means of a forcing pump, which is worked by men at the surface.

Persons who descend in diving-bells often experience a pain in the ears, and a sense of pressure, occasioned by the condensation of the air, within the cavity of the bell. These symptoms gradually pass off, or habit renders the body indifferent to them, so that workmen remain under water, at the depth of twenty feet or more, for seven or eight hours in a day, without detriment to the health.

* Edinburgh Philosophical Journal, vol. v. p. 8.

Submarine Navigation.—A machine was invented, during the American Revolution, by Mr Bushnell, of Connecticut, which was capable of containing a person in safety, under water, and of being governed, and steered in any direction, at pleasure. It is described* as being a hollow vessel, of a spheroidal form, composed of curved pieces of oak, fitted together, and bound with iron hoops, the seams being caulked, and covered with tar, to render them tight. A top, or head, was closely fitted to the vessel, and served the purpose of a door. In this were inserted several strong pieces of glass, to admit the light. The machine contained air enough to render it buoyant, and to support respiration. A quantity of lead was attached to the bottom, for ballast. The vessel was made to sink, by admitting water, and to rise, by detaching a part of the leaden ballast, or by expelling water with a forcing pump. It was propelled horizontally, by means of revolving oars, placed obliquely, like the sails of a windmill, on an axis which entered the boat through a tight collar, or water-joint, and was turned with a crank within. A rudder was also employed, for steering the vessel. When fresh air was required, the vessel rose to the surface, and took in air through apertures at the top. The intention of this machine was, to convey a magazine of powder under ships of war, for the purpose of blowing them up. Several experiments were made with it, which, though unsuccessful in their object, nevertheless proved the practicability of this species of locomotion.

The late Mr. Fulton made various experiments on submarine navigation, in a boat large enough to contain several persons, furnished with masts and sails, so as to be capable of proceeding at the surface of the water, and, also, of plunging, when required, below the surface.† While under water, its motions were governed by two machines, one of which caused it to advance horizontally, while the other regulated its ascent and descent, its depth below the surface being known, by the pressure on a barometer. A supply of fresh air was carried down in

* Silliman's Journal, vol. ii. p. 94.

† See Colden's Life of Fulton, 8vo. New York, 1810.

the boat, condensed into a strong copper globe, by which the air of the boat was replaced, when it became unfit for respiration. Mr. Fulton's object was the destruction of ships of war, by bringing underneath them an explosive engine, called a *torpedo*.

AEROSTATION.

Balloon.—A Balloon is a sphere, or bag, formed of some light material, such as silk, and rendered impervious to the air, by covering it with elastic varnish. It is filled with a gaseous fluid, lighter than the surrounding atmospheric air, and has a car suspended, at the bottom. If the specific gravity of the whole mass is less than that of an equal bulk of the atmospheric air, which surrounds it, the balloon will ascend into the atmosphere, and remain suspended, until, by the escape of its gas, or other means, it becomes heavier than the surrounding air, when it will again descend. Balloons were invented in France, by the Montgolfiers, about 1782. Those which were first employed by them were filled with common air, rarefied by heat; but these required, that a fire should be constantly kept burning beneath them, to keep them afloat. Hydrogen gas was afterwards employed; and this fluid, being permanently about fourteen times less dense than common air, is, undoubtedly, the best material for aerostation. Carburetted hydrogen, though heavier than hydrogen, has also been employed, of late, on account of its cheapness, being furnished, in large quantities, at the manufactories of illuminating gas.

Balloons are made, by sewing together pieces of silk, the shape of which corresponds to that of the part included by two meridians of the artificial globe. They have also been made of linen, and of paper. They are varnished with a solution of elastic gum, to render them tight. A net-work is thrown over the top of the balloon, to which is attached, by strings, a car of wicker-work, underneath the balloon. The whole is kept down, by a sufficient quantity of ballast, and ascends into the atmosphere, when a part of the ballast is thrown over. It is made to descend again, by suffering a part of the gas to escape through a valve, provided for the purpose.

The regulation of the ascent and descent of balloons is the extent of control, which has been hitherto obtained over them. All attempts to guide or propel them, by means of wings, sails, oars, &c., have hitherto failed, and the machine can only proceed at the mercy of the winds. The small degree of buoyancy, which balloons possess, does not permit them to carry sufficient weight of material, to furnish the medium of an adequate propelling force. By taking advantage, however, of favorable winds, voyages have been made in them to the distance of three hundred miles ; and persons have ascended to the height of twenty thousand feet, and upwards. The velocity of balloons varies with that of the wind, but has, in some instances, amounted to the rate of seventy miles an hour.*

Parachute.—The danger, which attends falling from great heights, is in consequence of the continual acceleration of velocity, which falling bodies experience. When, however, the resistance of the atmosphere becomes equal to the force of gravity, the motion is no longer accelerated, but becomes uniform. A parachute is an appendage to a balloon, formed somewhat like an umbrella, and is designed to break the force of a fall, by means of the large surface which it opposes, in its progress, to the atmosphere. It is made of silk or canvass, and is placed underneath the balloon, having the car suspended from it by cords. When the balloon is at any height in the air, the parachute may be detached from it, and will immediately fall with the car, to the ground. But the resistance of so large a surface to the atmosphere, causes the fall to be gradual and easy, so that a person may descend with a parachute, in safety, from the greatest heights. The size of the parachute, employed by M. Garnerin, and with which he descended from a height of two thousand feet, at Paris, in 1797, was twenty-five feet in diameter. The parachute was folded up, at the beginning of the fall,

* M. Gay-Lussac, on the 6th of September, 1804, ascended twenty-three thousand and one hundred feet above Paris. M. Garnerin, September 21st, 1827, passed, in seven hours and a half, from Paris to Mount Tonnere, a distance of three hundred miles. This voyage was performed in the night, and during a storm.

but soon expanded itself, by the resistance of the atmosphere. The only inconvenience, which was experienced, arose from a violent oscillating motion.

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CHAPTER XV.

ELEMENTS OF MACHINERY.

Machines, Motion. *Rotary, or Circular, Motion,* Band Wheels, Rag Wheels, Toothed Wheels, Spiral Gear, Bevel Gear, Crown Wheels, Universal Joint, Perpetual Screw, Brush Wheels, Ratchet Wheel, Distant Rotary Motion, Change of Velocity, Fusee. *Alternate, or Reciprocating, Motion,* Cams, Crank, Parallel Motion, Sun and Planet Wheel, Inclined Wheel, Epicycloidal Wheel, Rack and Segment, Rack and Pinion, Belt and Segment, Scapements. *Continued Rectilinear Motion,* Band, Rack, Universal Lever, Screw, Change of Direction, Toggle Joint. *Of Engaging and Disengaging Machinery. Of Equalizing Motion,* Governor, Fly Wheel. *Friction.* Remarks.

Machines.—By a machine, may be understood a combination of mechanical powers, adapted to vary the direction, application, and intensity, of a moving force, so as to produce a given result. The advantage which machines possess, over common manual labor, is generally that of increasing, or improving, the product of an operation. This end they accomplish, by enabling us to apply a common force, more advantageously, or to employ the most powerful force, derived from natural agents, with precision and efficacy. By the aid of machinery, any number of instruments, or operative parts, may be made to move in concert, in every possible direction, with any degree of velocity, and to reciprocate with each other in perfect harmony, so that complex operations are performed by them, with a precision which often exceeds the skill of the most expert artist.

Motion.—The motion which takes place in machines is, for the most part, either *rotary* or *reciprocating*. A rotary motion is that, in which the moving parts revolve round an axis, as in a wheel, a crank, or a fly. A reciprocating, or alternate, motion is that, in which a body retraces its own path, or moves alternately backward and forward, in the same track, which may be curved, as in the beam of a steam-engine, or rectilinear, as in the piston. Most compound machines possess both these kinds of motion, or varieties derived from them; and the different ways of producing and communicating them, in the requisite times and places, constitute a principal subject of attention with machinists.

ROTARY, OR CIRCULAR, MOTION.

When it is intended that one wheel, or axle, shall propel another, various contrivances are adopted, to connect the propelling part with that which is to be moved. The mode of connexion is varied, according to the distance, the relative velocity required, and the direction in which motion is to be communicated.

Band Wheels.—If two wheels be connected by a belt, or band, passing round their circumferences, they will move simultaneously, provided the friction of the band is sufficient to prevent it from slipping. When a round cord is used, any degree of friction may be produced, by receiving the cord in a sharp groove, at the edge of the wheel. But the stiffness of cords forms, in many cases, an objection to their use. When a strap, or flat band, is used, its friction may be increased, by increasing its width. The surface at the circumference of a wheel, or drum, which carries a flat band, should not be exactly cylindrical, but a little convex; in which case, if the band inclines to slip off, at either side, it returns again, by the tightening of its inner edge, as may be seen in a turner's lathe. When wheels are connected, in the shortest manner, by a band, as in Fig. 105, they move in the same

Fig. 105.

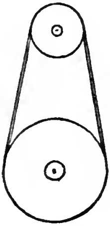
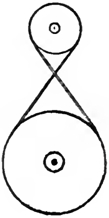


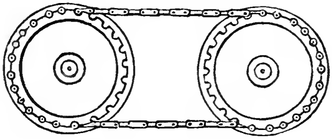
Fig. 106.



direction. If the band be crossed, as in Fig. 106, they will move in opposite directions. Wheels, whose axes are situated in different planes, may turn each other, if the band be sufficiently long. If no slipping were to take place in the band, wheels of equal size would move with equal velocity, and those of different sizes, with velocities inversely proportionate to their respective circumferences. But, since the band is liable to yield or slide, somewhat, during the revolution, the velocity of the driven wheel is, commonly, a little less, in proportion, than that of the wheel which drives it.

Rag Wheels.—Where it is necessary that the velocities should be exactly proportionate, also, where great resistance is to be overcome, chains of various kinds are substituted, by passing them round wheels, in the place of belts and ropes. These chains lay hold upon pins, or enter into notches, on the circumference of the wheels, so as to cause them to turn simultaneously. Such wheels are denominated *rag-wheels*, and have a uniform relative velocity. [Fig. 107.] They are used in locomotive steam-engines, chain water-wheels, &c.

Fig. 107.



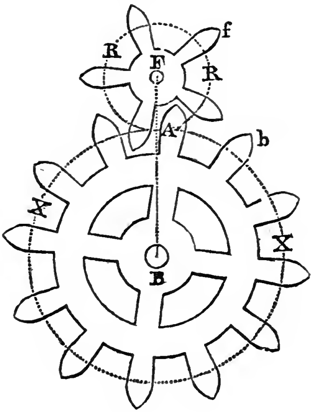
Toothed Wheels.—Toothed wheels afford a more regular and effectual mode of communicating rotary motion, than any other kind of connecting mechanism. They move, of necessity, in opposite directions, and their relative velocity is inversely proportionate to their number of teeth. Thus, if a wheel having forty teeth drives another of ten teeth, the second will make four revolutions, while the first makes one. The connexion of one toothed wheel with another is called *gear*, or *gearing* ; and, when both wheels, with their teeth, are in the direction of the same plane, it is called *spur-gearing*. It is desirable, in toothed wheels, as far as possible, to diminish friction, and to produce uniformity of force and motion. A uniform motion may be produced, if the form of the acting face of the teeth be a curve of the epicycloidal kind ; the outline of the teeth of one wheel being the curve which would be described, by the revolution of a curve upon a given circle, while the outline of the teeth of the other wheel is described, by the same curve rolling within the circle. It may also be produced, if the teeth of one wheel be straight, circular, or of any regular figure, whatever ; provided the teeth of the other wheel be of a figure, compounded of that figure and of an epicycloid.*

Of two wheels, which are unequal in size, the larger is called the *wheel*, and the smaller, the *pinion*. The acting portions of the wheel are called *teeth ;* and, of the

* For investigations relating to the teeth of wheels, see Camus, on the Teeth of Wheels, translated, London, 8vo. 1806 ;—Buchanan, on Mill Work, chap. i. &c. ;—Brewster's Ferguson's Lectures, vol. ii. p. 119 ;—Gregory's Mechanics, vol. ii. p. 451 ;—also, a Treatise, by Mr. Blake, in Silliman's Journal, vol. vii. p. 86.

pinion, more commonly, *leaves*. The name of *lanterns* is given to pinions with two heads, connected by cylindrical teeth, or *trundles*. In Fig. 108, the line, joining

Fig. 108



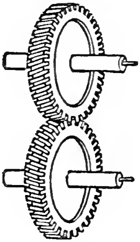
the centres, B and F, of the wheel and pinion, is called the *line of centres*, and, when this line is divided into two parts, FA and BA, which are to each other, as the number of leaves in the pinion is to the number of teeth in the wheel, BA is called the *primitive radius** of the wheel, and FA, the *primitive radius* of the pinion ; while the lines, or distances, Ff and Bb, are called the *true radii*. The circles, XAX and RAR, are called the *primitive circumferences*, and, by workmen, the *pitch lines*.

Friction, to a certain extent, cannot be avoided, in teeth of the common kind, whose acting faces are at right angles with the plane of the wheels, to which they belong. It may, however, be much diminished, by making the teeth as small and as numerous, as is consistent with their strength ; for the quantity of friction necessarily increases, with the distance of the point of contact from the line of centres.

* Called the *proportional radius*, by Buchanan

Spiral Gear.—In common cases, the teeth of wheels are cut across the circumference, in a direction parallel to the axis. In the spiral gear, now much used in cotton mills, in this country, the teeth are cut obliquely, so that, if continued, they would pass round the axis, like the threads of a screw. In consequence of this disposition, the teeth come in contact only in the line of centres, and thus operate without friction. [Fig. 109.] The action

Fig. 109.



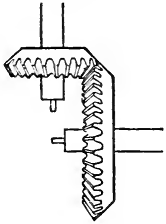
of these wheels, it is true, is compounded of two forces, one of which acts in the direction of the plane of the wheel, and the other in the direction of its axis. The latter force occasions a degree of friction, which, being expended at the end of the axle, may be regarded as inconsiderable. The remaining force goes to produce rotary motion.

The spiral gearing has been applied to clock-work, and has the peculiarity, that it admits of a smaller pinion than any other gearing. Thus, if a very small cylinder have a spiral groove so cut in it, as to extend once round its circumference, it will perform one revolution for every tooth of the wheel which drives it. The groove may be cut indefinitely near to the centre of the pinion, or cylinder, without weakening it so much as would happen in other forms of the pinion.*

* The spiral gear has been used at Waltham, Mass., and elsewhere, for about fifteen years, and is commonly considered, here, as the invention of Mr. White. Something analogous to it, under the name of *Inclined Plane Wheels*, was published in London, by Mr. T. Sheldrake, in 1811.

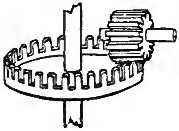
Bevel Gear.—When wheels are not situated in the same plane, but form an angle with each other, the spur gearing, already described, is changed for teeth of a different description. In this case, the *bevel gearing* is commonly employed, consisting of wheels, which are frusta of cones, having their teeth cut obliquely, and converging toward the point, where the apex of the cone would be situated. According as the relative magnitude of the wheels varies, the angle of the bevel must be different, so that the velocities of the wheels may be in the same proportion, at both ends of their oblique sides, or faces. For this purpose, the faces of all the teeth must be directed to the point, where the axes of the two wheels would meet. The bevel gearing is shown in Fig. 110, and Fig. 116.

Fig. 110.



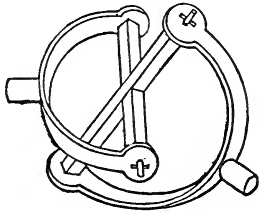
Crown Wheels.—Circular motion is also communicated, at right angles, by means of teeth or cogs, situated parallel to the axis of the wheel. Wheels, thus formed, are denominated *crown*, or *contrate*, wheels. They act either upon a common pinion, or upon a *lantern*. The crown-wheel is represented in Fig. 111. It is less in use than the bevel-gear, before described, having more friction

Fig. 111.



Universal Joint.—The contrivance called Hooke's universal joint, is sometimes used, instead of wheels, to communicate circular motion in an oblique direction. It consists of two shafts, or axes, each terminating in a semicircle, and connected together by means of a cross, upon which each semicircle is hinged. [Fig. 112.] It is

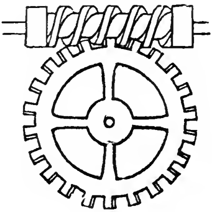
Fig. 112.



obvious, that when one shaft is turned, the other must revolve likewise; and this will be the case, whenever the angle, by which one shaft deviates from the direction of the other, does not exceed forty degrees. By means of a double universal joint, circular motion may be communicated, at an angle of from fifty to ninety degrees.

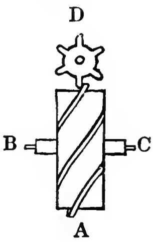
Perpetual Screw.—The perpetual, or endless, screw, sometimes called *worm*, by mechanics, is made use of to convey circular motion from an axle to a toothed wheel, situated in the direction of the same plane with the axle. The relative velocity of a wheel driven by a screw is very slow; for, if the screw have only a single thread, the wheel will advance the breadth of one tooth, only, for each

Fig. 113.



revolution of the screw. This mechanism is of great use in producing an equable slow motion, in machinery, and also, in increasing mechanical power. [Fig. 113.] The motion may be reversed, or conveyed from the wheel to the screw, if the obliquity of the threads be sufficiently increased. A spiral wheel and a toothed wheel may be made to turn, with equal velocity, or any desired proportion of velocity, by the construction represented in Fig. 114. A, is a wheel, seen edgeways, its axis being BC.

Fig. 114.

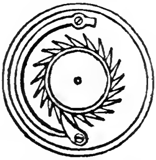


Its circumference is furnished with spiral ridges, which, as the wheel turns, cause the pinion, D, to revolve in the plane of the axis, BC.

Brush Wheels.—In light machinery, wheels sometimes turn each other by means of bristles, or brushes, fixed to their circumference. They may, also, communicate circular motion, by friction only. In this case, the surface brought in contact is formed of the end-grain of wood, or it is covered with leather, or some other elastic substance, and the two wheels are pressed together, to increase the friction.

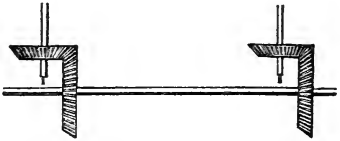
Ratchet Wheel.—The ratchet, or detent, wheel is intended to prevent motion in one direction, while it permits it in another. For this purpose, the teeth are cut with their faces inclining in one direction, and a small lever, or catch, is so placed, as to enter the indentations, and stop the wheel, if it turns backward, but slides over the teeth, without obstructing them, if it moves forward. [Fig. 115.] Ratchet-wheels are generally employed to prevent a weight, raised by a machine, from descending, and to obviate other retrograde movements.

Fig. 115.



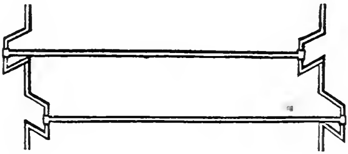
Distant Rotary Motion.—When it is required to transmit circular motion to a distance, for example, from one extremity, or story, of a building, to another, various methods are employed. The most common is, by band-wheels, or drums, connected by leather belts of the requisite length. This mode is considered most economical. When a precise velocity is required, a rolling shaft, geared at both ends, as in Fig. 116, is to be preferred. A double crank,

Fig. 116.



having its two parts at right angles with each other, and connected with a similar crank, by stiff rods, or bars, answers the same purpose. [Fig. 117.] If triple cranks are

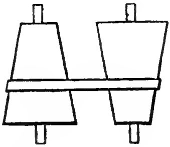
Fig. 117.



used, cords will serve, instead of bars, for connection, because, in this case, some part of the first crank will always be in a situation to draw the second, and a rigid medium will not be necessary.

Change of Velocity.—It is sometimes necessary, that a machine should be propelled with a velocity which is not equable, but which continually changes, in a given ratio. This happens in cotton-mills, where it is necessary that the speed of certain parts of the machinery should continually decrease, from the beginning to the end of an operation. To effect this object, two cones, or conical drums, are used, having their larger diameters in opposite directions. They are connected by a belt, which is so governed, by proper mechanism, that it is gradually moved from one extremity of the cones to the other, thus acting upon circles of different diameter, causing a continual change of velocity in the driven cone, with relation to that which drives it. [Fig. 118.]

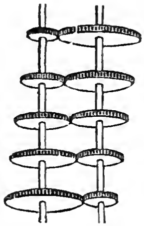
Fig. 118.



A change of speed is also effected, by a decreasing series of toothed wheels, placed, in the order of their size, upon a common axis, and fixed. A corresponding series, in an inverted order, are placed upon another axis, and not fixed, but capable of revolving about the axis, like loose pullies. The axis of this second series is made hollow, and contains a movable rod, which has a tooth, projecting through a longitudinal slit in one side of the axis. This tooth serves to lock any one of the wheels, by entering a notch, cut for its reception. Only one wheel, however, can be locked at a time, the others remaining loose, so that the axis will revolve with a velocity, which is due to the relative size of the particular wheel which is locked, and of the wheel which drives it. By successively locking the different wheels, an increase, or decrease, of speed is obtained.* [Fig. 119.]

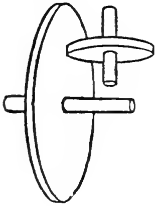
* A mechanism of this kind is used in the cotton factory at Newton, Massachusetts, and there is one, nearly similar, in Bramah's planing machine.

Fig. 119.



Another mode of changing speed is produced, by a large, and small, wheel, placed at right angles with each other, and acting by friction only. The edge of the smaller wheel is kept in close contact with the disc, or flat surface, of the larger wheel, so that the smaller wheel will revolve faster, or slower, according to the distance, at which it is kept from the centre of the larger wheel. The distance may be varied at pleasure [Fig. 120.]

Fig. 120.



It is sometimes requisite that a wheel, or axis, should move with different velocity, in different parts of a single revolution, as in orreries, &c. This may be effected, by an eccentric crown-wheel, acting on a long pinion as in

Fig. 121.

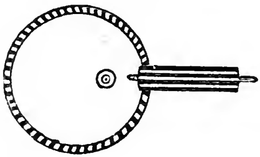
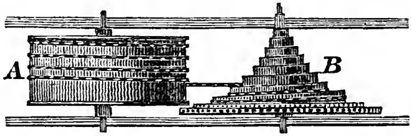


Fig. 121. It may also be accomplished in a different way, by a cone, furnished with spiral line of teeth, acting on another cone, the position of which is reversed.

Fusee.—In the preceding arrangements for changing velocity, there is a corresponding change of force, which is in an inverse ratio to the change of velocity. They may, therefore, be employed for varying force, as well as speed. The fusee of a common watch is a contrivance, adapted to this purpose. When a watch is recently wound up, the spring, which propels it, is in the state of greatest tension. As this spring relaxes, or uncoils itself, its power decreases, and, in order to correct this inequality, the chain, through which it acts, is wound upon a spiral fusee. The fusee, B, is an axis, surrounded by a spiral groove, the distance of the groove from the axis being made to increase gradually, from the top to the bottom, so that, in proportion as the force of the spring is diminished, it may act on a longer lever. The general outline of the fusee must be nearly such, that its thickness, at any part, may diminish, in the same proportion as it becomes more distant from the point, at which the force would cease altogether, the general curve being that of a hyperbole ; but the workmen have, in general, no other rule, than that of habitual estimation. [Fig. 122.]

Fig. 122.

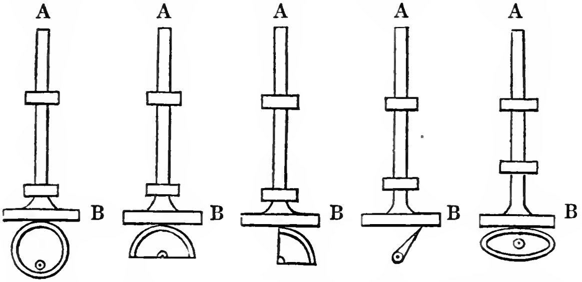


ALTERNATE, OR RECIPROCATING, MOTION.

This name is applied to movements which take place continually, backwards and forwards, in the same path. An alternate motion may take place about a centre, in which case, the moving parts will describe arcs of circles, as in a tilt-hammer, or the beam of a steam-engine ; or it may be confined by guides, so as to pursue a rectilinear path, as in the saw of a saw-mill. In most complex machines, both rotary and reciprocating motions occur, and these motions are converted into each other, by any of the following contrivances.

Cams.—If the axis of a wheel be situated in any other point than its centre, the wheel, thus rendered *eccentric*, may produce, by its revolution, an alternate motion in any part exposed to its action. Circles, hearts, ellipses, parts of circles, and projecting parts of various forms, are made to produce alternate motion, by continually altering the distance of some movable part of the machine, from the axis about which they revolve. Such projecting parts are called *cams*.* In the various forms which are shown in the figures, the part, removed by the cam, is supposed to return, by its own gravity, or by some other power, so as to keep up the alternate motion. In the circular eccentric cam, or wheel, [Fig. 123,] the sliding, or reciprocating, part, AB, will ascend and descend, with an easy motion, being never at rest, unless at the instant of changing its direction. Eccentric wheels, if surrounded by a hoop, as at H, in Pl. IX. perform the same office as cranks. In the semicircular cam, [Fig. 124,] the reciprocating part will remain at rest, on the periphery of the cam, during half the revolution, but, in the remaining half, it will approach the axis, and return. In the quadrant cam, [Fig. 125,] the reciprocating part will remain at rest, on the periphery, during the first quarter of the revolution;

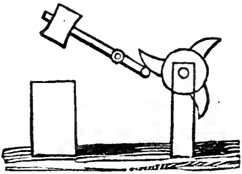
Fig. 123. Fig. 124. Fig. 125. Fig. 126 Fig. 127.



* This word is spelt *cam*, *camm*, and *camb*, by different writers. In French *came*.—*Borgnis*.

during the second, it will descend to the axis ; during the third, it will be at rest upon the axis ; and during the fourth, it will return to its original situation. The narrow cam, [Fig. 126,] causes the reciprocating part to rise and fall, in one half the revolution, and to remain at rest, on the axis, during the other half. In these figures, the angles of the cams are made sharp, for the sake of demonstration ; but, in practice, they are generally rounded, to produce more gradual changes of motion. The elliptical cam, [Fig. 127,] causes two alternate movements for each revolution ; and the triple cam, in Fig. 128, applied to a tilt, or trip,

Fig. 128.



hammer, causes three strokes for one revolution. In this case, the cams are called *wipers*, and it is common to accelerate the reciprocal motion, by adding to the action of gravitation, the elastic force of a spring, or by the recoil of the handle from a fixed obstacle. A cam, in the form of a heart, called a *heart-wheel*, is much used in cotton-mills, to cause a regular ascent and descent of the rail on which the spindles are situated.*

When an easy motion is desired, as in most large machinery, the acting outline of the cam should be curved . but, to produce a sudden stroke, it should be straight The number of cams may be indefinitely multiplied, if a rapid, or vibrating movement, is required. This is, in effect, done, when the teeth of a wheel act upon a spring, or weight, as in a watchman's rattle, or in the feeder of a grist-mill.

* For an investigation of the curves proper for different cams and wipers, see Brewster's edition of Ferguson's Mechanics, vol. ii. p. 126, &c. For producing an easy and uniform motion, spiral, epicycloidal, and other curves, are requisite ; but, for abrupt, forcible, motions, such as occur in tilt-hammers, curves of equal action are to be avoided.

Crank.—The common crank affords one of the simplest and most useful methods, for changing circular into alternate motion, and *vice versa*. The single crank, [Fig. 129,] can only be used upon the end of an axis. The bell-crank, [Fig. 130,] may be used in any part of an axis. The double crank, [Fig. 131,] produces two alternate

Fig. 129.

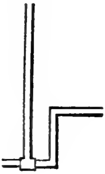


Fig. 130.

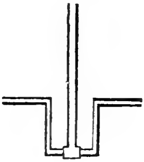
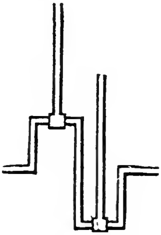


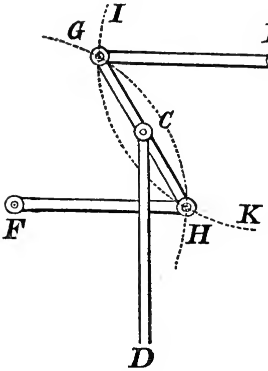
Fig. 131.



motions, reciprocating with each other. The alternating parts, in all these cases, are attached to the crank by connecting rods, or by some of the kinds of mechanism, hereafter described. The motion, produced by cranks, is easy and gradual, being most rapid, in the middle of the stroke, and gradually retarded, toward the extremes ; so that shocks and jolts, in the moving machinery, are diminished, or wholly prevented, by their use.

Parallel Motion.—The name of parallel motions is given to those arrangements, which convert circular motion, whether continued or alternate, into alternate rectilinear motion, and *vice versa*. Thus, the beam of a steam-engine moves in circular arcs, while the piston moves in right lines. They cannot, therefore, be rigidly connected together, without doing violence to the machine ; and it becomes necessary to convert one movement into the other, by the intervention of proper mechanism. A movable parallelogram is principally used, for this purpose, and will be described under the head of *Steam Engine*. A similar contrivance, of a more simple form, is shown in Fig. 132. CD, is a rod, moving back and forwards, in a right line. Every point of junction is a hinge, or joint.

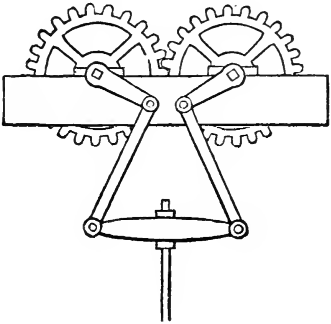
Fig. 132.



GE, is a rod, movable about E, as a centre ; and FH, a rod of the same length, movable about F, as a centre ; these centres being equally distant from the path of CD. GH, is a bar, connecting these two rods, and having the rod, CD, attached, by a joint, to its centre. When the whole is set in motion, the joint, G, will describe the circular arc, IK, and the joint, H, will describe the circular arc, GH, while the joint, C, will pursue an intermediate, or rectilinear, course.

Various other methods are practised, to insure a rectilinear motion, though most of them are attended with great

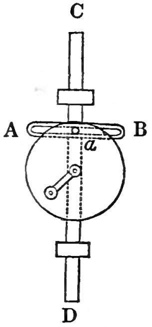
Fig. 133.



er friction than that last described. Thus, the alternating part is often confined to a rectilinear path, by sliding in grooves, guides, or holes, or between friction wheels; a connecting rod uniting the straight and circular motions, as in the last instance. In Cartwright's steam-engine, the straight movement of the piston is secured, by connecting it with two cranks, acting in opposition to each other, and having their axles geared together by wheels, as represented in Fig. 133, on page 66.

The connecting rod may be dispensed with, if a transverse groove, or slit, be cut in the alternating part, of a length equal to the diameter of the crank's revolution; as in Fig. 134. The end of the crank, seen at [*a*,] in its

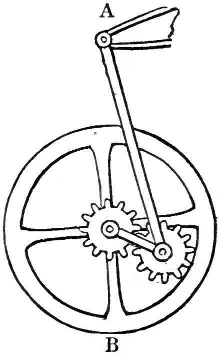
Fig. 134.



revolution, traverses the whole length of this groove, which is cut in the crossbar, AB, while the main bar, CD, has an alternate motion in the straight path to which it is confined. As the space of ascent, or descent, of the bar, CD, is always equal to the versed sine of the arc described by the crank, the motion of the bar will be accelerated, towards the middle of its oscillations, and retarded, towards the extremes. A more equal motion can be produced, if desired, by substituting for the straight groove, a curvilinear groove, somewhat like the figure ∞; but this method is attended with much friction, and little use.

Sun and Planet Wheel.—The mechanism which bears this name, was invented by Mr. Watt, to convert reciprocating into circular motion, in the steam-engine, the use of the crank, for this purpose, being, at one time, secured by patent to another individual. In Fig. 135, a

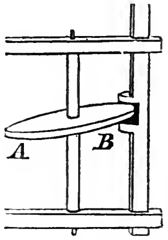
Fig. 135.



view is given of the sun and planet wheel. A, is the end of a beam, having a reciprocating motion. B, is the fly-wheel of the engine, to which a rotary motion is to be communicated. Upon the axis of this fly-wheel, a small toothed wheel is firmly fixed. A second toothed wheel is connected to the first, by a loose crank, so as to be capable of revolving freely about it. This second wheel is firmly fixed upon the end of a connecting rod, which is attached, by a joint, to the beam of the engine. The two wheels being in gear, it is obvious, that as the beam, A, rises and falls, the second wheel, with the assistance of the fly, will revolve quite round the first; and, if the number of teeth be equal, the first, or sun-wheel, must perform two rotations on its axis, while the second, or planet-wheel, revolves once round it.

The necessity of this will be more obvious, when we consider, that, if one tooth of the planet-wheel, were connected by a joint to one tooth of the sun-wheel, it would act as a simple crank, and cause one revolution. But an additional revolution is also necessary, because, during the circuit, all the teeth of the planet-wheel must act upon those of the sun-wheel, thus turning it round, as in common wheel-work.

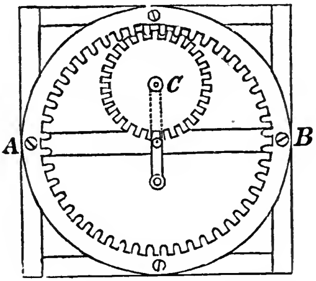
Fig. 136.



Inclined Wheel.—In Fig. 136, AB, is a wheel, placed obliquely on its axis, CD. The edge, or periphery, of this wheel, is received in a notch, at B, of a sliding bar, EF. As the wheel revolves, the bar, EF, will move up and down once, during each revolution. This reciprocal motion may be indefinitely varied, by bending the edge of the wheel into different curves and angles.

Epicycloidal Wheel.—A very beautiful method of converting circular into alternate motion, or alternate into circular, is shown in Fig 137. AB is a fixed ring, or wheel,

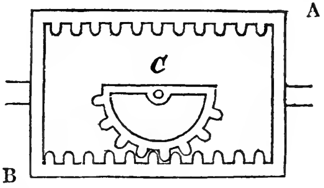
Fig. 137.



toothed on its inner side. C, is a toothed wheel, of half the diameter of the ring, revolving about the centre of the ring. While this revolution of the wheel, C, is taking place, any point, whatever, on its circumference, will describe a straight line, or will pass and repass through a diameter of the circle, once, during each revolution. This is an elegant application of the law, that, if a circle rolls on the inside of another of twice its diameter, the epicycloid described is a straight line. In practice, a piston, rod, or other reciprocating part, may be attached to any point on the circumference of the wheel, C.

Rack and Segment.—If an alternating motion is required, the velocity of which shall be always equal, a rack is best adapted to produce this effect. In Fig. 138, AB

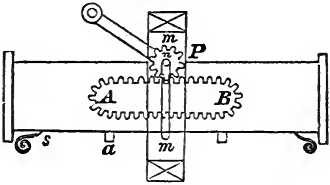
Fig. 138.



is a parallelogram, having a rack on two opposite sides. C, is a half wheel, toothed on its curved side, and having its centre equally distant from the two racks. It is obvious, from inspection, that, as this half wheel revolves, its teeth will act successively upon the two racks, and cause the parallelogram to move back and forwards, with a uniform motion. The change, however, from one direction to the other, will be nearly instantaneous, so that this plan will only answer in machinery which is very light, or of slow motion. The teeth of the half wheel must cover somewhat less than half a circle, that they may not become engaged in one rack, before they are disengaged from the other.

Rack and Pinion.—Another contrivance, which renders the change more gradual, is represented in Fig. 139. AB, is a double rack, with circular ends, fixed to a beam, capable of moving in the direction of its length. The rack is driven by a pinion, P, which is capable of moving up and down in a groove, [*mn*,] cut in the cross-piece. When the pinion has moved the rack and beam, until it comes to

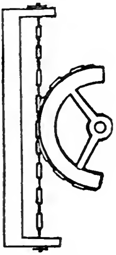
Fig. 139.



the end, B, the projecting piece [*a*] meets the spring, [*s*,] and the rack is pressed against the pinion. The pinion, then working in the circular end of the rack, will be forced down the groove, [*mn*,] until it works in the lower side of the rack, and moves the beam back in the opposite direction; and, in this way, the motion is continued. The motion of the pinion in the groove will be diminished, if, instead of a double rack, we use a single row of pins, which are parallel to the axis of the pinion, as in some of the machines, called *mangles*.

Belt and Segment.—An alternate circular motion is converted into an alternate rectilinear motion, in fire-engines, dressing-machines, &c., by a belt, or chain, fastened to each end of a segment, or other portion of a wheel. The two belts pass by each other, and are attached to the opposite ends of an alternating part. When the segment turns, in either direction, it draws after it the alternating part, in a straight line. [Fig. 140.]

Fig. 140.



Scapements.—In clocks and watches, an alternating motion is produced in the pendulum and balance-wheel, by means of the mechanism called a *scapement*. In the more simple scapements, two teeth, called *pallets*, are made to vibrate on a common axis. They are connected with a toothed wheel, in such a manner, that one pallet enters between the teeth of the wheel, whenever the other is thrown out of their reach. As the wheel revolves, its teeth successively impinge against one or the other of these pallets, and, by causing them successively to escape, communicate to their axis a vibrating, or alternate, motion. The *crutch* scapement, [Fig. 141,] is an arch, situated in the same plane with the scape-wheel, and parallel to the plane in which the pendulum vibrates. Its pallets successively enter and escape from the teeth of the wheel, and receive from it a vibrating motion. In the old, or common, *watch* scapement, [Fig. 142,] a contrate, or crown, wheel is used as the scape-wheel, and the pallets [*a* and *b*] are placed upon the axis of the balance-wheel, so as to meet the teeth, successively, on opposite sides of the circumference of the scape-wheel. A variety of other more complicated forms of the scapement are also in use.

Fig. 141.

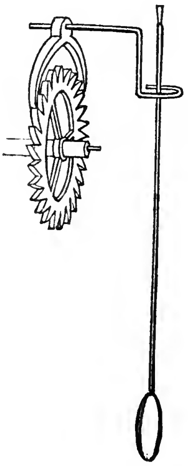
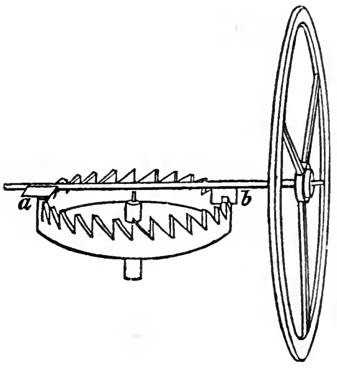


Fig. 142.



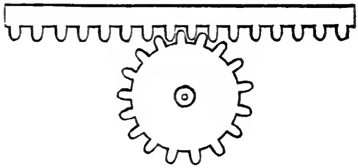
CONTINUED RECTILINEAR MOTION.

A long-continued rectilinear motion is not to be produced in the parts of a machine, except so far as it partakes of the nature of a rotary, or a reciprocating, motion. Thus, a band, passing round pullies, is a modification of rotary motion, and a rack, which is obliged to return at intervals, has a reciprocating motion. But, to a certain extent, the motions of both may be regarded as continuously rectilinear.

Band.—If it is required to produce motion, in a right line, which shall be always in one direction, as, for example, in the feeding parts of machines, a band, passing round pullies or drums, is the method most commonly practised, as in Fig. 105. If a precise velocity is required, the band may be perforated with holes, and received upon short pins, at the circumference of the wheels; or the rag-wheel and chain, represented in Fig. 107, may be substituted.

Rack.—If a slow rectilinear motion is required only for limited times, such a mechanism may be used, as will permit the moving part to retrace its own path, at intervals, and regain its original situation. [Fig. 143.] A

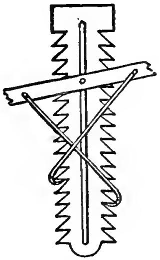
Fig. 143.



rack, which is a straight bar, having teeth on one side, will move in this manner, if it be acted on by a toothed wheel, or by a perpetual screw. If the thread of a perpetual screw be formed of different obliquity, in different parts of its circumference, the progressive velocity of the rack will be unequal, instead of being uniform. And, if a part of the thread be in a plane, at right angles with the axis of the screw, the rack will be at rest, while that part of the screw revolves in contact with it.

Universal Lever.—A rack is also propelled, by means of a catch, or dog, connected with some part of the machine, which has an alternating motion. The catch causes the rack to advance, the length of one tooth, at each stroke of the alternating part. The universal lever, sometimes called the lever of La Garousse, consists of a bar moving upon a centre, and having a movable catch, or hook, attached to each side, and acting upon the oblique teeth of a double rack, or of a ratchet-wheel, so that the alternating motion of the bar causes a progressive motion of the rack, or wheel. [Fig. 144.]

Fig. 144.

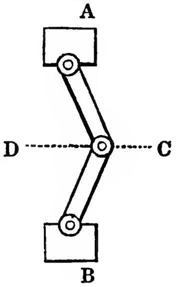


Screw.—A common screw is often made use of, to produce rectilinear movements, when the motion is intended to be very slow, or when great power is required.

Change of Direction.—A change, from one path, or direction, to another, forming an angle with it, may be produced, by several of the mechanical powers. Thus, a cord, passing over a pulley, may change a perpendicular to a horizontal motion, as at P, [Fig. 159,] or to one at any other angle required. A bent lever, like that represented by *y z*, in Pl. III., produces the same effect, provided the moving parts are confined, by guides, to their respective paths. An inclined plane, also, if it moves through the length of one side of a parallelogram, will cause another body to move through the length of the contiguous side, at right angles. This method, however, is attended with much friction.

Toggle Joint.—The *knee-joint*, commonly called, in this country, *toggle-joint*, affords a very useful mode of converting velocity into power, the motion produced being nearly at right angles with the direction of the force. Its operation is seen in the iron joints which are used, to uphold the tops of chaises. It is also introduced into various modifications of the printing press, in order to obtain the greatest power, at the moment of the impression. It consists of two rods, or bars, connected by a joint, and increases rapidly in power, as the two rods approach to the direction of a straight line.* In Fig. 145, a moving force, applied in the direction CD, acts with great and constantly increasing power, to separate the parts, A and B.

Fig. 145.



OF ENGAGING AND DISENGAGING MACHINERY.

In many cases, particularly where numerous machines are propelled by a common power, it is important to possess the means of stopping any one of them, at pleasure, and of restoring its motion, without interfering with the rest. To produce this effect, a great variety of combinations have been invented, under the name of *couplings*. These, in most instances, are sliding boxes, which move longitudinally upon shafts or axles, and serve to engage, or lock, a shaft which is at rest, with one which is in motion; so as practically to convert the two into one, until

* An investigation of the power of this combination, is given by the late Professor Fisher, in Silliman's Journal, vol. iii. p. 320.

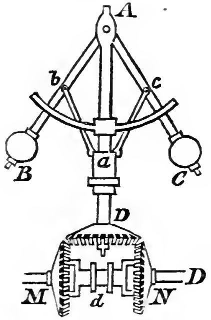
they are again unlocked. Couplings are sometimes provided with *clutches*, or *glands*, which are projecting teeth, intended to catch on other teeth, or levers, and thus lock the shafts together. Sometimes they have *bayonets*, or pins, adapted to enter holes. Sometimes, the connexion is produced by friction alone, by pressing together surfaces, which are either *flat*, or conical. Sometimes, also, wheels are thrown *into*, and *out of*, *gear*, which is done, by causing wheels to slide in the direction of their axles, or, in some cases, by elevating and depressing the axle itself. These methods, however, are difficult and unsafe. The *live* and *dead pulley* afford, perhaps, the simplest mode of engagement. They consist of two parallel band-wheels, on the same axle, one of which is fast, and the other loose, or capable of turning without the axle. The band, which communicates the power, is placed upon the loose pulley, when it is desired to stop the machine, and upon the fast pulley, when it is intended to set the machine in motion. A common band may, also, be made to admit of motion or rest, according as it is rendered tense, or loose, by a *tightening wheel*, pressed against its side by a lever.

OF EQUALIZING MOTION.

In most machines, both the moving force, and the resistance to be overcome, are liable to fluctuations of intensity, at different times. As such variations influence both the safety and efficiency of machines, it is necessary to provide against them, by some appendage, which shall equalize either the supply, or the distribution, of the power.

Governor.—The name of *governor* has been given to an ingenious piece of mechanism, which has been introduced, to regulate the supply of steam, in steam-engines, and of water, in water-mills, so as to render the power equable, and proportionate to the resistance to be surmounted. It is represented in Fig. 146, on the opposite page. AB, and AC, are two levers, or arms, loaded with heavy balls, at their extremities, B and C, and suspended, by a joint, at A, upon the upper extremity of a revolv-

Fig. 146.



ing shaft, AD. At [*a*,] is a collar, or sliding box, connected to the levers, by the rods [*ab*, and *ac*,] with joints at their extremities. It follows, that when the weights, B and C, diverge, the collar [*a*] will move upward, on the shaft, AD, and *vice versa*. The governor, thus constructed, is attached to some revolving part of the machine. In this state, if it turns too rapidly, the balls, B and C, move outwards, by their centrifugal force, and draw upward the collar, [*a*.] If, on the other hand, the speed diminishes, the balls are allowed to subside, and the collar moves down upon the shaft. In the steam-engine, the collar has a circular groove, which receives the end of a forked lever. As the collar rises and falls, this lever turns upon its fulcrum, and acts, remotely, to open or close a throttle-valve, which is placed in the main steam-pipe.* Whenever, therefore, the machine moves too rapidly, the balls recede from the centre, the collar rises, the lever moves the valve, and, by partially closing the pipe, diminishes the quantity of steam admitted from the boiler. If the machine moves too slowly, the reverse takes place, and a larger amount of steam is admitted.

In water-wheels, where a greater power is necessary to control the supply of water, the governor is usually connected to the sluice-gate, by the intervention of wheel-work. This may be done in several ways, one of which

* For a further account of the governor, see the article, *Steam Engine.*

is as follows. The lower part of the shaft, AD, carries a wheel at D, acting upon two others beneath it, M and N. While the machinery moves with its proper speed, the wheels, M and N, are both unlocked, and turn loosely round their axles, and the gate is stationary. But, when the velocity increases or diminishes, the collar [*a*] rises or falls, and, by means of a cam, acts upon a lever above it, or upon another below it, so as to lock one of the wheels, M or N, by moving a clutch situated at [*d*.] These wheels, being upon a common axle, are capable of turning this axle different ways. When, therefore, one wheel is locked to the axle, it acts by turning a perpetual screw, to open the sluice gate. When the other is locked, the axle and the screw turn in the opposite direction, and partially close the gate.

The foregoing are some, out of various, modes in which the governor is applied. In windmills, it is so adapted as to increase the feeding, or supply of corn, when the mill goes too fast, and also to vary the distance of the mill-stones from each other, if necessary. It has also been applied to clothe and unclothe the sails, in proportion to the strength of the wind.

Fly Wheel.—It is an object of great importance, in machines, to have the means of accumulating power, when the moving force is in excess, and of expending it, when the moving force operates more feebly, or the resistance increases. This equalization of motion is obtained, by what is called a *fly*, which is generally made in the form of a heavy wheel, though, sometimes, in the form of arms, or crossbars, with weights at their extremities. A fly being made to revolve about its axis, keeps up the force, by its own inertia, and distributes it, in all parts of its revolution. If the moving power slackens, it impels the machine forward; and if the power tends to move the machine too fast, it keeps it back.

Fly-wheels are capable of accumulating power to a great extent. A small force, continually applied to the surface of a heavy revolving wheel, will accelerate its velocity, till it shall be equal to that of a musket-ball, and its momentum almost irresistible. Fly-wheels, to act with the greatest efficacy, should be made with the least possible surface, that their motion may not be impeded, by the resistance of the air. They should be made of iron, and, if they cannot be cast in one piece, they should be firmly hooped, or bolted together, that the parts may not separate, by their centrifugal force. Fatal accidents have occurred from the bursting of large stones, used as flies, or as grindstones, in cutlery works, their velocity, and centrifugal force being so great, as to overcome their cohesive attraction, and to project the parts to a distance, with great violence.

Beside the modes already described, other methods are employed, to retard and equalize the velocity of machinery. A kind of fly is used, in music boxes, and in the striking part of clocks, in which the broad surface of vanes, upon the circumference of a wheel, is made to act against the air, until the resistance becomes equal to the propelling force, so that the velocity can increase no further, but becomes uniform. Pendulums and balances, acted on through the different kinds of scapements, are also means of equalizing motion.

FRICTION.

A part of the force, by which machines are moved, is expended in overcoming their friction. Hence it is desirable to obviate, as far as possible, this kind of resistance. Friction is supposed to arise, chiefly, from the roughness and inequality of the surfaces of bodies. No polish can be given to a surface, mechanically, so fine, as to render it perfectly smooth. When surfaces move over each other, a certain force is necessary to disengage the minute asperities of one surface from those of the other, either by causing them to rise over each other, or by bending or breaking them down.

Friction is increased, by the roughness of bodies, and, also, by the force with which they are pressed together. But it is very little affected by the extent of the surfaces in contact. It is greatest, at the moment when motion begins. It does not, however, change afterwards as the velocity changes, but continues to retard, with a uniform force, whether the motion performed be slow, or rapid. There are several points, in regard to friction, upon which writers are not agreed.

Friction in machinery is to be diminished, by making the surfaces, which rub upon each other, as smooth as possible, and by covering them w th some unctuous substance. Black lead, in fine powder, is sometimes interposed between surfaces, to diminish friction, and soapstone, applied in the same manner, is still more useful. It is supposed, by some, that different metals, moving upon each other, occasion less friction, than surfaces of the same metal. But the most important mode of diminishing friction is, to employ a rolling or turning motion, instead of a sliding motion, in all cases where it is practicable ; and, by simplicity of construction, to avoid all unnecessary contact of moving surfaces.

Remarks.—In the construction of machines, no subject is more deserving of attention, than simplicity of parts and structure. The more complex machines are, the more expensive they are to erect, the more liable to get out of order, and the more difficult to repair. An increased expenditure of power is also occasioned, by their friction. A complex machine may evince great ingenuity on the part of the inventor, and may have cost much labor and science to complete it. Yet it is sure to be superseded. the moment that a more simple, cheap, or expeditious way of attaining the same object is discovered. The im provement of the mechanist, or engineer, more frequent ly consists in the simplification of his means, than it does in the construction of complex and difficult pieces of work manship.

WORKS OF REFERENCE.—BUCHANAN, on Mill Work, and other Machinery, 2 vols. 8vo. 1823 ;—ROBISON's Mechanical Philosophy, vol. ii. p. 181 ;—NICHOLSON's Operative Mechanic, 8vo. 1825 ;—GREGORY's Mechanics, 1826 ;—BREWSTER's edition of Ferguson's Mechanics, 1823 ,—BORGNIS, *Mechanique Appliquee aux Arts*, 4to Paris, 1818, *Tom.* 3, *Composition des Machines* ;—LANZ et BETTANCOURT, *sur la Composition des Machines*, Paris, 4to. 1819 ;—HACHETTE, *Traité Elementaire des Machines* ;—LEUPOLD, *Theatrum Machinarum Universale*, 7 vols. folio, Leipsic, 1724 to 1774

CHAPTER XVI.

OF THE MOVING FORCES USED IN THE ARTS.

Sources of Power, Vehicles of Power. *Animal Power*, Men, Horses. *Water Power*, Overshot Wheel, Chain Wheel, Undershot Wheel, Back Water, Besant's Wheel, Lambert's Wheel, Breast Wheel, Horizontal Wheel, Barker's Mill. *Wind Power*, Vertical Windmill, Adjustment of Sails, Horizontal Windmill. *Steam Power*, Steam, Applications of Steam, By Condensation, By Generation, By Expansion, The Steam Engine, Boiler, Appendages, Engine, Non-condensing Engine, Condensing Engines, Description, Expansion Engines, Condenser, Valves, Pistons, Parallel Motion, Locomotive Engine, Power of the Steam Engine, Projected Improvements, Rotative Engines, Use of Steam at High Temperatures, Use of Vapors of Low Temperature, Gas Engines, Steam Carriages, Steam Gun. *Gunpowder*, Manufacture, Detonation, Force, Properties of a Gun, Blasting, Magnetic Engines.

Sources of Power.—It is the office of machines, to receive and distribute motion, derived from an external agent, since no machine is capable of generating motion, or moving power, within itself. The sources from which the moving power, applied to machinery, is obtained, are various, according to the nature of the object, and the amount of force, which is required. Men and animals, water, wind, steam, and gunpowder, are the principal agents, employed as first movers in the arts. Their power may be ultimately resolved into those of muscular energy, gravity, heat, and chemical affinity. But, although these are the sources of all the important force, which is artificially employed, in moving large masses of matter, yet, certain other agents are also capable of producing motion, upon a more limited scale; such as magnetism, electricity, capillary attraction, &c.

Vehicles of Power.—Besides the original forces which have been mentioned, there are certain intermediate agents, which serve to accumulate and transmit power, after the first mover has ceased to operate. These agents commonly act, either by their elasticity, their gravity, or their inertia. Springs, and compressed air, are examples of vehicles, acting by their elasticity, and their usefulness continues, only, till they have recovered the situation from which they were disturbed by another force. In like manner, a weight, acting by its gravity on an axle, or wheel, prolongs, for a season, the influence of the power, by which it was wound up. Fly-wheels are also vehicles which serve, by their inertia, to continue the action of a force while it intermits. Vehicles of power are highly useful, in equalizing the irregularities which are incident to prime movers, in prolonging their action through convenient periods of time, and in multiplying the modes of their application.

A fundamental distinction among mechanical agents, both original and secondary, consists in this; that, in some, the intensity of their action, or the acceleration they produce in a given time, is the same, whether the body acted upon be at rest, or in motion; in others, it is greatest, when the body acted on is at rest, and becomes less, as its velocity increases. Gravity is the only force, which is certainly known to act, with equal intensity, on bodies in motion, and at rest; though magnetism, probably, possesses the same property. Every other important power acts more forcibly on a body at rest, than on one which has already acquired motion, in the direction in which it acts.* This happens with the strength of animals, the impulse of fluids, and the elasticity of springs.

ANIMAL POWER.

Muscular energy is exerted through the contraction of the fibres which constitute animal muscles. The bones act as levers, to facilitate and direct the application of this force, the muscles operating on them, through the medium of tendons, or otherwise. Muscular power is much greater in some animals, than it is in man, owing to their size, or more active mode of life. It is greatest in beasts of prey.

Men.—The power of a man to produce motion, in weights or obstacles, varies, according to the mode in which he applies his force, and the number of muscles

* See Playfair's Outlines of Natural Philosophy, vol. i. p. 107.

which are brought into action. In the operation of turning a crank, a man's power changes, in every part of the circle which the handle describes. It is greatest, when he pulls the handle upward, from the height of his knees; next greatest, when he pushes it down, on the opposite side; though, here, the power cannot exceed the weight of his body, and is, therefore, less than can be exerted, in pulling upward. The weakest points, are at the top and bottom of the circle, where the handle is pushed, or drawn, horizontally.

If a windlass be provided with two cranks, placed at right angles with each other, two men will perform much more work, than they could, if the cranks were disconnected; because, at the moment one puts forth his strength to the least advantage, the other is exerting his with the greatest effect.

The mode in which a man can exert the greatest active strength, is in pulling upward from his feet; because the strong muscles of the back, as well as those of the upper and lower extremities, are then brought advantageously into action, and the bones are favorably situated, by the fulcra of the levers being near to the resistance. Hence, the action of rowing is one of the most advantageous modes of muscular exertion; and no method which has been devised for propelling boats, by the labor of men, has hitherto superseded it.

According to Mr. Buchanan, the comparative effect produced, by different modes of applying the force of a man, is nearly as follows. In the action of turning a crank, his force may be represented by the number seventeen. In working at a pump, by twenty-nine. In pulling downward, as in the action of ringing a bell, by thirty-nine. And in pulling upward from the feet, as in rowing, by forty-one.*

In estimating the different applications of animal force, we must take into consideration, not only the resistance they can overcome, but the velocity with which they move, and the length of time, for which they can be con-

* See Brewster's edition of Ferguson's Mechanics, vol. ii. p. 9 The whole numbers are 1742, 2856, 3883, and 4095.

tinued. Violent efforts are not true specimens of a man's labor, since they can be exerted for a short time only. A moderate computation of an ordinary man's uniform strength is, *that he can raise a weight of ten pounds, to the height of ten feet, once in a second, and continue this labor, for ten hours in the day.** This is supposing him to use his force, under common mechanical advantages, and without any deduction for friction.

Horses.—Horses are often employed as movers of machinery, by their draught. A horse draws with greatest advantage, when the line of draught is not horizontal, but inclines upward, making a small angle with the horizontal plane, as already stated, page 18. The force of a horse diminishes, as his speed increases. The following proportions are given by Professor Leslie, for the force of the horse, employed under different velocities. If his force, when moving at the rate of two miles per hour, is represented by the number one hundred, his force, at three miles per hour, will be eighty-one; at four miles per hour, sixty-four; at five miles, forty-nine; and, at six miles, thirty-six. These results are confirmed, very nearly, by the observations of Mr. Wood.† In this way, the force of a horse continues to diminish, till he attains his greatest speed, when he can barely carry his own weight.

Various estimates have been made of a horse's power, by Desaguliers, Smeaton, and others; but the estimate, now generally adopted, as a standard for measuring the power of steam-engines, is that of Mr. Watt, whose computation is about the average of those given by the other writers. The measure of a horse's power, according to Mr. Watt, is, *that he can raise a weight of thirty-three thousand pounds, to the height of one foot, in a minute.*

In comparing the strength of horses, with that of men, Desaguliers and Smeaton consider *the force of one horse* [to] *be equal to that of five men*; but writers differ on this subject.

* Young's Lectures on Natural Philosophy, vol. i. p. 131

† Treatise on Rail Roads, p. 239.

When a horse draws in a mill, or engine of any kind, he is commonly made to move in a circle, drawing after him the end of a lever, which projects, like a radius, from a vertical shaft. Care should be taken that the horse-walk, or circle, in which he moves, be large enough in diameter; for, since the horse is continually obliged to move in an oblique direction, and to advance sideways, as well as forward, his labor becomes more fatiguing, in proportion as the circle, in which he moves, becomes smaller.

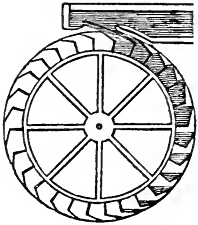
In some ferry-boats and machines, horses are placed on a revolving platform, which passes backward, under the feet, whenever the horse exerts his strength, in drawing against a fixed resistance; so that the horse propels the machinery, without moving from his place. A horse may act within still narrower limits, if he is made to stand on the circumference of a large vertical wheel, or upon a bridge, supported by endless chains, which pass round two drums, and are otherwise supported by friction wheels. Various other methods have been practised, for applying the force of animals; but most of them are attended with great loss of power, either from friction, or from the unfavorable position of the animal.

WATER-POWER.

Water and wind, considered as prime movers, are applications of the force of gravity; since, without gravity, there would be neither wind, nor currents of water. The force of water is, generally, applied to the circumference of wheels, which it causes to revolve, either by its weight, by its lateral impulse, or by both, conjointly. Water-wheels are generally used in one of three forms. These are, the *overshot-wheel*, in which the water descends from the top of the wheel to the bottom; the *breast-wheel*, in which it is received at about half the height of the wheel; and the *undershot-wheel*, where it acts by the impulse of a current, flowing under the wheel. The overshot wheel is the most powerful kind, and is always to be employed, where a sufficient fall of water can be obtained.

Overshot Wheel.—This is a wheel, or drum, the circumference of which is occupied by a series of cavities, commonly called buckets, into which the water is delivered from one, or more, spouts, at the top of the wheel. By inspecting Fig. 147, it will be seen, that the buckets

Fig. 147.



on one side of the wheel are erect, and will, consequently, become loaded with water ; while those on the other side are inverted, and, of course, empty. It follows, that the loaded side will always preponderate, and, by descending, will cause the wheel to revolve.

If it were possible, says Dr. Robison,* to construct the buckets in such a manner, as to remain completely filled with water, till they came to the bottom of the wheel, the pressure, with which the water urges the wheel round its axis, would be the same, as if the extremity of the horizontal radius were continually loaded with a quantity of water, sufficient to fill a square pipe, whose section is equal to that of the bucket, and whose length is the diameter of the wheel. But such a state of things is impossible ; and, if a bucket be full, while at top, it will begin to lose water, as soon as it turns into an oblique position, and must continue to do so, till it reaches the bottom.

The attention of engineers has been directed to giving the buckets such a form, as will enable them to retain the water, for the longest time, on the circumference of the wheel. The form represented in Fig. 148, on page 87, answers this purpose tolerably well, and, from its simplicity, is the one most commonly used ; but it may be improved still further, by giving an additional inclination,

* Mechanical Philosophy, vol. ii. p. 592.

Fig. 148.

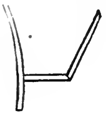
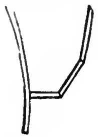


Fig. 149.



.nward, to the outer edge of the bucket, as seen in Fig. 149. As the best economy of the water-power requires that the buckets should not be completely filled, the form, here represented, will retain the water, until it has descended low on the wheel. To promote this object still further, Mr. Burns has divided the bucket by a partition, which is parallel to the rim of the wheel, constituting one bucket within another. In this mode of construction, the water does not enter with the same facility, but is longer in escaping.*

In order to prevent the inertia of the water, when it is first laid upon the buckets, from impeding the motion of the wheel, it is desirable that the water, when it enters, should have a velocity corresponding, as nearly as possible, to that with which the wheel is revolving. And, as we cannot give to the water, the direction of a tangent to the wheel, the velocity, with which it is delivered on the wheel, must be so much greater than the intended velocity of the rim, that it shall be equal to it, when it is estimated in the direction of a tangent. To facilitate, as much as possible, the entrance of the water, it is common to deliver the water through an aperture, which is divided by thin plates of board, or metal, placed in an oblique position, so as to direct the stream of water into the buckets, in the most perfect manner, as represented in Fig. 152, on page 93. In order to detain the water, as long as possible, the lower part of the wheel is often made to revolve in a concave cavity, just large enough to receive it, and called, in this country, the *apron*, as seen in Fig. 155, on page 95.

A difficulty often occurs, in the entrance of water into

* We are informed by Dr. Brewster, that Burns's improvement has not been introduced by him into practice, owing to the difficulty of filling the inner buckets.—*Mechanics*, vol. i. p. 49.

the buckets, by the resistance of the air, already in the bucket, which causes the water to regurgitate, and spill. This evil may be entirely prevented, by making the spout considerably narrower than the wheel, so as to leave room for the escape of the air, at the two ends of the bucket.

The pressure of the atmosphere occasions, sometimes, a serious obstruction to the motion of overshot-wheels, by causing a quantity of back-water to be lifted, or sucked up, by the ascending inverted bucket, when it first leaves the water. This difficulty is remedied, by making a few small holes, near the base of the bucket, and communicating with the next bucket. Through these, the air will enter, and prevent the suction. It is true, that, when on the descending side, these holes will allow the escape of some water ; but, as this water only flows from one bucket to the next, its effect is inconsiderable, when compared with the advantage gained. Air, as Professor Robison observes, will escape through a hole, about thirty times faster than water, under the same pressure.

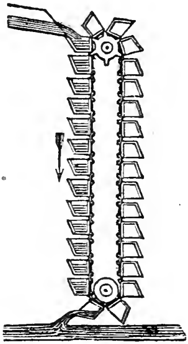
With respect to variations in the fall, the same writer remarks, that, since the active pressure is measured by the pillar of water, reaching from the horizontal plane, where it is delivered on the wheel, to the horizontal plane, where it is spilled by the wheel, it is evident, that it must be proportionate to this pillar ; and, therefore, we must deliver it as high, and retain it as long, as possible. This maxim obliges us to use a wheel, whose diameter is equal to the whole fall. We shall not gain anything by employing a larger wheel ; for, although we should gain by using only that part of the circumference, where the weight will act more perpendicularly to the radius, we shall lose more, by the necessity of discharging the water, at a greater height from the bottom.*

Chain Wheel.—When there is a very small supply of

* Mechanical Philosophy, vol. ii. p. 600.

On this subject, Dr. Brewster remarks, that, if we employ a wheel, the diameter of which is higher than the fall, we may take advantage of any casual rise of the water, above its usual level, and, by a particular form of the delivering sluice, introduce the water, higher upon the wheel, and thus actually increase the height of the fall water, falling from a very great head, the double overshot-wheel, with a chain of buckets, is a valuable machine. This wheel is represented in Fig. 150, where two rag-

Fig. 150.



wheels are placed, one at top, and the other at bottom, and a series of buckets are fixed to an endless chain, the links of which fall into notches in the circumference of the rag-wheels. The water, issuing from the mill course, is introduced into the buckets, on one side, at top. The descent of the loaded buckets, on this side, puts the rag-wheels in motion, and the power is conveyed from the shaft of the upper wheel, to turn any kind of machinery. When the buckets reach the bottom, they allow the water to escape ; and, ascending empty, on the opposite side, they again return to the spout, to be filled as before. In this machine, the buckets have, in every part of their path, the same mechanical effect to turn the wheels, and they do not allow the water to escape, till they have reached almost the lowest part of the fall.

This species of wheel possesses another advantage, namely, that, by raising the lower wheel, and taking out two or three of the buckets, it may be made to work, when there is such a quantity of back-water, as would, otherwise, prevent it from moving.

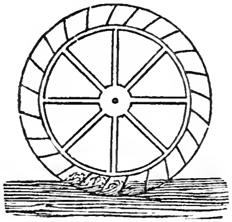
Dr. Robison has described a machine, of this kind, in which plugs, or horizontal float-boards, are fixed to a chain.

On the descending side, these plugs pass through a tube, a little greater in diameter than that of the floats ; and the water, acting upon these floats, as it does in the case of a breast-wheel, gives motion to the two rag-wheels.

In regard to the most advantageous velocity to be produced, with a given quantity of water, in an overshot-wheel, various mathematicians have concluded, that the slower a wheel moves, the greater is its power of perfor mance. But the experiments of Mr. Smeaton lead to the conclusion, that, in practice, there is a limit of velocity, and that overshot-wheels do most work, when their circumference moves at the rate of about three feet in a second.

Undershot Wheel.—An undershot water-wheel, is a wheel furnished with a series of plane surfaces, called floats, or float-boards, projecting from its circumference, for the purpose of receiving the impulse of the water, which is delivered by a proper canal, with great velocity, upon the under part of the wheel. A wheel of this kind is represented in Fig. 151.

Fig. 151.



When an undershot-wheel is put in motion, by a stream of water striking against one of its float-boards, in a direction at right angles with the radius, the action of the water will diminish, as the velocity of the wheel increases, till, at last, the momentum of the water, or of the accelerating force, is just equal to the momentum of the resistance, or of the retarding force. The motion of the wheel will then become uniform.

By calculation, it appears that a machine, thus driven by the impulse of a stream, produces the greatest effect, or does most work in a given time, when the wheel moves with one third of the velocity with which the water moves.* But, in practice, this rule is liable to some variation; for the water does not escape, as soon as it has given its impulse, but is confined by the channel, for some time, and acts with a variety of influences. In Mr. Smeaton's experiments, which are cited as authorities by most writers, since his time, it was found, that an undershot-wheel, when working to the greatest advantage, had a velocity, which varied from one third to one half the velocity of the stream; and that, in great machines, it was nearer to the latter of these limits, than the former.

It is advantageous, that the size of undershot-wheels should be as great as circumstances will permit, and it ought never, says Dr. Brewster, to be less than seven times the natural depth of the stream, at the bottom of the course.† In regard to the best number of float-boards, a difference of opinion has prevailed; but it is now generally admitted, that the more float-boards a wheel has, the greater and more uniform will be its effect.‡ According to the experiments of Bossut, it appeared, that a wheel with forty-eight float-boards produced a greater effect, than one with twenty-four; and the latter, a greater effect, than one with twelve. Smeaton's experiments justify the same conclusion, though he found, that, on adapting to the wheel a circular sweep of such length, that one float-board entered into the curve, before another left it, the effect came so near to the former, as not to give any hopes of advancing it, by increasing the number of floats, beyond twenty-four, in the wheel experimented on.§

In regard to the position of the float boards, they should not be in the direction of the radius, but inclined from it slightly, backwards. From the experiments of

* Playfair's Outlines of Natural Philosophy, vol. i. p. 214; and Robison, 622.

† Ferguson's Mechanics, vol. ii. p. 17.

‡ Gregory's Mechanics, vol. i. p. 462.

§ Ibid. p. 476.

Deparcieux and Bossut, it appears, that there is a very sensible advantage gained, by inclining the float-boards to the radius of the wheel, about twenty degrees, so that the lowest float-board shall not be perpendicular, but have its point turned up the stream, about twenty degrees. This inclination causes the water to heap up along the float-board, and act by its weight.* The floats should, for this purpose, be made much broader, in the direction of the radius, than the vein of water, which they intersect, is deep. Another advantage, attending this obliquity of the floats, is, that they are less resisted, when they rise out of the water.

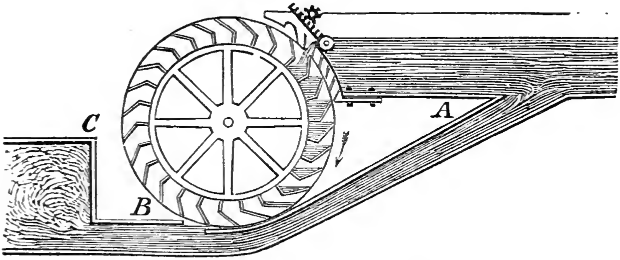
The best way of delivering the water, on an undershot-wheel, in a close mill-course, according to Dr. Robison, is to let it slide down a very smooth channel, without touching the wheel, till it arrives near the bottom, at which place the wheel should be exactly fitted to the course. The floats should be broader than the depth of the water, so as never to be wholly immersed, but allowing the intercepted water to heap up against them. If the bottom of the course be an arc of a circle, having a greater radius than that of the wheel, the water, which slides down, will be gradually intercepted by the floats, or strike upon more than one at a time. In this country, it is often the practice, to admit the water, directly, from the bottom of a pond, or reservoir, instead of causing it to glide down a separate channel, from near the top; and this method is found very effectual.

Back Water.—The back-water, or tail-water, is that portion which has passed by the wheel. This portion is not only useless, but, in most cases, injurious; since, by its inertia and weight, it resists the escape of the floats and empty buckets, in their passage upward. Its effect is increased, in times of floods, or freshets, so that it is often necessary to place wheels higher than they otherwise would be, to provide against it. A method of getting rid of back-water, in times of flood, has been invented by Mr. Perkins, in this country, and Mr. Burns in

* Robison's Mechanical Philosophy, vol. ii. p. 625.

Scotland. It consists in a separate passage, by which a current of water is taken from the mill-lead, or flume,

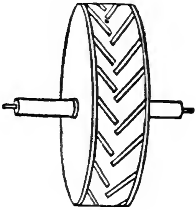
Fig. 152.



as at A, in Fig. 152, and passes, with great rapidity, under the wheel, and thence under the flooring, at B. This rapid current has the effect to take off, and carry away, the back-water from beneath the wheel, while it is prevented from returning, by the force of the same current, and the barrier, at C. The water, which is expended to maintain this current, is no more than would run over the waste gate, in a time of freshet.

Besant's Wheel.—To diminish the retardation occasioned by back-water, Mr. Besant has invented a wheel, in which the floats are placed obliquely in a double row, as in Fig. 153, where the wheel is represented as seen

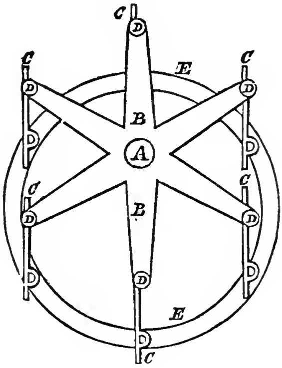
Fig. 153.



edgewise. Each pair of floats forms an acute angle, open at its vertex. By this construction, the floats escape more gradually, and with less resistance, from the back-water, and likewise the resistance of the atmosphere is prevented, by the admission of air, at the open angle of the floats.

Lambert's Wheel.—As water acts most advantageously upon undershot-wheels, when the floats are perpendicular to the surfaces of the stream, it has been attempted, in different ways, to keep them always in a vertical position. In the method proposed by Mr. Lambert, the floats are hung upon hinges, or pivots, at the extremities of the spokes, and are kept in a vertical position by a large iron ring, which is suspended from the lower extremities of the whole, and is allowed to pass, during the revolution, through a slit in the middle of each float. In Fig. 154,

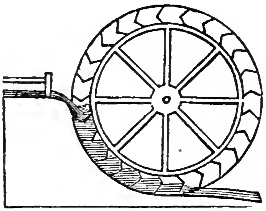
Fig. 154.



is a view of one side of the wheel, with the ring attached. A, is the centre of the wheel; BD, are spokes, or arms, of the water-wheel; CD, are the float-boards, which are here seen edgewise. EE, is a large iron ring, connected by joints to the lower extremity of all the float-boards, and serving, by its weight, to keep them in a vertical position. This wheel is, probably, too complicated for common use. The iron ring is kept from moving sideways by guides, or friction-wheels, placed at each side.

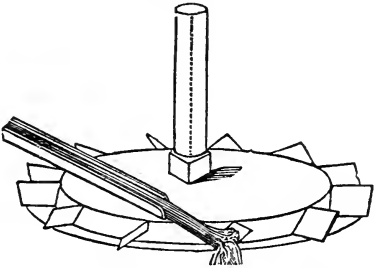
Breast Wheel.—The breast-wheel is intermediate between the overshot, and undershot, wheels, having the water delivered upon it, at about half its height, or at the level of its axis. In breast wheels, in England, buckets are not commonly employed, but the float-boards are fitted accurately, with as little play as possible, to the mill course, so that the water, after acting upon the float-boards, by its impulse, is detained between them in the mill course, and acts, by its weight, till it reaches the lowest part of the wheel. A breast-wheel is represented in Fig. 155, as it is often constructed in this country, with buckets, instead of floats, and with a part of its circumference fitted to the mill course, or apron.

Fig. 155.



Horizontal Wheel.—A horizontal wheel, with oblique floats, sometimes called, in this country, a *tub-wheel*, is turned by a current of water, discharged against the floats, in the manner represented in Fig. 156. This method is

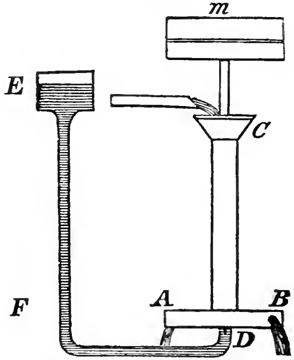
Fig. 156.



said to be in common use on the continent of Europe, and but seldom employed in England. It is a disadvantageous mode of applying power, and is only recom mended in corn-mills, by its simplicity; the millstones being turned directly by the axis of the water-wheel, without the intervention of other wheels, or gearing. In the same manner, another kind of *tub-wheel*, which is a sort of inverted cone, furnished with spiral floats on its inside, is made to revolve horizontally, by discharging into it a current of water, from above.

Barker's Mill.—This machine, which is also sometimes called *Parent's* mill, is driven by an application of the force of water, different from any of those which have been already described. This application consists, not in the direct use of the weight, or impulse of water, but in that of its reaction, or counter pressure. The principle of this simple machine may be seen, by inspecting Fig. 157, where CD, is a revolving vertical tube, carrying a millstone, [*m*,] on the upper part of its axis. At the bottom of this tube, is a horizontal tube, AB, at the extremities of which, are two apertures, A and B, opening in opposite directions. A stream of water is introduced from the mill course above, and flows out at the apertures, at A and B, and, in this way, keeps up a continued horizontal rotary motion, around the axis, [D*m*.]

Fig. 157.



In order to understand how this rotary motion is produced, we may suppose the apertures to be shut, and the tube, CD, filled with water. The area of the apertures, A and B, will then be pressed outward, by a force, equal to a column of water whose height is CD, and whose base is equal to the area of the apertures. Every part of the tube, AB, sustains a similar pressure ; but, as these pressures are balanced, by equal and opposite pressures, the machine remains at rest. But, when the aperture, at B, is opened, the pressure at that place is removed, and, therefore, the arm will be carried round, in a direction opposite to that of the aperture, by a pressure which is due to the height of the column, and area of the aperture. The same thing happens with the other arm, and the two pressures carry round the vertical axis, in the same direction.

An improvement has been made in Barker's mill, by dispensing with the tube, CD, retaining only its axis ; and introducing the water, on the under side of the transverse tube, at D. For this purpose, the water is brought down from the reservoir at E, by a separate passage, and introduced, at D, through a water-joint, which suffers the arms of the tube to revolve, without much loss of water. Such a passage is represented by the shaded part, EFD. The upward pressure of the water may be made to support a great part of the weight of the machine.

WIND-POWER.

Currents of water, being limited in magnitude, can be confined, in their action, to one side of a wheel. But it is not easy to do the same, with currents of wind, on account of their indefinite magnitude, and the difficulty of screening one half of the wheel, advantageously, from their action. It is, therefore, common, to employ vertical windmills, having a number of sails, placed obliquely to the wind, and turning on a horizontal axis which is parallel to the wind, or nearly so. The action of the wind, in this case, is resolved into two forces ; and, since the sails cannot obey the first, by moving in the direction of the wind, they obey the second, and move at right angles with it.

Vertical Windmill.—The common windmill has, usually, four sails, and, sometimes six or eight. The power of these sails, to turn their axis, depends, when other things are equal, upon their degree of obliquity in regard to the wind. The angle, which is most effectual for giving motion to the sails, from a state of rest, is an angle of thirty-five and one third degrees with the weather, or with the plane in which the sails revolve.* But the angle, which produces the greatest action upon a sail at rest, is not the most effectual, when a sail is in motion. As the motion increases, the action of the wind diminishes, and, in order to preserve this action, the sails require to be brought nearer to the wind. And, since each part of the sail, in revolving, has a different velocity, those parts which are nearest the circumference, being swiftest, are not acted upon so powerfully by the wind, as those which are nearer the centre; on which account, it is useful to give the sails a slight spiral curvature, so as to make the angle with the weather, at the extremity of the sail, less than it is at the centre. When, however, the sails are perfectly plane, it is advantageous, according to Mr. Smeaton, that the angle of the sails with the weather should be eighteen degrees, or less; in other words, that their angle with the axis should be seventy-two degrees, or more. The velocity of the sails, in this case, at their outer extremity, is often found to be more than twice that of the wind.

Adjustment of Sails.—On account of the inconstant nature of the motion of the wind, it is necessary to have some provision, for accommodating the resistance of the sails, to the degree of violence with which the wind blows. This is commonly done, by clothing and unclothing the sails; that is, by covering, with canvass, or thin boards, a greater or smaller portion of the frame of the sails, according to the force of the wind, at different times. A method has been devised, for producing the same effect, by altering the obliquity of the sails; and windmills have been so made, as to regulate their own adjustment, by the force of the wind. If we suppose a windmill, or wind-wheel, to consist of four arms, and that the sails were connected to these arms, at one edge, by

* Determined by Parent. See Brewster's Ferguson's Mechanics, vol. ii. p. 69.

means of springs, the yielding of these springs would allow the sails to turn back, when the wind should blow with violence ; and their elasticity would bring them up to the wind, whenever its force abated. This effect has been produced by a weight, acting on the sails, through a series of levers. A loose iron rod, passing through the centre of the axle of the wind-wheel, receives the action of the weight, at one end, and communicates it to the sails, at the other.

Sometimes, a governor, like that described on page 77, is used, to regulate the velocity of windmills, which are built for grinding, by increasing the supply of corn to be ground, or of work to be done, whenever the force of the wind increases. The governor is also applied, in a very ingenious manner, to furl or unfurl a portion of the sails, thus accommodating them to variations of the wind.

As it is necessary that a windmill should face the wind, from whatever point it blows, the whole machine, or a part of it, must be capable of turning horizontally. Sometimes, the whole mill is made to turn upon a strong vertical post, and is, therefore, called a *post-mill ;* but, more commonly, the roof, or head, only, revolves, carrying with it the wind-wheel and its shaft, the weight being supported on friction rollers. In order that the wind itself may regulate the position of the mill, a large vane, or weathercock, is placed on the side which is opposite the sails, thus turning them always to the wind. But, in large mills, the motion is regulated by a small supplementary wind-wheel, or pair of sails, occupying the place of the vane, and situated at right angles with the principal wind-wheel. When the windmill is in its proper position, with its shaft parallel to the wind, the supplementary sails do not turn. But, when the wind changes, they are immediately brought into action, and, by turning a series of wheel-work, they gradually bring round the head, to its proper position.

As the resistance, occasioned by the side of the building, makes a difference in the force of the wind upon the upper and under sails, it is common to incline the sails, and their axis, in such a manner, that the lower sails shall be further from the building, than they would be, if in a vertical position.

Horizontal Windmill.—This name is given to those windmills which turn on a vertical axis. Various methods are employed in their construction, in most of which, the wind acts by its direct impulse, as in an undershot water-wheel. In the most common forms, the sails, like float-boards, present their broadside to the wind, on the acting side of the wheel, but are folded up, or turned edgewise, on the returning side. These wheels, however, are found to be greatly inferior to the vertical windmill, in the amount of work which they are capable of performing, and, at the present day, they are little used.

As wind is the most uncertain of all the moving agents, and fails, totally, in times of calm, it is not common to depend upon this power, in large works, provided other moving forces can be obtained. The steam-engine has, in many cases, superseded it; but it is still used, in certain places, for grinding corn, pumping water, and driving inferior machinery. Upon the ocean, it is a locomotive agent, of incalculable importance.

STEAM-POWER.

Steam.—The power of steam depends on the tendency which water possesses, to expand into vapor, when heated to a certain temperature. Many other substances, and, perhaps, all, have the same tendency; and those which are volatile, at low temperatures, might, doubtless, be made the sources of moving power, in the arts. But, since water, which is the most cheap and abundant of these substances, fortunately possesses, also, the greatest number of requisites for an expansive agent, it is not likely to be superseded by any other material.

When water is converted into steam, it expands to about one thousand seven hundred times its original volume,* so that a cubic inch of water furnishes about a cubic foot of steam, at two hundred and twelve degrees

* One thousand six hundred and thirty-three times, according to Gay-Lussac. See Ure's Dictionary, article Caloric. One thousand seven hundred and eleven times, according to Tredgold.

of Fahrenheit, under the common pressure of the atmosphere. Water cannot, however, be converted immediately into steam, by the application of a boiling temperature, but requires a certain period, to effect its volatilization. This period is about six times as great, as that which is necessary to raise it from the freezing to the boiling point, supposing the supply of heat to be uniform. The amount of heat, which is absorbed, or rendered latent, by the conversion of water into steam, is about nine hundred and fifty degrees.*

The power of steam, to produce motion in other bodies, depends upon the increase of its own volume ; and whatever body resists this increase, will be acted upon by a force, proportionate to the elastic power of the steam, and the circumstances under which the resistance is made. In a vessel boiling in the open air, we are not sensible of the magnitude of this force, because the steam, and the resisting medium, against which it acts, are both invisible. But, when we consider that the steam, when first generated, has to lift off from the water, before it can assume its elastic form, the weight of the superincumbent atmosphere, and that this weight, in the atmospheric column which presses on a vessel, only two feet in diameter, is equal to several tons, we may easily conceive of the force which attends this expansion.

Furthermore, since steam has the property of immediately condensing into water, as soon as its temperature is reduced below two hundred and twelve degrees, it follows, that the atmospheric weight which has been lifted, by the formation of the steam, will immediately fall, when the steam condenses ; and with a force, equal to that by which it was raised. This furnishes an indirect, or secondary, application of the power of steam.

But the powers of steam are not limited by the effects which it produces, at the common boiling temperature. If steam be separated from the contact of water, and exposed to a further increase of temperature, it will continue to expand, by the law which governs the increase

* Nine hundred and fifty, according to Watt. Nine hundred and sixty-seven, Ure.

of all gaseous bodies, and will double its volume, once, for every four hundred and eighty degrees of Fahrenheit's thermometer.* And, furthermore, if water itself be enclosed in strong vessels, and thus heated, its expansive force will be prodigiously greater than that of steam alone; since every particle of the water tends to generate steam, of high temperature, and to occupy the space which is due to such steam. In a common boiler, containing water and steam, each addition of caloric causes a fresh portion of steam to rise, and to add its elastic force to that of the steam previously existing, so that an excessive pressure is soon exerted against the inside of the vessel, if the augmentation of heat has been considerable. At two hundred and twelve degrees, Fahrenheit, steam has an elastic force, equal to the pressure of the atmosphere. If it be farther heated, in contact with water, it will have a force, equal to that of two atmospheres, at about two hundred and fifty degrees; of four atmospheres, at two hundred and ninety-three degrees; and of eight atmospheres, at three hundred and forty-four degrees. These are the results, in round numbers, of Mr. Southern's experiments; and they are nearly confirmed, by those of Drs. Robison and Ure.†

At temperatures below two hundred and twelve degrees, steam has still a certain elastic force, which discovers itself, whenever the pressure of the atmosphere is taken off. Thus, its elastic force, at one hundred and eighty degrees, is equal to about half an atmosphere; and it has some force, at all temperatures above the freezing point.

Steam expands in all directions, alike, and is useful, as a moving agent, only by its pressure. It cannot, like water and wind, be made to act advantageously by its impulse,

* Ure's Dictionary of Chemistry, Art. Caloric and Gas.

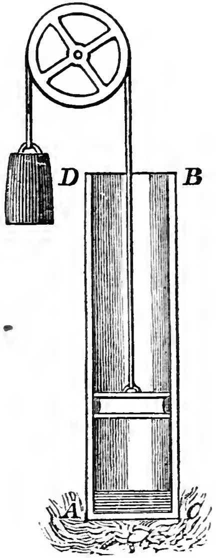
† The recent and elaborate experiments of Messrs. Arago and Dulong, have corrected these results, and carried the scale as high as fifty atmospheres. Thus, an elastic force, equal to the pressure of twenty atmospheres, is produced by a heat of about four hundred and eighteen degrees, Fahrenheit, and one of fifty atmospheres, by five hundred and ten degrees.

in the open air; for the momentum of so light a fluid, unless generated in vast quantities, would be inconsiderable. Some of the earliest attempts, however, at forming a steam-engine, consisted in directing the current of steam, from the mouth of an eolipile, against the vanes, or floats, of a revolving wheel.* In order that the pressure of steam may be rendered available, in machinery, the steam must be confined within a cavity, which is air-tight, and so constructed, that its dimensions, or capacity, may be altered, without altering its tightness. When the steam enters such a vessel, it enlarges the actual cavity, by causing some movable part to recede before it, and, from this movable part, motion is communicated to machinery. A hollow cylinder, having a movable piston, accurately fitted to its bore, constitutes a vessel of this kind. It was used, more than a century ago, by Newcomen; and, as it is found to combine more advantages, than any other kind of arrangement, for motion, its use has never been superseded The piston, thus employed, has a reciprocating motion, which is converted, when necessary, into a rotary one, by the appropriate mechanism.

Applications of Steam.—The pressure of steam is capable of being applied to use, in three different ways; and these modes have given rise to some of the most important varieties of the steam-engine. The three methods which are used, for obtaining power from steam, are, 1. By condensation, as in the atmospheric engine. 2. By generation, as in the simple high-pressure engines. 3. By expansion, as in Woolf's engine, Watt's expansion engine, and some others. These methods have been illustrated, by Mr. Tredgold, by a figure like that on page 104. Suppose a cylindric vessel, ABCD, to be placed in a vertical position, with a given depth of water in the bottom, and an air-tight piston, above the water, balanced by a weight, D, equal to its own weight and friction. In this state, let heat be applied to the base, AC; then, as the water becomes converted into steam, of slightly greater force than the atmospheric pressure, the piston

* Such was the engine of Branca, in the beginning of the seventeenth century.

Fig. 158.



will rise, till the whole water is in a state of steam. It must be observed, however, that the generation of this steam, which is of *atmospheric elastic force*, affords no available power, but is simply sufficient to balance the column of atmospheric air, and exclude it from a given height of the cylinder.

By Condensation.—In the state of things just described, if the steam be suddenly condensed into water, by the application of cold, it is obvious, that the piston will be driven downward, with a force, equal to the weight of the atmosphere which presses on the piston, and through a distance, equal to that which the piston had been raised, by the generation of steam. It follows, that the power of steam, which is of atmospheric elastic force, is, when speedily condensed, directly proportionate to the space which it occupies. If the temperature of this steam be raised above two hundred and twelve degrees, it will occupy a larger space, the increase being equal to the expansion of steam, by the given change of temperature. But a quantity of heat, nearly equivalent to the increase of volume, will be absorbed; and hence, says Mr. Tredgold, the effect of a given quantity of fuel would not be increased by the expedient.*

By Generation.—Suppose the same cylinder and apparatus to have heat applied to its base, with only the difference of the piston being loaded with a given pressure per inch of its area. The generation of the steam will raise the loaded piston; but the height, through which it will be raised, will be less than if it were not loaded. The steam having to act in opposition, both to the pressure of the atmosphere, and the load on the piston, the space it will occupy will be in the inverse ratio of the pressures which oppose it, supposing the steam of atmospheric elastic force to have been of the same temperature. Thus, if the load on the piston be equal to twice the atmospheric pressure, the piston will be raised only one third of the height; but, on rapid condensation, it descends with three times the pressure; and, therefore, whether the steam be generated of atmospheric elastic force, or of a greater force, the power it affords, by generation and condensation, is the same, at the same temperature, and this power is directly as the elastic force of the steam, multiplied by the space it occupies, supposing that the motion of the piston is rectilinear.

But if, as in the last case, a loaded piston be raised, and then a valve be opened, which allows the steam to escape, the whole power gained will be equal only to the weight raised, descending from the height to which it was raised; and the power, which would have resulted from condensation, will be lost, and the loss is equal to the pressure of the atmosphere, acting through the height, to which the piston was raised by steam. This is the nature of the common *high-pressure* steam-engine. It is obvious, that the greater the elastic force of the steam, the less is the proportionate loss, by neglecting to con-

* Tredgold, on the Steam Engine, p. 157—159.

dense it under these circumstances; but it may be remarked, that, unless the valve aperture be equal to the diameter of the cylinder, the steam cannot escape at the necessary rate, without part of the load acting to expel it; and so much more of the effective force will, of course, be lost. The effective power is as the space the steam occupies, multiplied by the excess of elastic force above the atmospheric pressure.

By Expansion.—Retaining the same loaded piston, let it be raised, by the conversion of a given quantity of water into steam, to the height which corresponds to the load and temperature. Then, if the load on the piston be wholly removed, at that height, the steam will raise the piston, by expanding, till it becomes nearly of the same elastic force as the atmosphere, and its condensation will produce the same effect, as if the steam had been generated of atmospheric elastic force, at first. Consequently, the effect, in raising the load on the piston, is wholly additional, and the joint effect of a high-pressure and condensing engine is produced, by the same steam. Hence, by this combination of effect, the power of steam, of high elastic force, will be nearly doubled.

This is not, however, the mode by which steam can be applied with the greatest advantage; for, instead of removing the load on the piston, wholly, at the height to which it was raised, by the generation of the high pressure steam, a part of it may be removed, and then the steam would expand, to a height depending on the portion of the load removed; at that height, remove a second portion, and so on, successively, till the steam becomes of atmospheric elastic force. In this case, as far as the load was raised, in parts, by the expansion of the steam. the effect is greater than in the preceding combination. This illustrates the principle of the high-pressure expansion engines of Evans, Woolf, and some others.

Again: let the piston be raised, unloaded, as in the first case, by the conversion of a certain quantity of water into steam of atmospheric elastic force. When the piston is at that height, add a weight, equal to half the atmospheric pressure, to the line passing over the pulley. Then the elastic force of the steam being unbalanced, the piston would rise, till that elastic force would be half the atmospheric pressure, or till the piston would be at double its former height. Now, suppose the steam to be condensed, and the weight removed from the pulley, at the same instant. Then, the power of the descent, after deducting the power added to produce the ascent, will be one half more than it would have been, by simply condensing steam of atmospheric elastic force. This illustrates the principle of the expansion engines of Hornblower and Watt; and it differs from the principle of Woolf, in using steam only of low pressure. The weight, added to the line passing over the pulley, is introduced here, merely to exemplify the mode of applying a portion of the excess of power, which is accumulated in the fly-wheel, in one part of the operation, to assist the machine, through the rest.

It has been assumed, that steam, at least of atmospheric elastic force, was generated; but this is not a necessary condition, for it frequently occurs, that engines work with steam of less elastic force. The same mode of illustration will show whence this happens. Let half the pressure of the atmosphere, on the piston, be balanced by a weight over a pulley. Then, on the application of heat, steam of half the atmospheric elastic force would be generated, and raise the piston to double the height that it would be raised, in common cases, by steam, capable of supporting the atmospheric pressure. Consequently, on its being condensed, the descending force will be half the atmospheric pressure, acting through double the height; and the steam produces the same effect, as before.

The foregoing methods of the application of steam will be found apparent, in the different forms of the steam-engine, in which they have been called into use.

The Steam Engine.—The steam-engine is a machine, by which the power, derived from steam, is converted to practical use. It has occupied the attention of philosophers and artists, for more than a century, and is now brought to so great a degree of perfection, as, in the opinion of many scientific men, to leave little probability of its further improvement. Whether viewed with reference to the great skill which has been employed, in perfecting it, or the importance and extent of its application, it may justly be viewed as the noblest production of the arts, in modern times. For acquiring a clear conception of the steam-engine, as it is now commonly constructed, it will be useful to consider, first, the *boiler*, in which the power is generated, and, second, the *engine*, in which it is directed, and applied to use.

Boiler.—On acccunt of the gradual rate at which water boils away, it is necessary, in most engines, to keep a large quantity constantly heated, to afford steam with sufficient rapidity for its consumption by the engine. This water is enclosed in a strong, tight, vessel, called the boiler, which is made of iron, or copper, and rests in contact with a furnace. It is requisite, that a boiler should be of sufficient strength, to resist the greatest pressure which is ever liable to occur, from the expansion of the steam. It must also offer a sufficient extent of surface to the fire, to insure the requisite amount of vaporization. In common low-pressure boilers, it requires about eight feet of surface of the boiler to be exposed to the action of the fire and flame, to boil off a cubic foot of water, in an hour; and a cubic foot of water, thus converted into steam, is equal to a one-horse power.*

The strongest form for a boiler, and one of the earliest which was used, is that of a sphere; but this form is the one which offers least surface to the fire. The figure of a cylinder is, on many accounts, the best; and it is now extensively used, especially for engines of high pressure It has the advantage of being easily constructed from sheets of metal, and the form is of equal strength, except at the ends. In such a boiler, the ends should be made thicker than the other parts. The furnace is so constructed, that the flame and hot smoke may pass under the whole length of the boiler, and afterwards around both its sides, before escaping to the chimney.

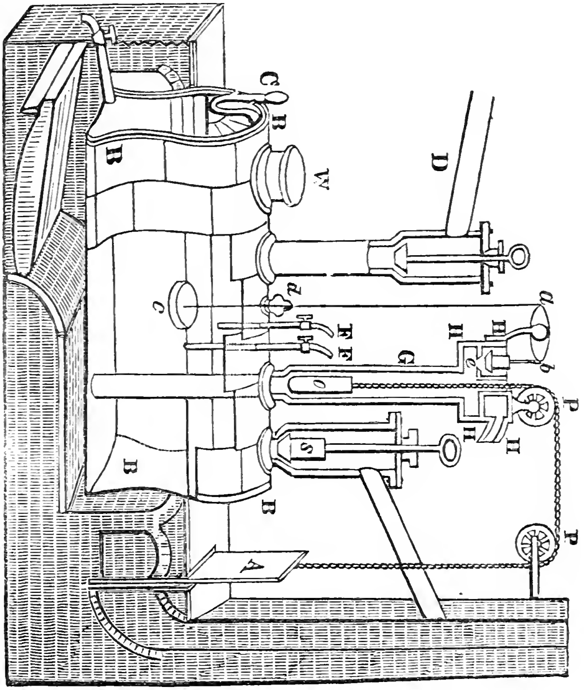
In what are called *flue-boilers*, a cylindrical furnace is placed within a cylindrical boiler, so that the fuel is sur-

* See Tredgold, on the Steam Engine, with the following correction, p. 124, line 2, from the bottom For *steam*, read *water*

rounded by water, on all sides, and communicates to it nearly all its heat, except the portion which passes up the chimney.

In large engines, which are of low pressure, the form of the boiler, which was used by Mr. Watt, still continues to be employed, particularly in England. In this boiler, the upper half is a semi-cylinder, while the lower half is nearly rectangular, with the under side concave, so that a cross section would nearly resemble a horse-shoe. This boiler is less strong than those of a cylindrical form, but it offers a larger surface to the fire, without occupying much more space. A boiler of this kind, as it is fitted up in large engines, with appendages for regulating its

Fig. 159.



own fire, water, and steam, is represented in the figure, [159,] on the preceding page. A part of the furnace is supposed to be taken away, to bring the boiler into view; and, also, a portion of the boiler is removed, to show its inside.

Appendages.—In the figure above referred to, BBBB, is the boiler, made of thick sheets, or plates, of rolled iron, strongly riveted together, a part of which are removed, to show the interior. It is supposed to be half full of water, at the boiling temperature. C, is the *steam-gauge*, the object of which is to determine the degree of pressure acting within the boiler. It is a bent iron tube, or inverted syphon, one end of which communicates with the boiler, and the other end with the atmosphere. The tube is partly filled with mercury, and, as the pressure of the steam increases, the mercury will be driven outward, and will rise in the external leg of the syphon. As the height of the column of mercury cannot be seen, the tube being opaque, a small wooden stem is made to float in the tube, with its end projecting by the side of a graduated scale. Every inch in height, which the stem rises, shows a difference of two inches in the two surfaces of the mercury in the tube, and indicates a pressure of about a pound, upon every square inch of the inner surface of the boiler. And, as low-pressure engines are seldom worked with more than three or four pounds to the square inch, the mercury seldom rises higher than three or four inches, in such engines. In high-pressure engines, the mercurial gauge is not so easily applied; for these engines are frequently worked, at a pressure of several atmospheres, and each additional atmosphere requires an addition, of nearly fifteen inches, to the column of mercury.

W, is a large opening, called the *man-hole*, of sufficient size to permit a man to enter the boiler, to clean or examine it. It is closed by a strong iron plate. D, is the steam-pipe, which conveys the steam to the engine. It is provided with a throttle-valve, which is a circular disc, or partition, turning on an axis, and connected with the *governor*, described on page 77. Its use is to regulate the supply of steam, by closing the pipe, i the engine goes too fast, or by opening it, if it is too slow. FF, are the *gauge-cocks*, which indicate the height of water in the boiler. Their extremities stand at different depths, in the boiler, one being below the surface of the water, and the other above it. When the water is at the proper height, one of these will emit steam, on being opened, and the other will emit water. They are frequently placed on the end, instead of the top, of the boiler.

For keeping up a regular supply of water to the boiler, a vertical tube, G, called the *feed-pipe*, is used. Upon its top, is a small cistern, HHHH, which is kept full of water, by a pump, worked by the engine. At the bottom of this cistern, is a valve, E, connected to one end of the lever, [*ab*.] At the other end of this lever, is a wire, [*dc*,] which passes through a steam-tight opening, at [*d*,] and supports a stone float, [*c*,] upon the surface of the water, the stone being counterbalanced by a weight, at the valve, [*e*.] When the water lowers, in the boiler, the stone float descends, and, by acting upon the lever, [*ab*,] opens the valve, [*e*.] Water immediately flows in, from the cistern, and continues to do so, till the float rises, and shuts the valve. It will be observed, that the column of water, in the feed-pipe, must be sufficiently high to counterbalance the pressure of steam, in the boiler. On this account, it can not be applied in high-pressure engines, without making it of a very inconvenient height. In these engines, therefore, water is supplied to the boiler, by a small forcing pump, worked by one of the reciprocating parts of the engine; and it is frequently heated, before being pumped in, that it may not check the production of steam.

For the purpose of regulating the fire, the feed-pipe is furnished with an iron bucket, O, hung by a chain, which passes over two pullies, PP, and is attached by its other extremity to an iron damper, A, which commands the chimney. When the steam in the boiler is urged to too great an extent, it forces the water upward, in the feed-pipe, and causes the iron bucket to ascend. This lowers the damper into the smoke-flue, and, by thus intercepting the current of air, checks the force of the fire. In some boilers, the passage, which brings air to the fire, is intercepted, instead of the smoke-flue.

To prevent the boiler from bursting, if, by accident, the pressure of the steam should become too great for the strength of the boiler, a *safety-valve* is provided, at S, opening outward. It is kept down by a weight, so that it cannot be raised, except by a greater force than that which is required to work the engine. It is highly important, however, that it should not be liable to any other weight, or encumbrance, than that which the engine requires ; and, to prevent this danger, it is enclosed in a case, which is kept locked. When the engine stops working, or the steam is generated too rapidly for its expenditure, the safety-valve rises, and the superfluous steam rushes out, with a hissing noise.

Another safety-valve is also provided, which differs from the preceding, in opening *inwards*. It is kept up by a counter weight, on a lever, and its use is to prevent the weight of the atmosphere from crushing in the sides of the boiler, when the engine stops working, and the steam cools.

As boilers are usually proved, before being submitted to use, the accident of bursting does not happen, from a general want of strength, unless the safety-valve be overloaded. It is most likely to happen, either from neglect, in suffering the water to get too low, in some part of the boiler, so that the metal is excessively heated, or else, from the corrosion of the metal, in places, by oxidation, after long exposure to the fire. If a sediment is suffered to accumulate, to a considerable depth, on the bottom of the boiler, it has the effect to exclude the water from contact with the metal, so that the metal becomes hotter, and is more rapidly oxidated, and even softened, by the heat

The violent explosions which have sometimes occurred, projecting the contents and fragments of the boiler to a great distance, have been rationally accounted for, by supposing that certain parts of the metal, through neglect, become heated to a high temperature, and, that portions of water, being suddenly brought into contiguity with them, produce steam, of which the initial elastic force is extremely great. In this case, the boiler may burst, before the inertia of the water or safety-valves, is overcome; and the stronger is the boiler, the greater may be the explosion.

As a great number of lives have been lost by the explosion of boilers, particularly on board of steam-boats, much attention has been bestowed on the means of preventing such accidents. The principal attempts have consisted, in a more accurate regulation of the safety-valves, and in the introduction of plugs of fusible metal, which melt, when the temperature is raised a little above the boiling point of water, and thus suffer the steam to escape. But absolute security has only been found, in placing the boiler in such a situation, that, if it should burst, it would occasion no injury to the passengers in the boat. This is effected, by placing the engine in a boat by itself, or by interposing a strong barrier between the boilers, and the persons on board the boat. Mr. Treadwell has proposed to use the steam, at a pressure not greater than that of the atmosphere, and to compensate the loss of force, by an increase in the size of the cylinder and piston.

Besides the forms of the boiler, already mentioned, various others have been employed, such as combinations of tubes, and other figures, intended to multiply surface, for the purpose of raising more steam, from the same amount of water, in a given time. They have been applied in some high-pressure engines, but, in most cases, the simpler forms are preferred.* In Brathwaite and Ericsson's engine, which has been applied, with particular success, to propelling carriages on rail-roads, the hot air of the furnace is forcibly drawn, in a circuitous flue, through the boiler, by means of a revolving, fan-like apparatus; thus communicating to the boiler a greater quantity of heat, in a given time, than could be obtained from the common atmospheric draught.

* In Perkins's engine, a strong vessel, called a *generator*, is kept full of water heated to a high temperature. Portions of the water are successively forced out; and reliance is placed on the heat already in this water, to produce from it the requisite amount of steam.

Engine.—The steam being generated in sufficient quantities in the boiler, it is next applied to use in the working, or moving, part, which we have called *the engine.* Of this engine, a great variety of forms and modifications have been proposed, and adopted, at different times. A few of those, which are effectual in their principle, and most extensively employed, will now be considered.

Non-condensing Engine.—The simplest form of the steam-engine is that of the non-condensing, commonly called the *high-pressure*, engine. In this engine, the apparatus for condensation is dispensed with, and the steam is worked at a high temperature, and afterwards discharged into the open air. Of course, a part of the force of the steam is expended, in overcoming the pressure of the atmosphere, and the surplus, only, can be applied to drive machinery. That this surplus may be sufficient to produce the requisite power, a pressure of thirty or forty pounds, on a circular inch, above the atmospheric pressure, is commonly kept up in these engines.*

The manner, in which the engine is made to operate, is, briefly, as follows. The steam, in escaping from the boiler to the open air, is obliged to pass through the cylinder, the cavity of which is closed, except where it communicates with the valves. By the opening and shutting of these valves, the steam is made to enter the cylinder, alternately, at each end, and escape by the opposite end. But, in doing this, its passage is always intercepted by the piston; so that, before it can escape, it must move the piston from one end to the other of the cylinder. The repetition of this movement gives motion to a beam, or other alternating part, from which it is communicated, by a connecting rod and crank, to a fly-wheel, in the same manner as is seen in the condensing engine, [Pl. III.] hereafter to be described. The figure, there represented, may be considered as a non-condensing engine, if we remove from it the condenser, and its appendages, occupying the lower part of the plate. B, represents the boiler; C, the pipe, which conveys the steam; D, the cylinder:

* See Tredgold, on the Steam Engine, p. 181.

E, the piston; F, the beam; [*h*,] the crank; G, the fly-wheel.

The different apparatus of valves, by which the entrance and escape of steam is regulated; also, the other appendages of the engine, will be considered in another place. In arranging the time of their opening and shutting, it is usual to allow not quite all the steam to escape, at the end of the stroke. A small portion is retained, to receive the shock of the piston, and, by its elasticity, to destroy its momentum, and cause it to recoil back, without loss of force.

Non-condensing engines sometimes work by the generative force of steam, and, sometimes, by the generative and expansive force. They are used in cases where simplicity and lightness are required, as in locomotive engines; also, in situations where a sufficient supply of water, for condensation, cannot easily be obtained. They are inferior, in safety, to condensing engines; yet, as they cost much less at the outset, for the expense of building, they are often preferred for small, or temporary, works. In proportion to the high temperature at which the steam is worked, great caution is necessary, in regard to the strength and management of the boiler, in these engines.

Condensing Engines.—Engines of this class are fitted up, with an apparatus for condensing the steam into water, so that a vacuum, nearly complete, is formed in one part of the cylinder, just before the stroke of the piston, into that part, takes place. By this construction, the resistance of the atmosphere is avoided; and, thus, the power of the engine, to perform work, is much increased. The steam, also, is sufficiently powerful for use, at comparatively low temperatures; and hence arises the increase of safety which is found in *low-pressure engines*, a name given to those condensing engines, which are worked with steam of moderate elastic force.

In the *atmospheric engine*, invented by Newcomen, the piston was raised by the steam, aided by a counter weight, till it arrived at the top of the cylinder, which was left perfectly open. A jet of water was then admitted into the bottom of the cylinder, which suddenly condensed the steam, so that, a vacuum being formed, the piston was driven down, by a force equal to the weight of the column of superincumbent air. The water was now excluded by a stop-cock, and the steam readmitted. The piston was thus again raised, and the process repeated as before.

A great inconvenience attended this method, arising from the circumstance, that the cylinder itself required to be heated and cooled, at each stroke of the piston, thus occasioning great delay, and an unnecessary expense, both of fuel, and of cold water. To remedy this evil, Mr. Watt invented the separate *condenser*, which is a strong vessel, situated at a distance from the cylinder, but communicating with it by a pipe, so as to form with it a common cavity, without reducing, materially, its temperature. Into this vessel, the jet of cold water is thrown, and, as all the communicating pipes are governed by valves, or cocks, the cylinder, below the piston, is alternately filled with steam, from the boiler, and emptied of steam, by the condenser.

In the *double-acting engine*, invented by Mr. Watt, the top of the cylinder was closed, and rendered air-tight, the rod of the piston, only, passing through it. Thus, the cylinder is divided, by the piston, into two cavities, both communicating with the boiler, and both with the condenser. By the aid of valves, an alternate communication is kept up, so that the steam, being alternately admitted at both ends, impels the piston, successively, in both directions, while the condenser, at the same time, destroys the resistance. In this engine, compared with the single engine of Mr. Watt, which was previously in use, a double quantity of steam is used, and a double power exerted, in the same space and time.

Description.—In Pl. III., is a view of a double-acting steam-engine, nearly as constructed by Murray, and upon the same general principles as those of Mr. Watt, varying, however, in the valves, and some other particulars.

A, represents the furnace, which is here shown in section, as is also the boiler, above it, and all the principal cavities of the engine. The flame and hot smoke, after passing underneath the boiler, for its whole length, return through the side passages, [*dd*,] before they are discharged into the chimney.

B, is the boiler, which, in this example, is of a cylindrical form, a shape better adapted for strength, than that represented in Fig. 159. The appendages represented in Fig. 159 are not here repeated. Some of them, indeed, are not used in steam-boats, and in small engines. The boiler is commonly made of sheets of iron, strongly riveted together, and tightened by hammering. If intended to contain salt water, the boiler is made of copper, to prevent corrosion.

CCC, is the steam-pipe, which carries the steam from the boiler to the cylinder, through the valve, I. It is made of cast-iron, and its joints screwed together by flanges.

D, is the cylinder, communicating, by passages at the top and bottom, with the valve, I. The cylinder is made of cast-iron, and accurately bored, to make its inner surface smooth and true.

E, is the piston, which, by its rod, [*e*,] gives an alternating motion to the beam, [*f f*,] about its centre, F, the other end of which, by another connecting rod, [*g*,] gives motion to the heavy fly-wheel, GG, by means of a crank, [*h*.] Thus, after the engine has begun to work, its power is accumulated in the fly-wheel, and a circular motion may be communicated from it to any machinery.

H, is an eccentric circle, on the axle of the fly-wheel, G. It gives motion through the medium of its levers, [*wx* and *yz*,] and the connecting rods, [H*wxy*, and *z*I,] in a manner easily understood, by inspection, to the valve, I.

I, is a coffer-valve, capable of sliding up and down, and having a cavity on the side next the cylinder. By moving up and down, it opens and shuts the passages, and admits the steam, alternately, to each end of the cylinder; and, at the same time, forms a communication between the opposite end, and the condenser.

W, is the governor, which regulates the speed of the engine. It resembles the governor described in chap. XV. but has its movable collar on the top, at [*s*.] It may be turned by a band, from the axle of the fly-wheel, or placed directly over the axle, and geared to it by bevel-wheels.

When the fly-wheel moves too fast, the balls of the governor recede from their centre, and, by acting on a lever, [*rs*,] cause it to turn upon its fulcrum, [*t*,] and partially to close the steam-pipe, by a throttle-valve, at K. When the velocity abates, the balls subside, and the valve opens, so as to admit more steam.

L, is the air-pump, the use of which is, to discharge the air and water, which collect in the condenser, M.

M, is the condenser, which is an empty, cylindrical vessel, immersed in a cistern of cold water, SS, and communicating with the cylinder by the pipe, O. It has a valve, or cock, communicating with the cistern, and moved by the rod, [*gg*,] through which a jet of cold water enters it, for the purpose of condensing the steam.

N, is a small cistern, filled with water. Into this cistern enters a pipe, from the condenser M, the top of which pipe is covered by a valve, which is called the *blow-valve*, or, sometimes, the *snifting-valve*. Through this valve, the air, contained in the cylinder, D, and passages from it, is discharged, on the engine being first set in motion.

O, is the eduction-pipe, which conducts the steam from the valve, I, to the condenser, M.

P, is the pump, which supplies with water the cistern, or cold well, SS, in which the condenser and discharging pump stand.

QQ, are iron columns, which support the beam. Of these, the engine has four, although only two are shown They stand upon one entire plate, seen edgewise, on which the principal parts of the engine are fixed.

RR, is the recess below the floor, for containing the cistern of the discharging pump, condenser, &c.

The condenser, M, and the air pump, L, communicate by means of a horizontal pipe, containing a valve, [*m*,] opening towards the pump; the piston [*n*,] of this pump, also contains two valves, and the cistern, T, at the top of the pump-cylinder, contains other two valves, which, like those of the piston, [*n*,] open upwards. When the piston, E, of the cylinder, is depressed, the piston [*n*,] of the discharging pump. it will be obvious to inspection, will be depressed, likewise, and its valves open, while the valve, [*m*,] closes ; hence, the water of the condensed steam, as well as the injection water, and any vapor of air, which may be present, having passed through the valve, [*m*,] passes through the piston, [*n* ;] and, when that piston is drawn up, its valves close, and prevent their return, as in common pump-work. The water and air, that have thus got above the piston, as the latter rises, open the valves at the bottom of the cistern, T, in which the water remains till it is full ; but the air passes into the atmosphere. As the water in the cistern, T, is in a hot state, a part of it, for the purpose of economizing fuel, is pumped up, and returned to the boiler, the pump-rod being attached to the great beam.

The steam, constantly rushing into the condenser, M, has a perpetual tendency to heat that vessel, as well as the water of the cistern, SS, in which it stands ; the whole of the steam, if this were unchecked, would not be condensed, or the condensation would not be sufficiently rapid, because the injection water itself flows out of this cistern. A part of the water is, therefore, allowed to flow from this cistern by a waste pipe, and an equal quantity of cold water is constantly supplied by the pump, P.

The cylinder, D, is, in many cases, surrounded by a case, to keep it from being cooled too much, by contact with the external atmosphere.

Expansion Engines.—The steam, which impels an engine is always diminished in volume, by the resistance which it has to overcome, and tends, naturally, to occupy a larger space, than that to which it is confined, while the engine is at work. If it be dismissed into the air, or into the condenser, while under its greatest working pressure, it will not have produced all the useful effect, which it is capable of affording. If, on the contrary, it be separated, and placed under circumstances, where it can still expand further, before it is dismissed, this expansion will be so much additional gain to the power of the engine. Its general principles have already been discussed.

The expansive power of steam may be converted to use, in various ways, and most of the common forms of the steam-engine may be made to act expansively, by a proper arrangement of their valves. In Watt's engine, this effect is produced, by cutting off the steam from the cylinder, before the stroke of the piston is completed, leaving it to the steam, already in the cylinder, to assist, by its expansion, in completing the stroke. The steam in the boiler, being thus intercepted, acts only at intervals Nevertheless, its whole disposable force is accumulated in the fly-wheel, while, at the same time, the force, arising from the expansion of steam in the cylinder, serves to increase the total amount. A great augmentation is thus produced, in the useful effect of an engine, with the same amount of fuel and water.

Mr. Hornblower, who was one of the first inventors of the application of expansive steam, employed two cylinders, having their pistons connected to the same beam. In the smaller of these, the steam was used, at full pressure, after which it was discharged into the larger cylinder, where it again acted, by its expansive force. This method affords a more equable mode of applying the expansive force of steam, than that used by Mr Watt; but the engine is more complex and expensive.

Mr. Woolf afterwards adopted the plan of two cylinders, with the addition of using his steam at a high pressure, together with a condenser. He appears to have exaggerated the expansive force of steam, at high temperatures, as various other projectors have done. His engines, however, continue to be used and approved, in different parts of England and Wales, and their performance is stated to exceed that of any other kinds.

Condenser.—It has already been stated, that, in the original atmospheric engine of Newcomen, the steam was condensed by a jet of cold water, thrown into the cylinder. A great improvement, in the economy of heat, was made by Mr. Watt, who introduced the separate condenser. But, even with this improvement, there is some loss of power, in consequence of the necessity of continually pumping out the water, which has been injected, to condense the steam. Sea-water, also, gives trouble, by the deposit of salt in the boiler. To obviate these difficulties, condensers have been made, of a multitude of small tubes, communicating with the eduction-pipe, and kept immersed in cold water. In this way, sufficient heat escapes, through the surface of the tubes, to condense the steam, without the necessity of injection; and the water is kept fresh. Some of the Atlantic steam-boats have had condensers of this kind. A difficulty, however, is found, in the expansion and contraction of the tubes, which makes it necessary to receive the ends of all of them in stuffing boxes, which admit motion, but are liable to get out of order. In a large engine, now working at the Iron-works, in Boston, Mr. Treadwell has introduced a condenser, the tubes of which are bows, having both ends soldered to the same surface, and, therefore, not liable to be displaced, by expansion, or contraction.

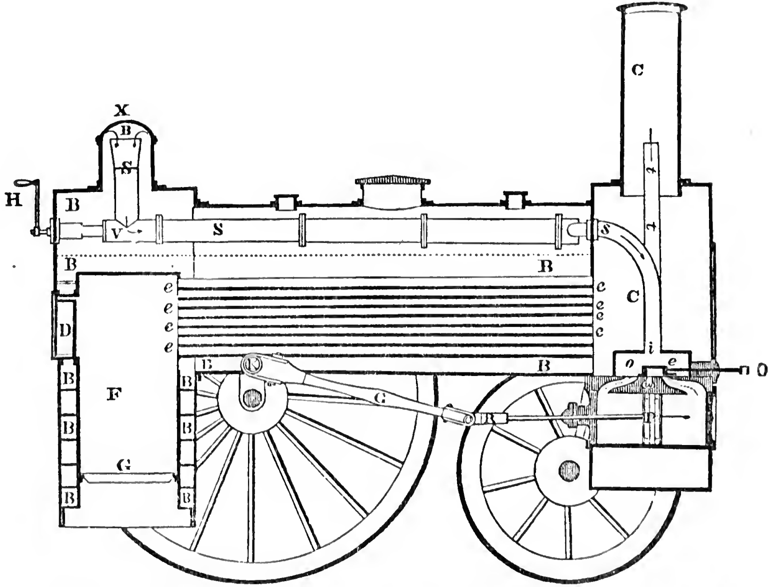
Valves.—The valves of steam-engines are shutters, which guard the avenues to the boiler and condenser, so that, by opening and shutting them, at the required time, the steam may be made to enter, or escape, at either end of the cylinder. Valves, of a great variety of forms, have been used in different engines, some of which have a reciprocating, others, a rotary, motion. The *puppet* valve is a cone, or frustum of a cone, which is fitted, like a cover, to a conical aperture, which it opens, by rising, and closes, by falling. *Sliding* valves are those which do not rise, but slide on and off of their apertures. Some of these have a cavity, on their under side, capable of connecting two apertures together, or of forming a communication between them, while a third aperture is shut. *Rotary* valves are usually constructed like common stop-cocks, excepting that they command more passages than one, at the same time. If the handle be placed in one position, it opens one passage, while it closes another; if in a different position, it closes the first, and opens the second. A *throttle* valve is a partition, turning on an axis, and placed across the interior of a pipe. If turned edgewise, it permits the steam to pass; but, if turned transversely, it obstructs its passage. This valve is commonly placed in the main steam-pipe, and connected with the governor, to regulate the quantity of steam supplied by the boiler.

On account of the heat which is kept up in steam-engines, the principal valves require to be of metal, and are fitted, by grinding, closely to their seats. Valves made with leather, like the common *clack* valve of a pump, can only be used about the condenser, where the temperature is low.

Pistons.—As the piston is liable to continual wear, by its friction against the inside of the cylinder, it can only be kept sufficiently tight, by rendering its circumference elastic. This is commonly done, by winding it with hemp, loosely twisted. The hemp packing, however, gets out of order, in time, and requires to be renewed. To remedy this evil, various plans have been introduced, for making elastic pistons of metal only. The pistons invented by Cartwright and Barton, consist of several parallel circular plates, in close contact with each other. These are cut into segments, and the segments pressed outward, by steel springs, care being taken, that the fissures, in the different plates, do not coincide. In the piston of Jessop, a spiral coil of steel is wound on the circumference of the piston, which expands, by its own elasticity, so as to keep in tight contact with the cylinder. To increase the tightness and elasticity of the piston, a hempen packing is placed within the coil.

Parallel Motion.—A simple form of a parallel motion, for converting the rectilinear motion of the piston into the curvilinear one of the beam, has already been described, on page 66. Another form is shown in Plate III., where the rod, [*ab*,] turns upon the joint, [*a*,] as a fixed centre, while the rod, [*cb*,] turns upon [*b*,] as a centre. While the point, [*c*,] would describe a curve about its centre, [*b*,] the point, [*b*,] describes an opposite curve about its centre, [*a*.] These two curvatures compensate each other, so that the point, [*c*,] to which the piston is attached, describes nearly a straight line.

The parallel motion was introduced by Mr. Watt, and is, probably, attended with less friction than any other arrangement, for effecting the same object. It requires



INTERNAL CONSTRUCTION OF A LOCOMOTIVE ENGINE.—[*To face page* 123.

however, to be constructed with great accuracy. Various other methods have been applied, to convert the rectilinear into a curvilinear movement. Sometimes, the piston is confined to its path by guides, or friction wheels, and connected to the beam by a double joint. In Newcomen's engine, where the principal force was in the downward stroke, the piston was connected, by a chain, to an arched head, at the end of the beam. In Cartwright's engine, the piston was attached to two opposite cranks, which were geared together, as shown on page 66. In some of Murray's engines, the epicycloidal movement was employed. [See page 69.]* In Maudslay's engine, and some others, instead of a beam, a cross-head is used, the whole of which moves up and down, in guides, instead of turning on a centre. In the vibrating engines of Lester, and others, the cylinder is hung upon a movable axis ; and, in Morey's engine, the cylinder revolves, like a fly-wheel, the piston being made to act on a fixed crank.

Locomotive Engine.—This engine is used, as a propelling power, on rail-ways, and has been introduced in a previous chapter. The accompanying figure shows the internal construction of one of these machines.

F, represents the fire-box, or place where the fire is kept ; D, the door, through which the fuel is introduced ; G, one of the bars of the grate, at the bottom ; the spaces, marked B, are the interior of the boiler, in which the water stands, at the height indicated by the dotted line The boiler is closed on all sides ; all its openings being guarded by valves. The tubes, marked [*ee*,] conduct the smoke and flame of the fuel, through the boiler, to the chimney, CC, serving, at the same time, to communicate the heat to the remotest part of the boiler. By this arrangement, none of the heat is lost ; as these tubes are all surrounded by the water. SSS, is the steam-pipe, open at the top, BS, having a steam-tight cock, or regulator, V, which is opened and shut by the crank, H,

* For an account and figure of an engine, of this kind, see Farey on the Steam Engine, p. 686, and Plate XVII.

extending outside of the boiler, and which is managed by the engineer.

The operation of the machine is as follows: The steam being generated in great abundance, in the boiler, and being unable to escape out of it, acquires a considerable degree of elastic force. If, at that moment, the cock, V, is opened, by the handle, H, the steam, penetrating into the tube, S, at the top, near X, and in the direction of the arrows, passes through the tube, and the valve, V, and enters the valve-box, [*i*.] There, a sliding valve, [*oo*,] which moves at the same time with the machine, opens for the steam a communication, successively, with each end of the cylinder. Thus, in the figure, the entrance, on the left hand of the sliding valve, is represented as being open, and the steam follows, in the direction of the dotted line, into the cylinder, where its expansive force will move the piston, P, in the direction of the arrow. The steam, or air, on the other side of the piston, passes out, in the direction of the dotted line, to [*u*,] which communicates with the tube, [*tt*,] from which it passes into the chimney, C, and thence into the open air. The sliding valve, [*oo*,] now moves, and leaves the right-hand aperture open, while it closes the one on the left. The steam then draws the piston back; and that portion of steam, on the left of the piston, having performed its office, passes out of the aperture, [*u*,] an opening to which is made, by the new position of the sliding valve. Thus, the sliding valve, opening a communication, alternately, with each side of the piston, the steam is admitted on both sides of the piston, and, having performed its office, it passes through the aperture, [*u*,] to the tube, [*tt*,] and the chimney, C, and from thence into the open air.

Motion being thus given to the piston, it is communicated, by means of the rod, R, and the beam, G, to the crank, K; which, being connected with the axle of the wheel, causes it to turn, and thus moves the machine.

Power of the Steam Engine.—Dr. Lardner has given the following statements, relating to the power of the steam-engine.

In a report, published in 1835, it was announced, that a steam-engine, erected at a copper-mine, near St. Aus tle, in Cornwall, had raised, by its average work, ninety five millions of pounds, one foot high, with a bushel of coals. This enormous mechanical effect having given rise to some doubts, as to the correctness of the experiments, on which the report was founded, it was agreed, that another trial should be made, in the presence of a number of competent, and disinterested, witnesses. This trial, accordingly, took place, and was witnessed by a number of the most experienced mining engineers, and agents. The result was, that, for every bushel of coals, consumed under the boiler, the engine raised one hundred and twenty-five and a half millions of pounds weight, one foot high.

It may not be uninteresting to illustrate the amount of mechanical virtue, which is thus proved to reside in coals, in a more familiar manner.

Since a bushel of coal weighs eighty-four pounds, and can lift fifty-six thousand and twenty-seven tons, a foot high, it follows, that a pound of coal would raise six hundred and sixty-seven tons, the same height; and, that an ounce of coal would raise forty-two tons, one foot high, or it would raise eighteen pounds, a mile high.

Since a force of eighteen pounds is capable of drawing two tons, upon a rail-way, it follows, that an ounce of coal possesses mechanical virtue sufficient to draw two tons, a mile, or one ton, two miles, upon a level rail-way.

The circumference of the earth measures twenty-five thousand miles. If it were begirt by an iron rail-way, a load of one ton would be drawn round it, in six weeks, by the amount of mechanical power which resides in the third part of a ton of coals.

The great pyramid of Egypt stands upon a base, measuring seven hundred feet, each way, and is five hundred feet high; its weight being 12,760,000,000 pounds. To construct it, cost the labor of one hundred thousand men, for twenty years. Its materials would be raised from the ground, to their present position, by the combustion of four hundred and seventy-nine tons of coals.

The weight of metal, in the Menai bridge, is four mil lion pounds, and its height, above the level of the water, is one hundred and twenty feet. Its mass might be lifted from the level of the water, to its present position, by the combustion of four bushels of coals.

Projected Improvements.—Besides the improvements which have been actually effected, in the construction and application of the steam-engine, a variety of projects, for increasing the power and usefulness of this agent, have, from time to time, occupied the attention of ingenious men. Of the improvements which have been attempted, some are opposed by obstacles, which have not yet been satisfactorily surmounted, and others, by difficulties, in themselves, insurmountable. The following have been among the most prominent subjects of speculation.

1. *Rotative Engines.*—These are engines, in which the steam is so applied, as to produce a direct rotary motion, without the intervention of a rectilinear movement. Engines, on this principle, have been constructed in many different ways. An idea of one of the most obvious forms, may be obtained from the eccentric pumps, de scribed in the following chapter, which have been con verted into steam-engines, by reversing the motions, and changing the resistance for the power. Some rotative engines have been constructed on the principle of Barker's mill ; others have been made, by immersing an overshot-wheel in a cistern of heated fluid, either water, oil, or melted metal, and delivering the steam under the ascending or inverted buckets ; so that, when these were filled with steam, the full buckets, on the opposite side, might preponderate, and cause the wheel to revolve. But, in general, the rotary engines hitherto constructed, have either been feeble in power, or encumbered with excessive friction, on account of the extensive packing, which is necessary, to keep them tight ; so that none of them have found their way into use. It is probable, that no method of constructing a variable cavity, for steam, which is, in other respects, suitable, affords so advantageous a mode of applying the power, as the cylinder and piston, producing rectilinear motion.

Use of Steam at high Temperatures.—In non-condensing, or high-pressure engines, the power, which is convertible to use, consists of the surplus which remains, after overcoming the pressure of the atmosphere. Of course, the higher is the temperature at which the steam is worked, the greater is the total gain, supposing the absorption of heat, and the production of power, to continue to take place, in equal proportions. This consideration, with other expected advantages, has given rise to many attempts to improve the steam-engine, by devising modes of applying steam, at much higher temperatures than those, which it has been ordinarily found practicable to employ. Attempts of this kind have, also, frequently been founded upon an undue estimate of the elastic force of steam, at high temperatures, and of the absorption of heat, during its production. In practice, it is found difficult to obtain a material, capable of confining water and steam, in safety, when raised to such a temperature, as to produce a pressure of ten, or more, atmospheres ; since, independently of the strain upon the joinings, the cohesive strength of metals is diminished, and their oxidation promoted, by exposure to great heat.

Use of Vapors of low Temperature.—Certain liquids, such as alcohol, ether, sulphuret of carbon, and a liquid, obtained by condensing oil-gas, have been proposed, as substitutes for water, in producing steam, on account of the low temperature, at which they are converted into vapor. Thus, alcohol boils at about one hundred and seventy-three degrees of Fahrenheit ; sulphuric ether, at ninety-eight degrees ; muriatic ether, at fifty-one degrees ;* sulphuret of carbon, at one hundred and sixteen degrees ; and oil-gas liquid, at one hundred and eighty-six ; all of which are lower than the boiling point of water. Some of these, when raised to the boiling point of water, have a much greater elastic force than that fluid. Thus, the sulphuret of carbon, at two hundred and twelve degrees, has an elastic force equal to about four atmospheres,† and sulphuric ether, of nearly six atmospheres. But these advan-

* Ure's Dictionary.

† See Tredgold's Tables, Steam Engine, p. 78—81.

tages are nearly counterbalanced, by the small spaces through which these vapors act, their volume, at their boiling point, being only from about an eighth to a third part of that of steam, at the boiling point of water. To this disadvantage may be added the expensive character of these substances, and the difficulty of condensing them, without loss, in any working engine. Some of them, likewise, as the ethers, act, chemically, upon metals, and could not, on this account, be employed in engines made of the common materials.

Gas Engines.—It has been attempted to obtain power for propelling machinery, from the combustion, or explosion, of inflammable elastic fluids, such as coal-gas, and the vapor of combustible liquids, mixed with atmospheric air. In combustions of this kind, rarefaction, and subsequent condensation, take place, which, if conducted within suitable cavities, may be made to afford a moving power, applicable to machinery. The principal engines, which have been constructed, for using this power, are those of Messrs. Morey, in this country, and Brown, in England. If a power of this kind could be made, to afford an adequate propelling force for locomotive engines, upon public roads, it would possess an advantage, in the lightness of the machinery, compared with the weight of steam-engines, with their water and fuel. But it remains for experience to determine, whether the space, through which the force will act, taken in connexion with the cost of the materials, can render this an economical source of power.

In addition to the foregoing method of procuring power, by the combustion of gases, Sir H. Davy has proposed the employment of certain fluids, which are volatile at common temperatures, but which have been condensed into liquids, under great pressure, such as carbonic acid, ammonia, &c. His views are founded upon the immense difference which exists, between the increase of elastic force in gases, under high, and low, temperatures, by similar increments of temperature. But doubts have been raised upon this subject, with regard to the space, through which the force of these gases will act, and, also, in regard to the quantity of heat, requisite to produce the change of temperature required.*

Steam Carriages.—It has long been a favorite object with projectors, to construct a form of the steam-engine, in connexion with a carriage, which should be capable of propelling itself upon the public roads. Locomotive engines are capable of moving themselves upon rail-roads, and of drawing with them additional loaded carriages; because, in this case, the motion is uniform, and very little of the power is expended, in surmounting obstacles, or changing the form of the road. But, upon a public highway, it requires, by a common estimate, about eight times as much power to propel a carriage, as it does upon a rail-road. Of course, the weight and inertia of an engine, capable of producing this power, must increase somewhat in the same proportion, and a great part of the power will become necessary, to transport the machine itself. The inertia, also, will be continually brought into unfavorable action, by the jolts and concussions, inseparable from highway travelling, and thus endanger the destruction of a machine, requiring such nice adaptation of parts, as the steam-engine. It appears, that steam-carriages have been made to run upon good roads, during short experiments, while the engine was new. But we have no account, as yet, of any one having long performed this kind of service.

Steam Gun.—Mr. J. Perkins,† whose experiments on the steam-engine are well known, has attempted the employment of the expansive force of steam, as a substitute for gunpowder, in throwing projectiles. The steam-gun, invented by him, is somewhat similar, in its construction, to the air-gun; but the power is derived from a magazine of water, heated to a very high temperature; so that, when portions of it are discharged from the vessel containing it, they produce steam enough to project a cannon ball with great force. The balls are admitted into the gun, in succession, from a hopper, and can be discharged, at

* Philosophical Transactions, 1826, Tredgold, on the Steam Engine, p 84.

† The public are indebted to Mr. Perkins, for the art of steel engraving, the nail machine, and many other useful inventions.

the rate of twenty-four in a minute. It appears, from some experiments made with these guns, in France, that the projectile force of steam is greatly inferior to that of gunpowder; a consequence, no doubt, of the vast difference, which is known to exist, in the initial force of the two agents; nevertheless, the rapidity, with which the discharges may be made, seems capable of advantageous employment, in some situations.

GUNPOWDER.

Manufacture.—Gunpowder is a solid, explosive, mixture, composed of nitre, sulphur, and charcoal, reduced to powder, and mixed intimately with each other. The proportion of the ingredients varies, very considerably; but good gunpowder may be composed of the following proportions; seventy-six parts of nitre, fifteen of charcoal, and nine of sulphur, equal to one hundred. These ingredients are first reduced to a fine powder, separately, then mixed, intimately, and formed into a thick paste. This is done, by pounding them, for a long time, in wooden mortars, at the same time moistening them with water, to prevent the danger of explosion. The more intimate is the mixture, the better is the powder; for, since nitre does not detonate, except when in contact with inflammable matter, the whole detonation will be more speedy, the more numerous the surfaces in contact. After the paste has dried a little, it is placed upon a kind of sieve, full of small holes, through which it is forced. By that process, it is divided into grains, the size of which depends upon the size of the holes, through which they have passed.

The powder, when dry, is put into barrels, which are made to turn round on their axis. By this motion, the grains of gunpowder rub against each other, their asperities are worn off, and their surfaces are made smooth. The powder is then said to be glazed. The granulation and glazing of the powder causes it to explode more quickly, perhaps, by facilitating the passage of the flame among the particles.

Detonation.—When gunpowder comes in contact with any ignited substance, it explodes, as is well known, with great violence. This effect may take place, even in a vacuum. A vast quantity of gas, or elastic fluid, is emitted, the sudden production of which, at a high temperature, is the cause of the violent effects which this substance produces. The combustion is, evidently, owing to the decomposition of the nitre, by the charcoal and sulphur. The products are, carbonic oxide, carbonic acid, nitrogen, sulphurous acid, and, probably, sulphureted hydrogen. Mr. Cruikshanks has ascertained, that no perceptible quantity of water is formed. What remains, after the combustion, is potash, combined with a small portion of carbonic acid, sulphate of potash, a very small proportion of sulphuret of potash, and unconsumed charcoal.

Force.—The elastic fluid which is generated, when gunpowder is fired, being very dense, and much heated, begins to expand, with a force, at least, one thousand times greater than that of air, under the ordinary pressure of the atmosphere. And, allowing the pressure of the atmosphere to be fourteen and three fourths pounds, upon every square inch, the initial force, or pressure, of fired gunpowder, will be equal to, at least, fourteen thousand seven hundred and fifty pounds, upon every square inch of the surface which confines it. But this estimate, which is that of Mr. Robins, is one of the smallest which has been made. According to Bernoulli, the initial elasticity, with which a cannon ball is impelled, is, at least, equal to ten thousand times the pressure of the atmosphere; and, from Count Rumford's experiments, it appears more than three times greater than this.

Gunpowder, on account of its expensiveness, and the suddenness and violence of its action, is not employed as a regular moving force, for machinery. It is chiefly applied to the throwing of shot, and other projectiles, and the blasting of rocks.

When a ball is thrown from a gun, the greatest force is applied to it, by each particle, at the moment of its explosion. But, since the ball cannot, at once, acquire the same velocity, with which the elastic fluid, if at liberty, would expand, it continues to be acted upon by the fluid, and its motion is accelerated, in common cases, until it has escaped from the mouth of the piece. The acceler ating force, however, is not uniform; and, hence, the following circumstances deserve attention. 1. The elasticity is, inversely, as the space which the fluid occupies; and, therefore, as it forces the ball out of the gun, it continually diminishes. 2. The elasticity would diminish, in this ratio, even if the temperature remained the same; but it must diminish, in a much greater ratio, because a reduction of temperature takes place, both from the dispersion of the heat, and the absorption of it, by the fluid itself, during its rarefaction. 3. The fluid propels the ball, by following it, and acts with a force that is, other things being equal, proportionate to the excess of its velocity, above the velocity of the ball. The greater the velocity that the ball has acquired, the less, therefore, is its momentary acceleration. 4. From this change of relative velocity, there must be a period, when the velocity of the ball will exceed that of the elastic fluid; and, therefore, the proper length for a gun must be that, in which the ball would leave the mouth, at the time when the velocities are equal; and all additional length of the piece, beyond this, can only serve to retard the ball, both by friction, and atmospheric pressure.

The force of fired gunpowder is found to be very nearly proportionate to the quantity employed; so that, if we neglect to consider the resistance of the atmosphere, then the height to which the ball will rise, and its greatest horizontal range, must be, directly, as the quantity of powder, and, inversely, as the weight of the ball. Count Rumford, however, found, that the same quantity of powder exerted somewhat more force upon a large ball, than on a smaller one.

Properties of a Gun.—The essential properties of a gun are, to confine the elastic fluid, as completely as possible, and to direct the course of the ball to a rectilinear path; and hence arises the necessity of an accurate bore. The *windage*, or space, produced by the difference of diameter between the ball and the bore, greatly diminishes the effect of the powder, by allowing a part of the elastic fluid to escape, before the ball. The advantage of a rifle barrel is chiefly derived from the more accurate contact of the ball with its cavity. When the bore is twisted, it is also supposed to produce a rotation of the ball round an axis, in the direction of its motion, which renders it less liable to deviate from its path, on account of irregularities in the resistance of the air. The usual charge of powder is one fifth, or one sixth, of the weight of the ball ; and, for battering, one third. When a twenty-four pounder is fired, with two thirds of its weight of powder, it may be thrown about four miles ; the distance being reduced, by the resistance of the air, to about one fifth of that, which it would describe, if thrown in a vacuum.*

It is certain, that the grains of gunpowder do not inflame at once, but that the inflammation occupies time, in being communicated from one particle to another ; so that they act, successively, rather than simultaneously, in impelling the ball. This circumstance contributes, greatly, to the safety of fire-arms ; for, if the whole charge of powder exploded at once, the piece would be in danger of bursting, before the inertia of the ball would be overcome. It is on account of the suddenness of their detonation, that the various fulminating powders are inapplicable to use, in fire-arms. The bursting of a gun may be occasioned, by the defective condition of the metal, the disproportionate amount of the charge, the adhesion and inertia of the shot, or the inertia of some other body, opposing the escape of the charge. It is from this last circumstance, that a gun is liable to burst, if fired with its muzzle under water.

To enable gunpowder to exert its full effect, the proportions of the cavity of the piece, to the charge, should be such, as to allow all the grains to explode, before they leave the cavity ; and, also, to permit the elastic fluid to expend as much of its pressure, as is capable of accelerating the ball. The superiority of a musket, over a pistol, arises from its prolonging the action of the powder in this way. But, for reasons already stated, there are limits to the length of the barrel, which cannot be usefully

* Young's Natural Philosophy, vol. i p. 350.

exceeded; and these have been nearly settled, by common practice.

Blasting.—The splitting of rocks, by gunpowder, is performed by drilling holes, to a certain depth, and inserting a charge of powder, at the bottom. The hole is then filled up, by ramming in fragments of stone, bricks, or other hard substances, keeping in a steel wire, which is afterwards withdrawn, to furnish a passage for the priming, by which fire is communicated to the charge. To prevent the danger of a spark, copper wire is often used, instead of steel. And, to prevent the small fragments from flying about, it is found useful to cover the rocks with brush-wood, or some other elastic substance.

Rocks may be blasted, at a considerable depth under water, by means of the diving-bell, which enables workmen to drill and charge them in safety. In the method practised at Howth, in Ireland, after the charge is inserted, a tin tube is carried up from the rock, to the surface of the water. It is kept empty, and made water-tight, by screwing the joints to each other, as the bell ascends. The powder is ignited, by dropping pieces of red-hot iron, through the tube, from a boat at the surface. When the depth exceeds twelve feet, no danger or inconvenience is experienced by the boats, beyond a violent, eruptive, ebullition of the water.

Magnetic Engines.—Since the discovery of electro-magnetism, by aid of which, very powerful magnets have been obtained, various persons have introduced machines, which revolve, and act upon a small scale, by magnetic power. But a radical difficulty has hitherto attended them, that the magnetic force acts at distances, so extremely small, and diminishes, in such a rapid ratio, as the distance increases, that these machines have not been found convertible to any very important use.

WORKS OF REFERENCE.—SMEATON'S Miscellaneous papers 4to. 1814;—ROBISON'S Mechanical Philosophy, vols. ii. and iii.;—GREGORY'S Mechanics;—BREWSTER'S Ferguson's Mechanics;—NICHOLSON'S Operative Mechanic, 8vo.;—FAREY'S Treatise on the Steam Engine, 4to 1827; this is the most extensive work, on its subject;—TREDGOLD, on the Steam Engine, 4to. 1828; this is the most philosophic work, on the subject;—STUART, on the Steam Engine, 8vo. 1824 ;—Partingdon, on the Steam Engine, 8vo. 1825 ;—Renwick, on the Steam Engine, 8vo. New York, 1830 ;—Bossut, *Traité Theoretique et Experimental d' Hydrodynamique*, 1771 ;—Du Buat, *Traité d' Hydraulique*, &c. 1786, &c. ;—Playfair's Outlines of Natural Philosophy, 8vo. 1819 ;—Ure's Dictionary of Chemistry ;—Works of Coulomb, Desaguliers, De La Hire, Deparcieux, Hutton, Robins, Rumford, &c.

CHAPTER XVII.

ARTS OF CONVEYING WATER.

Of Conducting Water, Aqueducts, Water Pipes, Friction of Pipes, Obstruction of Pipes, Syphon. *Of Raising Water*, Scoop Wheel, Persian Wheel, Noria, Rope Pump, Hydreole, Archimedes' Screw, Spiral Pump, Centrifugal Pump, Common Pumps, Forcing Pump, Plunger Pump, De La Hire's Pump, Hydrostatic Press, Lifting Pump, Bag Pump, Double-acting Pump, Rolling Pump, Eccentric Pump, Arrangement of Pipes, Chain Pump, Schemnitz Vessels or Hungarian Machine, Hero's Fountain, Atmospheric Machines, Hydraulic Ram. *Of Projecting Water*, Fountains, Fire Engines, Throwing Wheel.

The employment of water, as an agent for producing motion, has already been considered. It remains to attend to the various modes, by which this fluid may be conveyed, from one place to another, either for use in the arts, or for application to the necessary purposes of life. The principal circumstances which require attention, under this head, are the following. 1. The conducting of water, from one place to another, having the same, or a lower, level. 2. The raising of water, to a higher level. 3 The projection of water, through the atmosphere.

OF CONDUCTING WATER.

Aqueducts.—When water flows in a current, or stream, as in rivers or canals, it does so in obedience to gravitation, and in consequence of the surface being lower at the end towards which it is flowing, than in that from which it proceeds. Its motions are governed by laws, somewhat different from those of solid bodies, descending upon inclined planes, and this difference is owing to the want of cohesion among the particles. Instead of moving simultaneously, the particles continually change their relative position; so that, while one portion of the fluid may be moving rapidly, another may be stationary, or even moving, by an eddy, in a contrary direction. The motion, however, will continue, both in open channels, and in properly constructed pipes, until an equilibrium is produced, by the surface, at both ends of the channel, arriving at the same level. Aqueducts are artificial channels, or conduits, for the conveyance of water, in a horizontal, or descending, direction. The aqueducts, constructed by the ancient Romans, were among the most costly monuments of their arts. Several of these were from thirty to a hundred miles in length, and consisted of vast covered canals, built of stone. They were carried over valleys, and level tracts of country, upon arcades, which were sometimes of stupendous height and solidity. A similar method has been practised, in some modern cities, of warm, or temperate, climates.

In colder latitudes, if the course of the aqueduct is above the ground, the water is liable to be interrupted, by freezing, in winter. It has, therefore, become common, to resort to subterranean passages for water, which are placed so deep, as to be below the reach of frost, and are, also, favorably situated, both for convenience and economy. Culverts, and drains, which are intended merely to remove and expend water, are usually made of brick, or stone; but, for conveying water with the smallest expenditure by loss, *water-pipes* are most frequently resorted to.

Water Pipes.—The pipes, by which water is conveyed beneath the ground, are, generally, of small, or moderate, size, and are intended to be water-tight. In consequence of a well-known law of fluids, a water-pipe may possess any degree of flexure, and any number of curvatures, below the level of the fountain-head; yet, if it be not obstructed by air, or any other internal obstacle, it will rise, at the discharging end, and may be delivered, at the height of the original level. Pipes, for transmitting water, have been made from a great variety of materials.* It is desirable that they should possess strength, tightness, and durability, and that the material, of which they are composed, should not be capable of contaminating the water. *Wooden pipes* are, commonly, hollow logs, perforated, by boring through their axis, and connected together, by making the end of one log conical, and inserting it into a conical cavity in the next. When large trunks are required, they are composed of thick staves and hoops, like a cask. They should, where practicable, be imbedded in clay, and buried at a greater depth, than the frost is ever known to penetrate. Wooden pipes are in common use, in this country, but are liable to decay, especially at the joints, where their thickness is smallest. In salt marshes, they are more durable, though still liable to decay, from the attrition, and decomposing effect, of the water within them.

Iron pipes are, at the present day, considered preferable to those of wood, being stronger, and, in most situations, more durable. They are made of cast-iron, with a socket, or enlarged cavity, at one end, into which the end of the next pipe is received. The joints, thus formed, are rendered tight, either by filling the interstices with lead, or by driving in a small quantity of hemp, and filling the remainder of the socket with iron cement, made of sulphur, muriate of ammonia, and chippings of iron. *Copper pipes* are extremely durable, and are made of sheet copper, with the edge turned up, and soldered. They require to be tinned, inside, on account of the poisonous character of some of the compounds, which are liable to be formed in them. *Lead pipes* are much employed, for small aqueducts, owing to the facility with which they can be soldered, and bent in any direction. They are commonly cast in short pieces, and afterwards elongated, by drawing them through holes, in the same manner as wire. Leaden pipes, in general, are supposed not to contaminate the water contained in them, because the carbonate of

* It appears, that the use of water-pipes was not unknown to the ancients. Some rules, respecting the use of leaden and earthen pipes are given by Vitruvius de Architecturà, Lib. viii.

lead, which is sometimes formed in them, is insoluble in water. They are not safe, however, for pumps and pipes, intended to convey acid liquors. *Stone pipes* preserve the water, contained by them, in a very pure state. They are, however, expensive, on account of the labor of working them, with the exception of soap-stone, which, being easily shaped and bored, may be usefully applied to the purpose of conveying water, in those places where it is easily procured. *Earthen pipes*, made of common pottery ware, and glazed on the inside, are sometimes used, but are more liable to be broken, than most of the other kinds.

Friction of Pipes.—In a river, or open channel, it is observable, that the water flows most rapidly, in the middle of the upper surface, while it is most retarded, at the edges, and at the bottom. In like manner, in a cylindrical pipe, the fluid has the greatest velocity, at the centre, or axis, and the smallest velocity, at the surface, or where it is in contact with the pipe. The force, by which this retardation is occasioned, is commonly called friction. It differs, in many respects, from the friction of solids; and more resistance is occasioned, by the internal action of the fluid particles upon each other, than by the contact of the solid surface, in which they are contained. The investigation of the laws which govern the movements of fluids is intricate, and the results of experiment have not agreed with the previous conclusions of theory. Various writers, on the science of hydraulics, have treated this subject with an extensiveness of research, which can only be understood from their own works. Among the more simple, practical, facts, to which it is useful to attend, the following may be briefly stated. 1. The velocity of water is greater in a large pipe, than in a small one, having the same position; and hence, a large pipe will discharge more water, in a given time, than a number of small ones, having, jointly, the same capacity. A pipe, of two inches diameter, will give more water, than five pipes, of one inch diameter; it being ascertained, that the squares of the discharges are, very nearly, as the fifth powers of the diameters.* 2. Irregularities and inequalities,

* Robison's Mechanical Philosophy, vol. ii. p 578.

in the diameter of the pipe, diminish the amount of water which they transmit, by altering the direction of the particles, and by changing their velocity, so as to renew the resistance of inertia. 3. In like manner, all curves and angles, which occur in the pipe, have a similar retarding effect, by creating new motions, or counter currents. 4. The form of the end of the pipe, which communicates with the fountain-head, or reservoir, greatly affects the quantity of water received by it. If it be gradually enlarged, like a trumpet mouth, a larger quantity of water will be received, than by any of the modes which follow, because the direction, given to the particles by this form, is most favorable to their admission. If the entrance to the pipe be abrupt, in consequence of the cavity being wholly cylindrical, the particles will have a tendency to cross each other, and less water will enter the pipe, in a given time. And, if the end of the pipe projects into the reservoir, a variety of opposing forces will be produced, among the particles moving toward the entrance; so that a smaller quantity will be received by the pipe, than in either of the preceding cases.

The form of the discharging orifice, also, influences the quantity of water delivered by a pipe, in a given time. If the end of the pipe be enlarged, by adding to it a frustum of a hollow cone, the amount of water discharged, in some cases, may be prodigiously increased.* This fact, described by Venturi, appears to be the result of the pressure of the atmosphere, aided by the inertia and cohesiveness of the water.

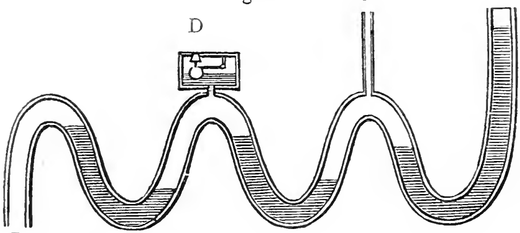
Obstruction of Pipes.—Water pipes are liable to be obstructed, chiefly, by the following circumstances. 1. By the freezing of the water, in winter, if the pipe has not been laid sufficiently deep. 2. By the deposition of sand and mud, in the lower parts of the pipe. To obviate this, the water should pass through a strainer, before it enters the pipe. And, if plugs are placed at the lower parts of the bendings, then, whenever these are opened, the water rushes out with sufficient rapidity, and carries

* See Edinburgh Encyclopedia, Art. *Hydrodynamics*, pp. 494, 495

the deposition with it. 3. By the penetration of roots, or the growth of aquatic vegetables, in the cavity of the pipe This principally happens in wooden pipes, after they begin to decay. 4. By the collection of air, in the upper parts of the bendings. This is a serious evil, and may take place in all pipes, which have an undulating course, or more vertical curvatures than one. When air is thus confined in the pipes, the water will not rise to the same height, at the discharging end, as at the fountain head. The air, being the lighter fluid, tends to occupy the highest part of the bendings. Any pressure, applied at the fountain-head, tends to push this air a little beyond the highest part, so as to make it occupy a portion of the descending side of the curve. Of course, the sum of the weights, in the descending sides, will be less than the sum of the weights, in the ascending sides, and the fluids will not be in equilibrium, except when the water, at the fountain-head, is higher than that at the discharging end. The conditions, upon which this equilibrium is produced, are the same as those which sustain the fluid, at different levels, in Hero's fountain, the spiral pump, and the hydrostatic lamp.

The prevention of this evil consists, in avoiding vertical curves, and in laying the pipe, if possible, with an uninterrupted slope, or, at least, with only one slope in each direction. When this is done, the air will escape at one, or both, ends of the pipe. But, when vertical curves are unavoidable, an open tube, the height of which is equal to that of the fountain-head, should be attached to the highest part of the curve. By this arrangement, the air will readily escape. In like manner, if a tight air-box be fastened upon the upper part of the curve, and filled with water, the air will escape into this box, and displace the water, without interrupting the current in the pipe. The air-box may be made to regulate itself, and to discharge the air, when it is full, by means of a valve in the top, connected with a floating, hollow, copper ball. As the air increases, the copper ball will subside with the water, till it opens the valve, for the air to escape. In Fig. 160, AB, represents an undulating pipe, of which

Fig. 160.



A, is the fountain-head, and B, the discharging end. The water and air will arrange themselves, as represented by the darker and lighter parts of the tube, and, being in equilibrium, no water will be discharged. If an upright tube, C, be attached to either of the upper flexures, it will discharge the air from that flexure. Or, if a tight box, or vessel, D, be substituted, with a copper float and valve, it will have a similar effect. Simple punctures, made in the upper part of the pipe, also answer a temporary purpose.

Syphon.—The syphon may be regarded as an instrument for the lateral conveyance, rather than the rising, of water; since the fluid must always be delivered, at a lower level than that at which it is received. The syphon is a bent tube, of which one extremity, or leg, is longer than the other. If the shorter leg be inserted in a fluid, and the air be exhausted from the longer leg, by suction, or otherwise, till the syphon is full of water, then the column of fluid in the longer leg will preponderate, and the current will take place. This will continue, either till the water, in the feeding vessel, sinks below the end of the syphon, or that in the receiving vessel rises to the same height with the other. As the movement depends upon the pressure of the atmosphere, water cannot be raised, in a syphon, to a greater height than thirty-four feet.

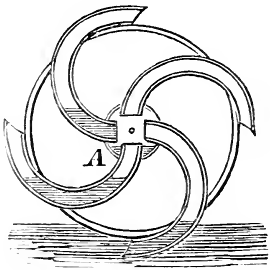
For practical use, the longer leg of the syphon is often closed with a stop-cock, and the air exhausted from it, by a small pump, till the leg is full. The stop-cock is then opened, and the fluid immediately flows through the syphon.

OF RAISING WATER.

The lateral conveyance of water is effected, in the modes already described, by the aid of its own gravity. The *raising* of water is effected, against gravity, by the employment of some moving force. Hydraulic machines, for raising water, may be impelled by a current, or fall, of the water itself, or by any other moving agent. Among a great variety of machines, which have been constructed for this use, the following are some of the most noticeable.

Scoop Wheel.—If a water-wheel is provided with a hollow axle, and if, in the place of spokes, or radii, it is furnished with crooked tubes, or cavities, of a suitable curvature, it will raise water to the height of its own axis, whenever it revolves in the direction of the mouths of the tubes. Each spoke, or curved tube, as it dips its extremity in the water, lifts a certain portion of the fluid; and, as the revolution continues, this water will flow through the tube, approaching nearer to the axis, until it is discharged into the central hollow. To prevent the water from regurgitating, the inner ends of the tubes must be guarded by valves, or else made to project, for a short distance, into the central cavity, as seen at A, in Fig. 161. In the latter case, it is necessary, that they

Fig. 161.



should enter, at different distances from the end of the axle. The axle may also be divided into as many longitudinal compartments, as there are tubes in the wheel.

This was done in the ancient tympanum, a machine described by Vitruvius, which was somewhat similar, in its principle, to the scoop-wheel.

Persian Wheel.—The Persian wheel, in certain respects, resembles the scoop-wheel, and is sometimes combined with it, in the same machine. It differs from it, in its effect, by raising the water through the whole diameter of the wheel. Its form is easily understood, by supposing a number of buckets to be hung round the circumference of a water-wheel, upon pivots, at equal distances. As the wheel turns, the buckets are successively immersed in the water, at the bottom, and filled. They then pass upwards, till they arrive at the top of the wheel, where they strike a fixed obstacle, and are overset, discharging their water into a trough, placed at the top, to receive it. This machine is said to be in common use, in several of the Oriental countries.

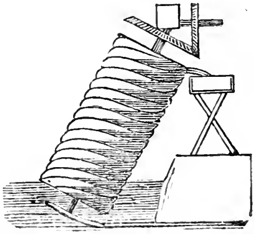
Noria.—The machine used in Spain, under the name of noria, consists of revolving buckets, like the Persian wheel. But, instead of a single wheel, two drums, or trundles, are employed, and the buckets are attached to ropes, or chains, passing round them. In Spain, earthen pitchers are said to be used; but, in other countries, wooden buckets are employed, like those of an overshot-wheel. A sufficient idea of the form of the noria may be obtained, by inspecting the figure of the chain-wheel, on page 89, and supposing the motion reversed.

Rope Pump.—Instead of a series of buckets, connected by ropes, or chains, a similar effect is, sometimes, produced by a simple rope, or a bundle of ropes, passing over a wheel above, and a pulley below, moving with a velocity of about eight or ten feet in a second, and drawing up a certain quantity of water, by its friction. It is probable, that the water commonly ascends, with about half the velocity of the rope. While the water is, principally, supported by the friction of the rope, its own cohesion is sufficient to prevent it from wholly falling, or being scattered, by any accidental inequality of the motion. The portion raised is collected in a trough, at the top.

Hydreole.—This name is given by M. Mannoury Dectot, to an invention for raising water, by the admixture of atmospheric air. If a column of water be intimately mixed with air, in small bubbles, the air will occupy some time in ascending to the surface; and the meanwhile, the collective specific gravity of the whole column will be much less, than if it consisted of water alone. If a vertical tube be placed in a reservoir of water, and if a quantity of air be injected into the bottom of the tube, by a bellows, or forcing pump, the water in the tube will immediately rise to a higher level, and remain, until the air has escaped at the top. And, if the tube be of proper height, the water will overflow, in the same manner as it does during the ebullition of boiling liquids. This appears, however, not to be a very economical mode of applying force.

Archimedes' Screw.—This name is given to a machine, formed by one or more pipes, wound spirally round a cylinder, which revolves on an axis, in an oblique situation. It is used, in some places, under the name of *water-snail.* Its mode of operation may be easily conceived, by supposing a tube, formed into a hoop, to be rolled up an inclined plane, in which case, the fluid would be forced, by the elevation of the tube behind it, to run, as it were, up hill. The screw is usually turned, by a water-wheel. During each revolution, the lower end of each spiral tube is immersed in the water, and dips up a certain quantity. This water, by its gravity, keeps to the lower side of the screw, as seen in Fig. 162; but, at the

Fig. 162.



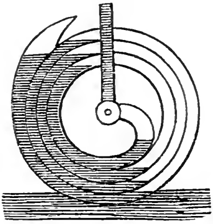
same time, in consequence of the revolutions of the screw, it passes continually upward, until it is delivered, at the highest end.

This instrument is sometimes made, by fixing a spiral partition round a cylinder, and covering it with an external coating, either of wood, or of metal. It should be so placed, with respect to the surface of the water, as to fill, in each turn; one half of a convolution; for, when the orifice remains always immersed, its effect is much diminished. It is generally inclined to the horizon, in an angle of between forty-five and sixty degrees; hence it is obvious, that its utility is limited to those cases, in which the water is only to be raised to a moderate height. The spiral is seldom single, but usually consists of three or four separate coils, forming a screw, which rises, more rapidly, round the cylinder.

A *water-screw*, which operates in a similar manner, may be made, by a spiral partition, wound upon a central axis, and revolving, by itself, within a smooth hollow cylinder, to the cavity of which it is nearly fitted. In this form, however, there is some loss, by the leakage between the screw, and the cylinder which contains it.

Spiral Pump.—This machine is formed, by a spiral pipe, consisting of many convolutions, arranged either in a single plane, as in Fig. 163, or in a cylindrical, or con-

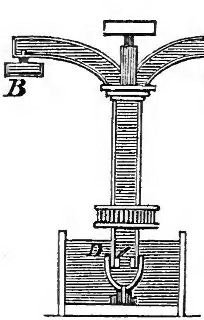
Fig. 163.



ical, surface, and revolving round a horizontal axis. The pipe is connected, at one end, by a central water-tight joint, to an ascending pipe, while the other end receives, during each revolution, nearly equal quantities of air and water. It was invented, about 1746, by Andrew Wirtz, a pewterer, at Zurich; whence it is often called the *Zurich machine.* It is said to have been used, with great success, at Florence, and in Russia. Dr. Young states, that he has made use of it, for raising water, to a height of forty feet. The end of the pipe is furnished with a *spoon*, containing as much water as will fill half of one of its coils. The water enters the pipe, a little before the spoon has arrived at its highest situation, the other half remaining full of air. The air communicates the pressure of the column of water to the preceding portion; and, in this manner, the effect of nearly all the water in the wheel is united, and becomes capable of supporting the column of water, or of water mixed with air, in the ascending pipe. The air, nearest the joint, is compressed into a space, much smaller than that which it occupied at its entrance; so that, where the height is considerable, it becomes advisable to admit a larger portion of air than would, naturally, fill half the coil. This lessens the quantity of water raised, but it lessens, also, the force required to turn the machine. The joint should be conical, in order that it may be tightened, when it becomes loose; and the pressure ought to be removed from it, as much as possible. The loss of power, supposing the machine well constructed, arises only from the friction of the water on the pipes, and the friction of the wheel on its axis; and, where a large quantity of water is to be raised to a moderate height, both of these resistances may be rendered inconsiderable. But, when the height is very great, the length of the spiral must be much increased, so that the weight of the pipe becomes extremely cumbersome, and causes a great friction on the axis, as well as a strain on the machinery.

Centrifugal Pump.—The centrifugal force has sometimes been employed, in conjunction with the pressure of the atmosphere, as an immediate agent, in raising water, by means of a rotary pump. The machine, called centrifugal-pump, consists of a vertical pipe, capable of revolving round its axis, and connected, above, with a horizontal pipe, which is open at one, or at both, ends; the whole being furnished with proper valves, to prevent the escape of the water, when the machine is at rest. As soon as the rotation becomes sufficiently rapid, the centrifugal force of the water, in the horizontal pipe, causes it to be discharged, at the ends, its place being supplied, by means of the pressure of the atmosphere on the reservoir below, which forces the water to ascend, through the vertical pipe. This machine may be so arranged, that, according to theory, very little of the force applied is lost; but it has failed of producing, in practice, a very advantageous effect. In Fig. 164, a centrifugal pump is

Fig. 164.

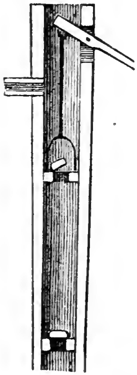


represented. The machine is first filled witn water, through the funnel, A, while the valve, at D, prevents the water from descending. The whole is then made to turn rapidly, and the water is discharged, from the ends of the horizontal part, into a circular trough, a section of which is seen at B, and C.

Common Pumps.—A pump is a machine, so well known, and so generally used, that the denomination has sometimes been extended to hydraulic machines of all kinds. The term, however, in its strictest sense, is to be understood of those machines, in which the water is raised, by the motion of one solid within another; and this motion is usually alternate, but sometimes continued, so as to constitute a rotatior. In the pumps most com monly used, a cavity is enlarged and contracted, by turns, the water being admitted into it through one valve, and discharged through another.

The common *household-pump* has otherwise been called the *sucking-pump*, from the circumstance, that the water is raised in it, by the pressure of the atmosphere. In this country, pumps are made for common use, both in wells, and in ships, by boring logs, so as to produce a large hollow, and inserting two hollow wooden plugs, called *boxes*, at different heights, both of which are furnished with valves, or clappers, opening upwards. The lower box is made stationary, and serves merely to prevent the water, which is raised, from running back. The upper box is a hollow movable piston, attached, by its rod, to the handle, or *brake*, of the pump. When the pump is full of water, every stroke of the handle raises this box, together with the column of water above it. When the handle is lifted, the box is pushed further down into the water, while its valve opens, to allow the water to pass through. In Fig. 165, this pump is represented,

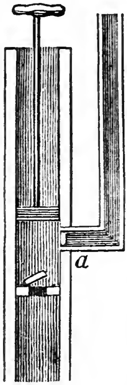
Fig. 165.



with the box just beginning to descend. The valve then shuts, and the second stroke of the pump raises another column of water to the spout. As the action of this pump depends upon the pressure of the atmosphere, water cannot be raised by it, from a depth of more than thirty-four feet below the upper valve; and, in practice, a much shorter limit is commonly assigned.

Forcing Pump.—The forcing-pump differs from the common sucking-pump, just described, in having a solid piston, without a valve, and the spout, or discharging orifice, placed below the piston. When the piston is raised, the lower valve of the pump rises, and admits the water from below, as in the common pump. But when the piston is depressed, the water is thrown out, through a spout in the side, which has a valve opening outward, at [*a*,] in Fig. 166. In a forcing-pump, the water cannot

Fig. 166.

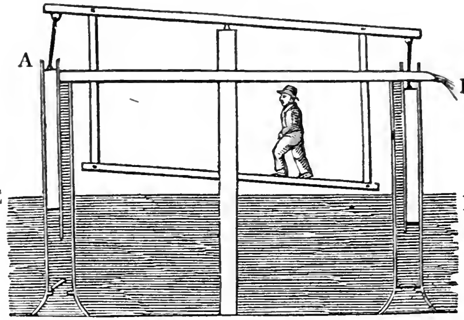


be brought from a depth, of more than thirty-four feet below the piston; but it can afterwards be sent up, to any height desired, in a pipe, [*ab*,] because the pressure, communicated by the downward stroke of the piston, is not dependent on the pressure of the atmosphere, but upon the direct force applied to the piston.

Plunger Pump.—A very effectual pump, for raising a large quantity of water, to a small height, is shown in Fig. 167, on the following page.

It is made, by fitting two upright beams, or plungers, A and B, of equal thickness, throughout, into cavities,

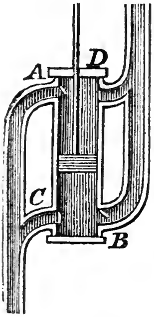
Fig. 167.



nearly of the same size, allowing them only room to move without friction, and connecting the plungers together, by a horizontal beam, moving on a pivot. The water being admitted, during the ascent of each plunger, by a large valve, in the bottom of the cavity, at C and D, it is forced, when the plunger descends, to escape through a second valve, at E or F, in the side of the cavity, and to ascend, by a wide pipe, to the top of the machine. The plungers ought not to be, in any degree, tapered; because, in this case, a great force would be unnecessarily consumed, when they descend, in throwing out the water, with great velocity, from the interstice formed by their elevation. This pump may be worked by a laborer, walking backwards and forwards, either on the beam, or on a board, suspended below it. By means of an apparatus of this kind, described by Professor Robison, an active man, loaded with a weight of thirty pounds, has been able to raise five hundred and eighty pounds of water, every minute, to a height of eleven and a half feet, for ten hours a day, without fatigue. This, says Dr. Young, is the greatest effect produced by a laborer, that has ever been correctly stated, by any author; it is equivalent to somewhat more than eleven pounds, raised through ten feet, in a second, instead of ten pounds, which is a fair estimate of the usual force of a man, without any deduction for friction.

De La Hire's Pump.—A pump, partaking of the nature of a forcing and a sucking pump, is sometimes called a *mixed* pump. In De La Hire's pump, which is of this kind, and shown in Fig. 168, the same piston is made to serve

Fig. 168.



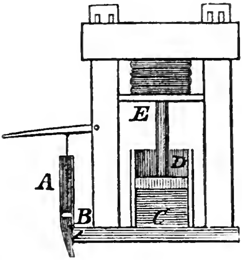
a double purpose ; the rod working in a collar of leathers, and the water being admitted and expelled, in a similar manner, above and below the piston, by means of a double apparatus of valves and pipes. When the piston is depressed, the water enters the barrel at the valve, A, and goes out at B. When the piston is elevated, it enters at C, and escapes at D.

For forcing-pumps, of all kinds, the common piston, with a collar of loose and elastic leather, is preferable to those of a more complicated structure. The pressure of the water, on the inside of the leather, makes it sufficiently tight, and the friction is inconsiderable. In some pumps, the leather is omitted, for the sake of simplicity, the loss of water being compensated by the greater durability of the pumps ; and this loss will be the smaller, in proportion, as the motion of the piston is more rapid.

Hydrostatic Press.—This powerful machine is essentially a forcing-pump, aided, in its action, by the well-known properties of hydrostatic pressure. It appears to have been invented by Pascal, previously to 1664, and recommended by him, as a new mechanical power. It was, however, practically, lost sight of, till it was re-invented by

Mr. Bramah, more than a century afterwards. In this press, the water is forced, by a small pump, into a strong iron cylinder, in which it acts on a much larger piston; consequently, this piston is urged by a force, as much greater than that which acts on the first pump-rod, as its surface is greater than that of the small one. In Fig. 169, the water is forced, by the pump, A, through the

Fig. 169.

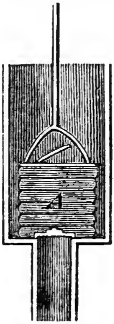


pipe, B, into the cylinder, C, in which it acts, very powerfully, upon the large piston, D, and raises the bottom of the press, E. The upward force, by which the material, above E, is compressed, exceeds the force, which is applied to the pump, as much as the surface of the piston, D, exceeds that of the piston of the pump. In practice, the cylinder, C, requires to be made much thicker than here represented.

Lifting Pump.—Where the height, through which the water is to be raised, is considerable, some inconvenience might arise, from the length of the barrel, through which the piston-rod of a sucking-pump would have to descend, in order that the piston might remain within the limits of atmospheric pressure. This may be avoided, by placing the movable valve, below the fixed valve, and introducing the piston, at the bottom of the barrel. It is then worked, by means of a frame, on the outside. Such a machine is called a *lifting-pump*. In common with other forcing-pumps, it has the disadvantage of thrusting the piston before the rod, and thus tending to bend the rod, and produce an unequal friction on the piston, while, in the sucking-pump, the principal force always tends to straighten the rod.

Bag Pump.—A bag of leather has sometimes been employed, for connecting the piston of a pump with the barrel, and, in this manner, nearly all friction is avoided. It is probable, however, that the want of durability would be a great objection to such a machine. In Fig. 170, A,

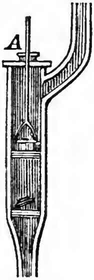
Fig. 170.



represents a leathern bag, attached to a number of hoops. This bag is alternately extended and contracted, like a bellows, by every stroke of the piston, and raises the water, without friction against the pump.

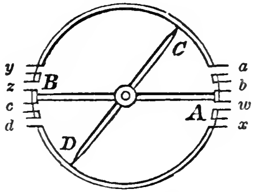
Double-acting Pump.—The rod of a sucking-pump, may also be made to work in a collar of leather, at the top, as at A, in Fig. 171, and the water may be forced

Fig. 171.



through a valve, into an ascending pipe, B. By applying an air-vessel to this, or to any other, forcing-pump, as is done in fire-engines, its motion may be equalized, and its performance improved ; for, if the orifice be large enough, the water may be forced into the air-vessel, during the stroke of the pump, with any velocity that may be required, and with little resistance, from friction ; whereas, the loss of force, from the frequent accelerations and retardations of the whole body of water, in a long pipe, must always be considerable. The condensed air, reacting on the water, expels it more gradually, and in a continual stream, so that the air-vessel has an effect, analogous to that of a fly-wheel, in mechanics.

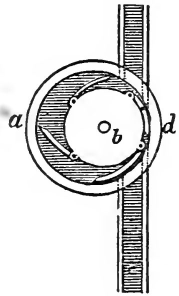
Fig. 172.



Rolling Pump.—A pump of this kind is formed, by a barrel, or hollow cylinder, shown in section, in Fig. 172, having two partitions. One of these, AB, is fixed, and the other, CD, is composed of two wings, or valves, capable of an alternate motion, about the axis of the cylinder. When the partition, CD, turns in one direction, the water, in the cavity, C, is driven out at the orifice, [*a*,] and will rise in a pipe, attached to that orifice. At the same time, the water, in the cavity, D, is forced out at the orifice, [*d*]. While this is taking place, fresh portions of water enter the remaining cavities, [at *w* and *z*]. When the partition, CD, has moved, as far as possible, it then returns, in the opposite direction, and drives out the water, through [*y* and *x*,] and receives fresh water, through [*b* and *c*]. The orifices, which receive the water, have valves, opening inward, and those, which discharge it, have valves, opening outward. The machine is worked by arms, attached to the axis of the cylinder, which, for this purpose, projects through a collar, in the ends of the vessel.

For the sake of simplicity, a sector of a cylinder is sometimes used; in which case, a single partition, or valve, like a door on hinges, traverses the whole cavity, and only half the number of orifices are necessary, to admit and discharge the water. Fire-engines, for projecting water, have been constructed, in both these methods, by different inventors.

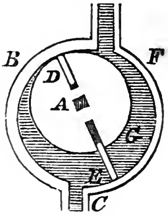
Fig. 173.



Eccentric Pump.—The eccentric pump, a section of which is shown at Fig. 173, consists of a hollow cylinder, [*ad*,] in the interior of which, a solid cylinder, [*b*,] of the same length, but of about half the diameter, is made to revolve, by its axle, passing through water-tight collars, in the ends of the exterior cylinder. The internal cylinder is so placed, that its surface comes in contact with some part of the internal surface of the larger cylinder. The surface of the small cylinder, is also furnished with four large valves, or flaps, turning on hinges, and partaking of its own curvature; so that, when they are shut down, they form no projections, but appear as parts of the same cylinder. These valves are made to open, by springs, or otherwise; so that, when one of them is brought, by the revolution of the internal cylinder, into the narrowest part of the internal space, it is pressed down, and shut; but, as the inner cylinder moves on, the valve, being gradually carried forward, will continue to open, until it arrives at the widest part of the cavity. It is then pressed down again, by a continuation of the revolution. In this way, the water behind the valve is drawn up, from the feeding-pipe, by the atmospheric pressure, while that before the valve is forced upward, into the delivering pipe. As each of the valves performs the same operation, in its turn, this pump affords a constant supply of water.

Rotative steam-engines have been constructed, by different projectors, on the principle of this pump, as well as the following.

Fig. 174.



Another form of an eccentric pump, is seen in Fig. 174. The roller, or solid cylinder, A, revolving within the reservoir, or hollow cylinder, BF, carries with it the slider, DE, which is made to sweep the internal surface of this cylinder, by revolving, in the direction from C to F, so that the water is drawn up, by the pipe, C, and discharged, by the pipe, F.

An objection to all pumps of this sort is, that, if they are made tight enough to hold water, they occasion a great degree of friction, on account of the extensive contact of the moving surfaces. The continual change, also, which takes place, both in the direction and velocity of the water, is productive of great resistance from inertia. The stream, at the delivering orifice, although never wholly intermitted, is, by no means, uniform in its velocity.

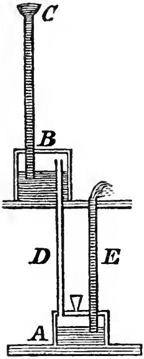
Arrangement of Pipes.—The pipes, through which water is raised, by pumps of any kind, ought to be as short, and as straight, as possible. Thus, if we have to raise water, to a height of twenty feet, and to carry it, to a horizontal distance of one hundred, by means of a forcing-pump, it will be more advantageous to raise it first, vertically, into a cistern, twenty feet above the reservoir, and then to let it run along horizontally, or find its level in a bent pipe, than to connect the pump immediately with a single pipe, carried to the place of its destination. And, for the same reason, a sucking-pump should be placed as nearly over the well as possible, in order to avoid a loss of force, in working it. If very small pipes are used, they will much increase the resistance, by the friction which they occasion.

Chain Pump.—Water has sometimes been raised by stuffed cushions, or by oval blocks of wood, connected with an endless rope, or chain, and caused, by means of two wheels, or drums, to rise, in succession, in the same barrel, carrying the water in a continual stream before them. The magnitude, however, of the friction, appears to be an objection to this method. From the resemblance of the apparatus to a string of beads, it has been called a *bead-pump*, or *paternoster-work*. When flat boards are united by chains, and employed, instead of these cushions, the machine has been denominated a *cellular* pump; and, in this case, the barrel is usually square, and placed in an inclined position. There is, however, a considerable loss, from the facility with which the water runs back. The *chain-pump*, used in the Navy, is a pump of this kind, with an upright barrel, through which leathers, strung on a chain, are drawn in constant succession. These pumps are only employed, when a large quantity of water is to be raised, and they must be worked with considerable velocity, in order to produce any effect at all.

The Chinese work their cellular pumps, or bead-pumps, by walking on bars, which project from the axis of the wheel, or drum, that drives them; and, whatever objection may be made to the choice of the machine, the mode of communicating motion to it, must be allowed to be advantageous.

Schemnitz Vessels, or Hungarian Machine.—The mediation of a portion of air is employed for raising water, not only in the spiral-pump, but also in the air-vessels of Schemnitz, in the manner, shown in Fig. 175. A

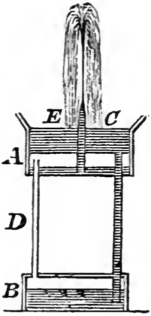
Fig. 175.



column of water, descending through a pipe, C, into a closed reservoir, B, containing air, obliges the air to act, by means of a pipe, D, leading from the upper part of the reservoir, or air-vessel, on the water in a second reservoir, A, at any distance, either below or above it, and forces this water to ascend, through a third pipe, E, to any height less than that of the first column. The air-vessel is then emptied, the second reservoir filled, and the whole operation repeated. The air must, however, acquire a density, equivalent to the pressure, before it can begin to act; so that, if the height of the columns were thirty-four feet, it must be reduced to half its dimensions, before any water would be raised; and thus, half of the force would be lost. But, where the height is small, the force lost in this manner is not greater, than that which is usually spent in overcoming friction, and other imperfections, of the machinery employed; for the quantity of water, actually raised by any machine, is not often greater than half the power which is consumed. The force of the tide, or of a river, rising and falling with the tide, might easily be applied, by a machine of this kind, to the purpose of raising water. Thus, if, at low tide, the vessel, A, was filled with air, then, at high tide, the water, flowing down the tube, E, would cause the water in the vessel, B, to ascend in the pipe, C.

Hero's Fountain.—The fountain of Hero, precisely resembles, in its operation, the hydraulic vessels of Schemnitz, which were probably suggested to their inventor, by the construction of this fountain. It may be used, simply, to raise water, or to project it upwards, in the form of a jet, as in Fig. 176. The first reservoir, C, of the foun-

Fig. 176.



tain, is lower than the orifice of the jet. A pipe descends from it, to the air-vessel, B, which is at some distance below, and the pressure of the air is communicated, by an ascending tube, D, to a third cavity, A, containing the water which supplies the jet. In this form of the machine, the water will continue to spout from the pipe, E, until all the water in the reservoir, C, has descended into the vessel, B. The principle of Hero's fountain has been applied, to raise oil in lamps; and one of its most simple forms has already been described, under the head of *Hydrostatic Lamp*, page 334, vol. I.

Atmospheric Machines.—The spontaneous vicissitudes of the pressure of the air, occasioned by changes in the weight and temperature of the atmosphere, have been applied, by means of a series of reservoirs, furnished with proper valves, to the purpose of raising water, by degrees, to a moderate height. But it seldom happens, that such changes are capable of producing an elevation in the water of each reservoir, of more than a few inches, or, at most, a foot or two, in a day; and the whole quantity raised must therefore be inconsiderable.

Hydraulic Ram.—The momentum of a stream of water, flowing through a long pipe, has also been employed, for raising a small quantity of water, to a considerable height. The passage of the pipe, being stopped by a valve which is raised by the stream, as soon as its motion becomes sufficiently rapid, the whole column of fluid must necessarily concentrate its action, almost instantaneously, on the valve. In this manner, it loses the characteristic property of hydraulic pressure, and acts, as if it were a single solid; so that, supposing the pipe to be perfectly elastic, and inextensible, the impulse may overcome any pressure, however great, that might be opposed to it. If the valve opens into a pipe, leading to an air-vessel, a certain quantity of the water will be forced in, so as to condense the air, more or less rapidly, to the degree that may be required, for raising a portion of the water, contained in it, to a given height. Mr. Whitehurst appears to have been the first that employed this method. It was afterwards improved by Mr. Boulton; and the same machine has attracted much attention, in France, under the denomination of the hydraulic ram of M. Montgolfier.

Fig. 177.

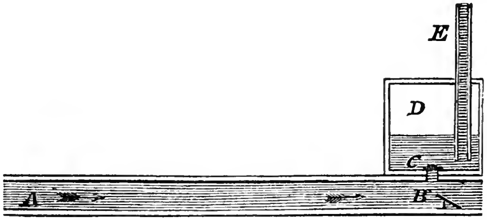


Fig. 177, represents this machine. When the water in the pipe, AB, has acquired sufficient velocity, it raises the valve, B, which immediately stops its further passage. The momentum, which the water has acquired, will ther force a portion of it, through the valve, C, into the air-vessel, D. The condensed air, at D, causes the water to rise into the pipe, E, as long as the effect of the horizontal column continues. When the water becomes quiescent, the valve, B, will open again, by its own weight, and the current will be renewed, until it acquires force enough to shut the valve, and repeat the operation.

OF PROJECTING WATER.

If a degree of force, or pressure, be applied to water, sufficient to raise it, through a tube, to a given height, the same force would also cause it to spout through an orifice, in a continued stream, or jet, to nearly the same height, in common cases. The height, however, can never be fully as great, for various reasons. One of these is found, in the friction of the ajutage, or discharging orifice, which acts as a retarding force. Another obstacle is, the resistance of the atmosphere, which increases, in a rapid ratio, as the velocity of the water becomes greater, and which is also greatly augmented, as the water divides, and spreads out a greater surface to the resistance of the air. A third obstacle consists, in the resistance which the water offers to itself. The parts first projected, being constantly retarded in their ascent, by gravity, and atmospheric resistance, oppose the progress of the parts, which are last projected, and which have the greatest velocity. And, as fluids move, in all directions, this impulse, of different parts of the water, against each other, tends to widen, and, consequently, to shorten, the column. In a vertical jet, moreover, the weight of the falling water opposes the ascending column; and, hence, a fluid will spout higher, if the jet be turned a little to one side, than if it be perpendicular.

Fountains.—Artificial fountains, which throw a perpetual jet of water, usually act by the pressure of a reservoir of water, situated at a greater height than that of the jet produced. The water is conveyed from the reservoir, to the place of the fountain, in pipes; and, if the orifice, from which it issues, be directed upward, it will spout, to a height approaching that of the reservoir. It will always, however, fall short of this height, for the reasons already stated ; and the difference will be greater, in jets of great height, than it is in lower ones ; since it is found, by experiment, that the differences between the heights of the jets and of the reservoirs, are as the squares of the heights of the jets themselves.* Fountains are chiefly used, for purposes of ornament, and, when of large size, require to be fed from the elevated parts of rivers, or bodies of water, having a high level. At Peterhoff, in Russia, there are two fountains, which spout a column of water, nine inches in diameter, to the height of sixty feet, and the fall of the returning water produces a concussion, sufficient to shake the ground.

Fire Engines.—The engines used for extinguishing fires, in buildings, are, in effect, a species of forcing pumps, in which the water is subjected to pressure sufficiently strong to raise it, by a jet, or otherwise, to the required height. But, if the forcing pump were used alone, the water would issue only in intermitting jets, in consequence of the reciprocating motion of the pump, and thus, a great part of it would become ineffectual. In order to make the discharge uniform, and thus keep up a continual stream, a strong vessel, filled with air, is attached to the engine. Into this vessel, the water is forced, by the pumps ; and, as the air cannot escape, it is condensed, in proportion as the water accumulates, until it reacts upon the surface of the water, with great power. If the air be condensed, into half the space which it originally occupied, it will act upon the water with a pressure, equal to that of two atmospheres, and will be adequate to raise water, through a tube, to the height of thirty-three feet, or to project it, through the atmosphere, to nearly the same height. When the air is condensed, to one third of its former volume, in consequence of the air-vessel being two thirds filled with water, its elasticity will be three times greater than that of the atmosphere. It will therefore raise water, in a tube, to the height of sixty-six feet, and would throw, it to nearly the same height,

* Ascertained by Mariotte.—*Bossut*, Tom. ii § 615.

were it not for the resistances, which have already been explained.

The foregoing principle of the fire-engine has been variously modified, by adapting different kinds of pumps to the air-vessel, and by altering various details. In the engines of Newsham, and others, two cylinders, constructed like forcing-pumps, are worked by the reciprocating motions of transverse levers, to which the handles are attached. In this way, the water is forced into the air-vessel, from which it afterwards spouts, through a movable pipe. In some other engines, a single cylinder is used, the piston-rod passing through a tight collar, as it does in Watt's steam-engine, thus alternately receiving and expelling the water, at each end of the cylinder. In Rowntree's engine, and some others, a mechanism is used, like that of the rolling-pump, a part of the inside of a cylinder being traversed by a partition, like a door, hinged upon the axis of the cylinder, which drives the water, successively, from each side of the cylinder, into the air vessel.

A long flexible tube, made of leather, and known among firemen by the name of *hose*, is of great use in carrying the spouting orifice near to the flames, and thus preventing the water from being scattered too soon. It also serves an important purpose, in bringing water from distant reservoirs, by suction, created in the pumps of the engine.

Throwing Wheel.—A throwing-wheel, otherwise called a flash-wheel, or fen-wheel, is used for raising water, both by lifting and projecting it. Its structure resembles that of an undershot water-wheel, or, more properly, of a breast-wheel. Its under surface is received in a trough, or channel, which curves upward. When the wheel is made to revolve, it drives the water before it, and throws it out from the trough, at a considerable elevation. These wheels are used, for draining ponds, marshes, &c., and are turned by wind-mills, or any other power. If their movement is slow, they simply lift the water, and cause it to overflow, at the end of the trough. But, if they revolve w'th much velocity, they are capable of throwing the water to a still higher level.

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CHAPTER XVIII.

ARTS OF COMBINING FLEXIBLE FIBRES.

Theory of Twisting, Rope Making, Hemp Spinning. *Cotton Manufacture*, Elementary Inventions, Batting, Carding, Drawing, Roving, Spinning, Mule Spinning, Warping, Dressing, Weaving, Twilling, Double Weaving, Cross Weaving, Lace, Carpeting, Tapestry, Velvets, Linens. *Woollens*. *Felting*. *Paper Making*. *Bookbinding*.

Theory of Twisting.—The strength of cordage, which is employed in uniting bodies, and the utility of flexible textures, which serve for furniture, or for clothing, depend, principally, upon the friction, or lateral adhesion, produced by the twisting and intermixture of their constituent fibres.

A twisting cord is not so strong as the fibres which compose it, supposing the fibres and cord to be of the same length. The object of twisting is, to connect successive numbers of short fibres, in such a manner, that besides the mutual pressure which their own elasticity causes them to exert, any additional force, applied in the direction of the length of the aggregate, may tend to bring their parts into closer contact, and augment their adhesion to each other. The simple art of tying a knot, and the more complicated processes of spinning, rope-making, weaving, and felting, derive most of their utility from this principle.

By considering the effect of a force, which is counteracted by other forces, acting obliquely, it will be seen, that the operation of twisting has a useful effect, in binding the parts of a rope, or thread, together; and also, that it has an inconvenience, in causing the strength of the fibres to act with a mechanical disadvantage. The greater is the obliquity of the fibres, the greater will be their adhesion to each other, but the greater, also, will be their immediate strain, or tension, when a force acts upon them, in the direction of the whole cord. From this, it follows, that, after employing as much obliquity, and as much tension, as is sufficient to connect the fibres firmly together, all that is superfluously added tends to weaken the cord, by overpowering the primitive cohesion of the fibres, in the direction of their length.

The mechanism of simple spinning is easily understood. Care is taken, where the hand is employed, to intermix the fibres sufficiently, and to engage their extremities, as much as possible, in the centre; for, it is obvious, that, if any fibre were wholly external to the rest, it could not be retained in the yarn. In general, however, the materials are, previously, in such a state of intermixture, as to render this precaution unnecessary.

Rope Making.—A single thread of yarn, consisting of fibres twisted together, has a tendency to untwist itself, the external parts being strained, by extension, and the internal parts, by compression; so that the elasticity of all the parts resists, and tends to restore the thread to its natural state. But, if two such threads, similarly twisted, are retained in contact, at a given point of the circumference of each, this point is rendered stationary, by the opposition of the equal forces, acting in contrary directions, and becomes the centre, round which both threads are carried, by the forces which remain; so that they continue to twist round each other, till the new combination causes a tension, capable of counterbalancing the remaining tension of the original threads. Three, four, or more, threads may be united, nearly in the same manner. A *strand*, as it is called by rope-makers, consists of a considerable number of yarns, thus twisted together, generally from sixteen to twenty-five; a *halser* consists of three strands; a *shroud*, of four; and a *cable*, of three halsers, or shrouds. Shroud-laid cordage has the disadvantage of being hollow in the centre, or else of requiring a great change of form in the strands, to fill up the vacuity; so that, in undergoing this change, the cordage stretches, and is unequally strained. The relative position, and the comparative tension, of all the fibres, in these complicated combinations, are not very easily determined by calculation; but, it is found, by experience, to be most advantageous for the strength of ropes, to twist the strands, when they are to be compounded, in such a direction, as to untwist the yarns, of which they are formed; that is, to increase the twist of the strands themselves; and, probably, the greatest strength is obtained, when the ultimate obliquity of the constituent fibres is least, and the most equable.*

A very strong rope may, also, be made, by twisting five or six strands round a seventh, as an axis. In this case, the central strand, or heart, is found, after much use, to be chafed to oakum. Such ropes are, however, considered unfit for rigging, or for any use, in which they are liable to be frequently bent.

Ropes are most commonly made of hemp; but various other vegetables are occasionally employed. The Chinese even use woody fibres; and the barks of trees furnish cordage to other nations. In spinning the yarn, in the process of rope-making, the hemp is fastened round the waist of the workman; one end of it is attached to a wheel, turned by an assistant, and the spinner, walking backwards, draws out the fibres with his hands. When one length of the walk has been spun, it is immediately reeled, to prevent its untwisting. The machines, employed in continuing the process of rope-making, are mostly of simple construction; but both skill and attention are

* Young's Natural Philosophy, vol. i. Lect. xvi.

required, in applying them, so as to produce an equable texture, in every part of the rope. The tendency of two strands to twist, in consequence of the tension, arising from the original twist of the yarns, is not sufficient to produce an equilibrium, because of the friction and rigidity to be overcome. Hence, it is necessary to employ force, to assist this tendency, and the strands, or ropes, will afterwards retain, spontaneously, the form which has thus been given them. The largest ropes, even, require external force, in order to make them twist at all.

The constituent ropes of a common cable, when separate, are stronger than the cable, in the proportion of about four to three ; and a rope, worked up from yarns, one hundred and eighty yards in length, to one hundred and thirty-five yards, has been found to be stronger, than when reduced to one hundred and twenty yards, in the ratio of six to five. The difference is owing, partly, to the obliquity of the fibres, and, partly, to the unequal tension, produced by twisting.*

Hemp Spinning.—The desideratum of spinning hemp, by machinery, has been attained by Mr. Treadwell, in his machines for that purpose, now at work, at the Charlestown Navy Yard, and elsewhere. By this invention, the hemp is drawn out to the requisite size, by a long series of teeth, fixed upon a revolving belt, and afterwards twisted, by the revolutions of the machine. The equality, or uniform size, of the yarn, is ensured, by a roller, or small wheel, which rests upon the part just twisted, and which rises, or is pushed up, if the twist becomes too large, and moves a comb, which immediately falls, and intercepts the superfluous part of the fibres. On the other hand, if the twist becomes too small, the roller descends, and, in so doing, increases the rapidity of the machine, and causes it to supply the hemp faster.

COTTON MANUFACTURE.

When the fibres of cotton, wool, or flax, are intended to be woven, they are reduced to fine threads, of uniform

* Young's Natural Philosophy, vol. i. Lect. xvi.

size, by the well-known process of *spinning*. Previously to the middle of the last century, this process was performed by hand, with the aid of the common spinning-wheel. Locks of cotton, or wool, previously carded, were attached to a rapidly-revolving spindle, driven by a large wheel, and were stretched or drawn out by the hand, at the same time that they were twisted by the spindle, upon which they were afterwards wound. Flax, the fibres of which are longer, and more parallel, was loosely wound upon a distaff, from which the fibres were selected, and drawn out by the thumb and finger, and, at the same time, were twisted by flyers, and wound upon a bobbin, which revolved with a velocity, somewhat less than that of the flyers.

The manufacture of flexible stuffs, by means of machinery, operating on a large scale, is an invention of the last century. Although of recent date, it has given birth to some of the most elaborate and wonderful combinations of mechanism, and already constitutes, especially in England, and in this country, an important source of national wealth and prosperity.

Elementary Inventions.—The character of the machinery which has been applied to the manufacture of cotton, at different times, has been various. There are, however, several leading inventions, upon which most of the essential processes are founded, and which have given to their authors a greater share of celebrity than the rest. These are, 1. The *spinning-jenny*. This machine was invented by James Hargreaves,* in 1767, and, in its simplest form, resembled a number of spindles, turned by a common wheel, or cylinder, which was worked by hand. It stretched out the threads, as in common spinning of carded cotton. 2. The *water spinning-frame*, invented by Richard Arkwright, in 1769. The essential, and most important, feature in this invention consists in the drawing out, or elongating, of the cotton, by causing it to pass between successive pairs of rollers, which revolve, with different velocities, and which act as

* Mr. Guest, in a late work, attributes the invention, both of the jenny, and water spinning-frame, to Thomas Highs, of Leigh, England

substitutes for the finger and thumb, as applied in common spinning. These rollers are combined with the spindle and flyers of the common flax wheel. 3. The *mule*. This was invented by Samuel Crompton, in 1779. It combines the principles of the two preceding inventions, and produces finer yarn, than that which is spun in either of the other machines. It has now nearly superseded the jenny. 4. The *power-loom* for weaving, by water or steam power, which was introduced about the end of the eighteenth century, and has received various modifications.

The foregoing fundamental machines are used in the same, or different establishments, and for different purposes. But, besides these, various auxiliary machines are necessary, to perform intermediate operations, and to prepare the material, as it passes from one stage of the manufacture to another. The number of these machines, and the changes, and improvements, which have been made in their construction, from time to time, render it impossible to convey, in a work like the present, any accurate idea of their formation, in detail. A brief view, however, of the offices which they severally perform, may be taken, by following the raw material, through the principal changes which it undergoes, in a modern cotton-factory, founded and improved upon the general principles of Arkwright.

Batting.—The cotton, after having been cleared from its seeds, at the plantation, by the operation of *ginning*, described on page 111, Vol. I., is compressed into bags, for exportation, and arrives at the factory, in a dense and matted mass. The first operation to which it is submitted has, for its object, to disentangle the fibres, and restore the cotton to a light, open, and uniform, state. For this purpose, after being weighed out, it is submitted to the operation of a machine, called a *picker*, or of another, denominated a *batter*. In some of these machines, it is subjected to the action of a series of pins ; in others, to a sort of blunt knives, revolving with great rapidity ; the effect of which is, to beat up and separate the fibres, to disengage their unequal adhesions, and to reduce the whole to a very light, uniform, flocculent, mass.

Carding.—The cotton next passes to the carding-machines, of which, when there are two, the first is called the *breaker*, and the second, the *finisher*. In this operation, the cotton is carried over the surface of a revolving cylinder, which is covered with card-teeth of wire, and which passes in contact with an arch, or part of a concave cylinder, similarly covered with teeth. From this cylinder, it is taken off by another, called the *doffing* cylinder, which revolves in an opposite direction ; and from this, it is again removed, by the rapid vibrating movement of a transverse *comb*, otherwise called the *doffing-plate*, moved by cranks. It then exists in the state of a flat, uniform, fleece, or *lap*, which, after passing the breaker, undergoes the process of *plying*, or doubling, by causing it to perform a certain number of revolutions upon a cylinder, or a perpetual cloth. It is then carded a second time, by the finisher, and the fleece, after being taken off from this machine, is drawn by rollers, through a hollow cone, or trumpet mouth, which contracts it to a narrow band, or *sliver*, and leaves it coiled up in a tin can, ready for the next operation. The process of carding serves to equalize the substance of the cotton, and to lay its fibres somewhat in a more parallel direction.

Drawing.—The slivers of cotton are next elongated, by the process of drawing. This operation is the groundwork, or principle, of Arkwright's invention, and is used in the *roving*, and *spinning*, as well as in the *drawing-frame*. It is an imitation of what is done by the finger and thumb, in spinning by hand, and is performed, by means of two pairs of rollers. The upper roller, of the first pair, is covered with leather, which, being an elastic substance, is pressed, by means of a spring, or weight. The lower roller, made of metal, is fluted, in order to keep a firm hold of the fibres of cotton. Another similar pair of rollers are placed near those which have been described. The second pair, moving with a greater velocity, pull out the fibres of cotton from the first pair of rollers. If the surface of the last pair move at twice, or thrice, the velocity of the first pair, the cotton will be drawn twice, or thrice, finer than it was before. This relative velocity is called the *draught* of the machine. This mechanism being understood, it will be easy to conceive the nature of the operation of the *drawing-frame*. Several of the narrow ribands, or slivers, from the cards, (sometimes termed *card-ends*,) by being passed through a system of rollers, are thereby reduced in size. By means of a detached, single pair of rollers, the several reduced ribands are *plied*, or united into one sliver.

The operations of drawing and plying serve to equalize, still further, the body of cotton, and to bring its fibres more into a longitudinal direction. These slivers are again combined, and drawn out, so that one sliver of the finished drawing contains many plies of card-ends. Hitherto, the cotton has acquired no twist, but is received into movable tin cans, or canisters, similar to those used for receiving the cotton from the cards.

Roving.—The operation of roving communicates the first twist to the cotton. It is performed by a machine, called the *roving-frame*, or *double-speeder*. The tin cans, containing the slivers of cotton, are placed upon this machine, and are made to revolve, slowly, about their axes, so as to produce a slight degree of twisting. The slivers then pass again, through several pairs of rollers, moving with different speeds, and are thus still further attenuated, by drawing. They are then slightly spun, by the revolution of flyers, and are wound upon the bobbins of the spindles, in the form of a loose, soft, imperfect, thread, denominated the *roving*.

The mechanism of the double speeder is complicated, and interesting, and great ingenuity has been displayed, in overcoming the difficulties of its construction. In order that the yarn, or roving, may be wound upon the bobbins, in even, cylindrical, layers, it is necessary, that the *spindle rail*, or horizontal bar, which supports the spindles, should continually rise and fall, with a slow alternate motion. This is effected by heart-wheels, or cams, in the interior of the machine. Again, since the collective size of the bobbin is augmented, by the addition of each layer of roving, it is obvious, that, if the axis of the bobbin revolved, always, with the same velocity, the thread of rov ing would be broken, in consequence of being wound up too fast. To prevent this accident, the velocity of the spindles, and, likewise, the motion of the spindle-rail, is obliged gradually to diminish, from the beginning to the end of an operation. This diminution of speed is effected, by transmitting the motion, both to the spindle-rail, and to the bobbins, through two opposite cones, one of which drives the other with a band, the band being made to pass, slowly, from one end to the other of the cones, and thus continually to alter their relative speed, and cause a uniform retardation of the velocity of the moving parts.* As the roving is not strong enough to bear any violence, the spindles, which support the bobbins, are geared to each other, so as to prevent any deviation from the proper velocity.

A more simple form of the roving-frame has been invented,† in which the gearing is dispensed with, as well as the pair of cones, which regulates the motion of the bobbins. In this machine, the bobbins are not turned by the rotation of their axes, but by friction, applied to their surface, by small wooden cylinders which revolve in contact with them. In this way, the velocity of the surface of the bobbin will always be the same, whatever may be its growth, from the accumulation of roving, so that the winding goes on, at an equable rate. To prevent the roving from being stretched, or broken, in its passage from the drawing rollers to the bobbins, it is made to pass through a tube, which has a rapid rotation, and which twists it, in the middle, into a cord of some firmness. It is again untwisted, as fast as it escapes from the tube, and is wound upon the bobbins, in the form of a dense, even, cord, but without any twist.

Spinning.—The bobbins, which contain the cotton, in a state of roving, are next transferred to the spinning-frame. It is here once more drawn out by rollers, and twisted by flyers, so that the spinning is little more than

* Instead of band cones, an ingenious mode of using geared cones, now introduced in several American factories, has already been described, page 60.

† By Mr. Danforth, of Massachusetts.

a repetition of the process gone through, in making the roving, except that the cotton is now twisted into a strong thread, and cannot any longer be extended, by drawing. The flyers of the spinning-frame are driven by bands, which receive their motion, in some cases, from a horizontal fly-wheel, and, in others, from a longitudinal cylinder.* As the thread is sufficiently strong not to break with a slight force, the resistance of the bobbins, by friction, is relied on to wind it up, instead of having the spindles geared together, and turned with an exact velocity, as they are in the common double-speeder. In the spinning frame, the heart-motion is retained, to regulate the rise and fall of the rail; and, in those frames which spin the woof, or filling, it is applied, by a progressive sort of cone, the section of which is heart-shaped, and which acts, remotely, to distribute the thread, in conical layers, upon the bobbins, that it may unwind the more easily, when placed, afterwards, in the shuttle.

Mule Spinning.—The processes of water-spinning, already described, are adequate to produce yarns, of sufficient fineness for ordinary fabrics. But, for producing threads of the finest kind, another process is necessary, which is called *stretching*, and which is analogous to that which is performed, with carded cotton, upon a common spinning-wheel. In this operation, portions of yarn, several yards long, are forcibly stretched, in the direction of their length. It differs, therefore, from the operation of drawing, in which a few inches, only, are extended at a time. The stretching is performed, with a view to elongate and reduce those places in the yarn, which have a greater diameter, and are less twisted, than the other parts so that the size and twist of the thread may become uniform throughout. To effect the process of stretching, the spindles are mounted upon a carriage, which is moved, back and forwards, across the floor; receding, when the threads are to be stretched, and returning, when they are to be wound up. The yarn, produced by mule-spinning, is more perfect than any other, and is employed in the

* The latter method, which had gone into disuse, is beginning to be revived, and to be considered most advantageous.

fabrication of the finest articles. The sewing-thread, spun by mules, is a combination of two, four, or six, constituent threads, or plies. Threads have been produced, of such fineness, that a pound of cotton has been calculated to reach one hundred and sixty-seven miles.

Warping.—The first step, preparatory to weaving, is to form a *warp*, which consists of parallel threads, continued through the whole length of the intended piece, and sufficient, in number, to constitute its breadth. It was, formerly, the practice to attach the threads to as many pins, and to draw them out, to the required length. But, as this method required too much room, a warping machine was subsequently used, in which the mass of threads, intended to constitute a warp, was wound in a spiral course, upon a large revolving frame, which rose and fell, so as to produce the spiral distribution.

These methods are now superseded, in this country by Moody's warping-machine,* an ingenious piece of mechanism, in which a number of bobbins, equal to one eighth part of the number of threads in the intended warp, are arranged upon the surface of a concave frame. The threads pass through a reed, which separates the alternate threads, as they are to be kept in the loom ; after which, they are wound upon a beam, with rods interposed at the end, to preserve the separation. But the most interesting part of the mechanism is a contrivance for stopping the machine, if a single thread of the warp breaks. To effect this object, a small steel weight, or flattened wire, is suspended, by a hook, from each thread, so that it falls, if the thread is broken. Beneath the row of weights, a cylinder revolves, furnished with several projecting ledges, extending its whole length, parallel to the axis. When one of the weights falls, by the breaking of its thread, it intercepts one of the ledges, and causes the cylinder to exert its force upon an elbow, or toggle-joint, which disengages a clutch, and stops the machine. After the thread is tied, and the weight raised, the machine proceeds.

* Mr. Paul Moody, formerly of Waltham, and now of Lowell, is the inventor of this machine ; likewise of the spinning-frame, which winds the woof in conical layers ; and of great improvements in the roving frame, the dressing-frame, &c.

Dressing.—As the threads, which constitute the warp, are liable to much friction, in the process of weaving, they are subjected to an operation, called dressing, the object of which is, to increase their strength and smoothness, by agglutinating their fibres together. To this end, they are pressed between rollers, impregnated with mucilage, made of starch, or some gelatinous material, and, immediately afterwards, brought in contact with brushes, which pass repeatedly over them, so as to lay down the fibres in one direction, and remove the superfluous mucilage from them. They are then dried, by a series of revolving fans, or by steam-cylinders, and are ready for the loom.

Weaving.—Woven textures derive their strength from he same force of lateral adhesion, which retains the twised fibres of each thread in their situations. The manner, in which these textures are formed, is readily understood. On inspecting a piece of plain cloth, it is found to consist of two distinct sets of threads, running perpendicularly to each other. Of these, the longitudinal threads constitute the *warp*, while the transverse threads are called the *woof*, *weft*, or *filling*, and consist of a single thread, passing backwards and forwards. In weaving with the common loom, the warp is wound upon a cylindrical beam, or roller. From this, the threads pass through a *harness*, composed of movable parts, called the *heddles*, of which there are two or more, consisting of a series of vertical strings, connected to frames, and having loops, through which the warp passes. When the heddles consist of more than one set of strings, the sets are called *leaves*. Each of these heddles receives its portion of the alternate threads of the warp; so that, when they are moved, reciprocally, up and down, the relative position of the alternate threads of the warp is reversed. Each time that the warp is opened, by the separating of its alternate threads, a *shuttle*, containing the woof, is thrown across it, and the thread of a woof is immediately driven into its place, by a frame, called a *lay*, furnished with thin reeds, or wires, placed among the warp, like the teeth of a comb. The woven piece, as fast as it is completed, is wound up on a second beam, opposite to the first.

Power looms, driven by water, or steam, although a late invention, are now universally introduced into manufactories of cotton and woollens. As the motions of the loom are, chiefly, of a reciprocating kind, they are produced, in some looms, by the agency of cranks, and in others, by cams, or wipers, acting upon weights, or springs.

Twilling.—In the mode of plain weaving, last described, it will be observed, that every thread of the warp crosses at every thread of the woof, and *vice versa.* In articles, which are *twilled*, or *tweeled*, this is not the case; for, in this manufacture, only the third, fourth, fifth, sixth, &c., threads cross each other, to form the texture. In the coarsest kinds, every third thread is crossed; but, in finer fabrics, the intervals are less frequent, and, in some very fine twilled silks, the crossing does not take place, till the sixteenth interval. In Fig 178, is shown a magnified

Fig. 178.

section of a piece of plain cloth, in which the woof passes, alternately, over and under every thread of the warp. In Fig. 79, is a piece of twilled cloth, in which the thread

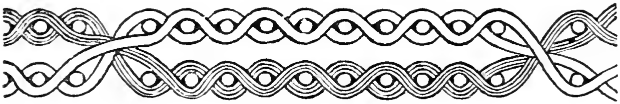
Fig. 179.

of the woof passes, alternately, over four, and under one, of the threads of the warp, and performs the reverse, in its return. To produce this effect, a number of leaves of heddles are required, equal to the number of threads contained in the interval, between each intersection, inclusive. By the separate movements of these, the warp is placed in the requisite positon, before each stroke of the shuttle. A loom, invented in this country, by Mr. Batchelder, of Lowell, has been applied to the weaving of twilled goods, by water-power.

Twilled fabrics are thicker than plain ones, when of the same fineness, and more flexible, when of the same thickness. They are also more suceptible of ornamental va nations. Jeans, dimities, serges, &c., are specimens of this kind of texture.

Double Weaving.—In this species of weaving, the fabric is composed of two webs, each of which consists of a separate warp, and a separate woof. The two, however, are interwoven, at intervals, so as to produce various figures. The junction of the two webs is formed, by passing them, at intervals, through each other; so that each particular part of both is sometimes above, and sometimes below. It follows, that, when different colors are employed, as in carpeting, the figure is the same, on both sides, but the color is reversed. A section of double cloth is shown in Fig. 180.

Fig. 180.



The weaving of double cloths is commonly performed, by a complicated machine, called a *draw-loom*, in which the weaver, aided by an assistant, or by machinery, has the command of each particular thread, by its number. He works by a pattern, in which the figure before him is traced, in squares, agreeably to which the threads to be moved are selected, and raised, before each insertion of the woof. Kidderminster carpets, and Marseilles quilts, are specimens of this mode of weaving.

Cross Weaving.—This method is used, to produce the lightest fabrics, such as gauze, netting, catgut, &c. In the kinds of weaving which have been previously described, the threads of the warp always remain parallel to each other, or without crossing. But, in gauze-weaving, the two threads of warp, which pass between the same splits of the reed, are crossed over each other, and partially twisted like a cord, at every stroke of the loom. They are, however, twisted to the right and left, alternately, and each shot, or insertion of the woof, preserves the twist which the warp has received. A great variety of fanciful textures are produced, by variations of the same general plan. Fig. 181, represents the cross-weaving, used in common gauze.

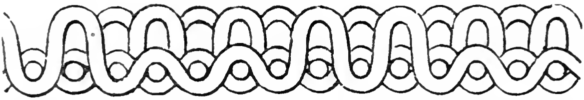
Fig. 181.

Lace.—Lace is a complicated, ornamental, fabric, formed of fine threads of linen, cotton, or silk. It consists of a net-work of small meshes, the most common form of which is hexagonal. In perfect thread-lace, four sides of the hexagon consist of threads which are twisted, while, in the remaining two, they are simply crossed. Lace has been commonly made upon a cushion, or pillow, by the slow labor of artists. A piece of stiff parchment is stretched upon the cushion, having holes pricked through it, in which pins are inserted. The threads, previously wound upon small bobbins, are woven round the pins, and twisted, in various ways, by the hands, so as to form the required pattern. The expensiveness of the different kinds of lace is proportionate to the tediousness of the operation. Some of the more simple fabrics are executed with rapidity, while others, in which the sides of the meshes are plaited, as in the Brussels lace, and that made at Valenciennes, are difficult, and bear a much greater price.

The cheaper kinds of lace have long been made by machinery ; and, recently, the invention of Mr. Heathcoat's lace-machine has effected the fabrication of the more difficult, or twisted lace, with precision and des patch. This machine is exceedingly complicated and ingenious, and is now in operation in this country, and in France, as well as in England.

Carpeting.—Carpets are thick textures, composed, wholly or partly, of wool, and wrought by several dissimilar methods. The simplest mode is that used in weaving the *Venetian* carpets, which is a plain texture, composed of a striped woollen warp, on a thick woof of linen thread. *Kidderminster* carpeting is composed by two woollen webs, which intersect each other, in such a manner, as to produce definite figures. *Brussels* carpet ing has a basis, composed of a warp and woof, of strong linen thread. But, to every two threads of linen, in the warp, there is added a parcel of about ten threads of woollen, of different colors. The linen thread never appears on the upper surface; but parts of the woollen threads are, from time to time, drawn up in loops, so as to constitute ornamental figures, the proper color being, each time, selected from the parcel to which it belongs. A sufficient number of these loops is raised, to produce a uniform surface, as seen in Fig. 182; and to render them

Fig. 182.



equal, each row passes over a wire, which is subsequently withdrawn. In some cases, the loops are cut through with the end of the wire, which is sharpened for the purpose, so as to cut off the threads, as it passes out. In forming the figure, the weaver is guided by a pattern, which is drawn in squares, upon a paper. *Turkey* carpets appear to be fabricated upon the same general principles, as the Brussels, except that the texture is all woollen, and the loops larger, and always cut.

Tapestry.—The name of tapestry is given to certain delicate and complicated fabrics, in which the forms and colors of natural objects are produced, with such accuracy, as to resemble fine paintings. The mode of texture used, to produce this effect, is, in many respects, analogous to that by which the finer carpetings are made. The minuteness, however, of the constituent parts, causes the sight of the texture to be lost, in the general effect of the piece. The fabrication of tapestry is slow, intricate, and very expensive. The most celebrated manufactory is that established by the family of Gobelins, and kept up by their successors, at Paris.

Velvets.—The fine soft nap, by which velvet is covered, is produced by a method, not unlike that which is used in carpeting and tapestry. It is formed of a part of the threads of the warp, which the workman puts, in loops, on a long, channelled wire. Before the wire is withdrawn, the row of loops is cut open, by a sharp steel instrument which is drawn along the channel of the wire. Various other fabrics of silk, cotton, and wool, such as thicksets, plushes, corduroys, velveteens, &c., are cut in a similar manner.

Cotton counterpanes are woven with two shuttles, one containing a much coarser woof than the other. The coarser of the threads is picked up, at intervals, with an iron pin, which is hooked at the point, thus forming knobs, which are made to constitute regular figures.

In cotton fabrics, the web, when taken from the loom, is covered with an irregular nap, or down, formed by the projecting ends of the fibres. This is removed, in the finest articles, by burning it off, the heat being so managed, as not to injure the texture of the cloth. The operation is performed, by drawing the web, very rapidly, over an iron cylinder which is kept constantly red hot, by a fire within it. The velocity of the cloth prevents it from burning, while the loose filaments, which constitute the nap, are singed off. The flame of coal-gas has, of late, been applied to the same purpose.

Linens.—This name belongs to fabrics, which are manufactured from flax; but those made of hemp are similar in their properties, except in fineness. The length and comparative rigidity, of the fibres of flax, present difficulties, in the way of spinning it, by the machinery which is used for cotton and wool. It cannot be prepared, by carding, as these other substances are, and the rollers are capable of drawing it but very imperfectly. The subject of spinning flax, by machinery, has attracted much attention, and the Emperor Napoleon, at one time, offered a reward of a million of francs, to the inventor of the best machine, for this purpose. Various individuals, both in this country, and in Europe, have succeeded in constructing machines, which spin coarse threads of linen, sufficiently well, and with great rapidity. But the manufacture of fine threads, such as those used for cambrics and lace, continues to be performed, by hand, upon the ancient spinning-wheel.

Linen was manufactured by the Egyptians, probably, one thousand five hundred years before Christ. Some of it was of exceeding fineness. Vast quantities, in the form of mummy-cloths, still remain.

WOOLLENS.

The fibres of wool, being contorted and elastic, are drawn out and spun, by machinery, in some respects similar to that used for cotton, but differing in various particulars. Independently of the quality of fineness, there are two sorts of wool, which afford the basis of different fabrics, the *long* wool, and the *short*. Long wool is that, in which the fibres are rendered parallel, by the process of combing. It is also known by the name of *worsted*, and is the material, of which camlets, bombazines, &c., are made. Short wool is prepared, by carding, like cotton, and is used, in different degrees of fineness, for broadcloths, flannels, and a multitude of other fabrics. This wool, when carded, is formed into small, cylindrical rolls, which are joined together, and stretched, and spun, by a *slubbing*, or roving, machine, and a jenny, or mule; in both of which, the spindles are mounted on a carriage, which passes backwards and forwards, so as to stretch the material, at the same time that it is twisted. On account of the roughness of the fibres, it is necessary to cover them with oil, or grease, to enable them to move freely upon each other, during the spinning and weaving. After the cloth is woven, the oily matter is removed, by scouring, in order to restore the roughness to the fibres, preparatory to the subsequent operation of fulling.

In articles which are made of long wool, the texture is complete, when the stuff issues from the loom. The pieces are subsequently dyed, and a gloss is communicated to them, by pressing them between heated metallic surfaces. But, in cloths made of short wool, the weaving cannot be said to have completed the texture. When the web is taken from the loom, it is too loose and open, and, consequently, requires to be submitted to another operation, called *fulling*. This is performed by a fulling-mill, in which the cloth is immersed in water, and subjected to repeated compressions, by the action of large beaters, formed of wood, which repeatedly change the position of the cloth, and cause the fibres to felt, and combine more closely together. By this process, the cloth is reduced in its dimensions, and the beauty and stability of the texture are greatly improved. The tendency to become thickened, by fulling, is peculiar to wool and hair, and does not exist in the fibres of cotton, or flax. It depends on a certain roughness of these animal fibres, which permits motion, in one direction, while it retards it, in another. It thus promotes entanglements of the fibres, which serve to shorten and thicken the woven fabric. Before the cloth is sent to the fulling-mill, it is necessary to cleanse it from all the unctuous matter, which was applied, to prepare the fibres for spinning.

The nap, or downy surface, of broadcloths, is raised, by a process, which, while it improves the beauty, tends somewhat to diminish the strength, of the texture. It is produced, by carding the cloth, with a species of burrs, the fruit of the common teazle, (*Dipsacus fullonum*,) which is cultivated for the purpose. This operation extricates a part of the fibres, and lays them in a parallel direction. The nap, composed of these fibres, is then cut off, to an even surface, by the process of *shearing*. This is performed in various ways; but in one of the most common methods, a large spiral blade revolves, rapidly, in contact with another blade, while the cloth is stretched over a bed, or support, just near enough for the projecting filaments to be cut off, at a uniform length, while the main texture remains uninjured.

FELTING.

The texture of modern hats, which are made of fur and wool, depends upon the process of *felting*, which is similar to that of fulling, already described. The fibres of these substances are rough, in one direction only; a circumstance which may be perceived, by passing a hair through the figures, in opposite directions. This roughness allows the fibres to glide among each other, so that, when the mass is agitated, the anterior extremities slide forward, in advance of the body, or posterior half of the hair, and serve to entangle, and contract, the whole mass together. The materials, commonly used for hat-making, are the furs of the beaver, seal, rabbit, and other animals, and the wool of sheep. The furs of most animals are mixed with a longer kind of thin hair, which is obliged to be first pulled out, after which, the fur is cut off, with a knife. The materials to be felted are intimately mixed together, by the operation of *bowing*, which depends on the vibrations of an elastic string; the rapid alternations of its motion being peculiarly well adapted to remove all irregular knots and adhesions, among the fibres, and to dispose them in a very light and uniform arrangement. This texture, when pressed under cloths and leather, readily unites into a mass of some firmness. This mass is dipped into a liquor, containing a little sulphuric acid; and, when intended to form a hat, it is first moulded into a large conical figure, and this is afterwards reduced in its dimensions, by working it, for several hours, with the hands. It is then formed into a flat surface, with several concentric folds, which are still further compacted, in order to make the brim, and the circular part of the crown, and forced on a block, which serves as a mould, for the cylindrical part. The nap, or outer portion of the fur, is raised with a fine wire brush, and the hat is subsequently dyed and stiffened, on the inside, with glue.

An attempt has been made, and, at one time, excited considerable expectation in England, to form woollen cloths by the process of felting, without spinning or weaving. Perfect imitations of various cloths, were produced; but they were found deficient in the firmness and durability, which belongs to woven fabrics.

PAPER-MAKING.

The combination of flexible fibres, by which paper is produced, depends on the minute subdivision of the fibres, and their subsequent cohesion. Linen and cotton rags are the common material, of which paper is made; but hemp, and some other fibrous substances, are used for the coarser kinds. These materials, after being washed, are subjected to the action of a revolving cylinder, the surface of which is furnished with a number of sharp teeth, or cutters, which are so placed, as to act against other cutters, fixed underneath the cylinder. The rags are kept immersed in water, and continually exposed to the action of the cutters, for a number of hours, till they are minutely divided, and reduced to a thin pulp. During this process, a quantity of chloride of lime is mixed with the rags, the effect of which is to *bleach* them, by discharging the coloring matter, with which any part of them may be dyed, or otherwise impregnated. Before the discovery of this mode of bleaching, it was necessary to assort the rags, and select only those which were white, to constitute white paper. If, however, the bleaching process be carried too far, it injures the texture of the paper, by corroding and weakening the fibres.

The pulp, composed of the fibrous particles, mixed with water, is transferred to a large vat, and is ready to be made into paper. The workman is provided with a *mould*, which is a square frame, with a fine wire bottom, resembling a sieve, of the size of the intended sheet. With this mould, he dips up a portion of the thin pulp, and holds it in a horizontal direction. The water runs out through the interstices of the wires, and leaves a coating of fibrous particles, in the form of a sheet, upon the bottom of the mould. The sheets, thus formed, are subjected to pressure, first between felts, or woollen cloths, and afterwards alone. They are then *sized*, by dipping them in a thin solution of gelatin, or glue, obtained from the shreds and parings of animal skins. The use of the size is to increase the strength of the paper, and, by filling its interstices, to prevent the ink from spreading among the fibres, by capillary attraction. In *blotting* paper, the usual sizing is omitted.

The paper, after being dried, is pressed, examined, selected, and made into quires and reams. *Hot-pressed* paper is rendered glossy, by pressing it between hot plates of polished metal.

Paper is also manufactured by machinery; and one of the most ingenious methods is that invented by the

Messrs. Fourdrinier. In this arrangement, instead of moulds, the pulp is received in a continual stream, upon the surface of an endless web of brass wire, which extends round two revolving cylinders, and is kept in continual motion forwards, at the same time that it has a tremulous, or vibrating, motion. The pulp is thus made to form a long, continual sheet, which is wiped off from the wire web, by a revolving cylinder, covered with flannel, and, after being compressed between other cylinders, is finally wound into a coil, upon a reel, prepared for the purpose.

Another machine for making paper, consists of a horizontal revolving cylinder of wire web, which is immersed in the vat, to the depth of more than half its diameter. The water penetrates into this cylinder, being strained through the wire web, at the same time depositing a coat of fibrous particles on the outside of the cylinder, which constitute paper. The strained water flows off, through the hollow axis of the cylinder, and the paper is wound off, from the part of the cylinder which is above water, in the form of a continued sheet.

As a specimen of the rapidity with which paper may now be manufactured, Mr. Passey, of Birmingham, has in his possession, a document, the material of which was in a state of rags, was made into paper, dried, and printed, in the space of five minutes, in the presence of many witnesses.

Bookbinding, according to the present mode, is performed in the following manner. The sheets are first folded into a certain number of leaves, according to the form in which the book is to appear; viz., two leaves for folios, four for quartos, eight for octavos, twelve for duodecimos, &c. This is done with a slip of ivory or boxwood, called a folding-stick. In the arrangement of the sheets, the workmen are directed by catchwords or signatures, at the bottom of the pages. When the leaves are thus folded, and arranged in proper order, they are usually beaten upon a stone, with a heavy hammer, to make them solid and smooth, and are then condensed in a press, or by passing through iron rollers. After this preparation, they are sewed in a sewing-press, upon transverse cords, or packthreads, called bands, to receive which, notches are previously sawed in the back.

The number of bands is usually six to a folio, and five for quartos, or any smaller size. The backs are now brushed over with glue, and the ends of the bands opened, and scraped with a knife, that they may be more conveniently fixed to the pasteboard sides; after which, the back is turned with a hammer, the book being fixed in a press, between boards, called backing-boards, in order to make a groove, for admitting the pasteboard sides.

When these sides are applied, holes are made in them, for drawing the bands through, the superfluous ends are cut off, and the parts are hammered smooth. The book is next pressed, for cutting, which is done by a particular machine, called the plough, to which is attached a knife. It is put into a press, called the cutting-press, betwixt two boards, one of which lies even with the press, for the knife to run upon; and the other above, for the knife to cut against. After this, the pasteboards are cut square, with a pair of iron shears; and the colors are sprinkled on the edges of the leaves, with a brush, made of hog's bristles.

The pasteboard sides are now covered, by pasting upon them leather, or whatever other material is intended to form the outside. The sprinkling, or marbling, of the covers is performed, with a brush and a coloring liquid. The covers are glazed, by applying to them the white of an egg, and rubbing them with a heated steel-polisher. A thin piece of morocco is glued upon the back, to receive the lettering, which is impressed with gold-leaf and heated types.

Cloth Binding is a recent improvement, in which a piece of cloth, usually dyed cotton, is embossed with ornamental figures, by passing it through a roller-press, between engraved steel cylinders. It is afterwards pasted upon the volume, in the same manner as leather. Cloth binding is executed with more despatch, and at less expense, than that with leather.

Works of Reference.—Gray's Treatise on Spinning Machinery, 8vo. 1819;—Duncan's Essay on the Art of Weaving, 8vo. 1808;—Guest's History of the Cotton Manufacture, 4to. 1823;—Borgnis' *Mechanique Appliquee aux Arts*, 1818; *tom.* 7, *Machines a Confectionner les Etoffes*;—Ure, The Cotton Manufacture of Great Britain, 8vo. 1836;—Lardners' Cabinet Cyclopedia, 12mo. vol. xxii. entitled *Silk Manufacture*;—Rees' Cyclopedia, articles *Cotton Manufacture*, *Woollen Manufacture*, &c.;—Edinburgh Encyclopedia, articles *Cotton Spinning*, *Cloth Manufacture*, &c. Much of the machinery, invented in this country, is not described in European works.

CHAPTER XIX.

ARTS OF HOROLOGY.

Sun Dial, Clepsydra, Water Clock, Clock Work, Maintaining Power, Regulating Movement, Pendulum, Balance, Scapement, Description of a Clock, Striking Part, Description of a Watch.

Horology, or the art of measuring time, has received the attention, and exercised the ingenuity, of mankind, from the earliest periods. The lapse of thought, and the routine of ordinary occupation, afford but imperfect indications of the real passage of time; and the only exact standard, by which periods of duration can be estimated, is that of governed and regular motion.

Sun Dial.—The diurnal movement of the earth, with relation to the heavenly bodies, is the most perfect standard of admeasurement, for large periods of time. It is the only one, by which the brute creation, and the uncivilized part of mankind, govern their habits of life. This motion has been converted to practical use, for measuring small periods, by the employment of the sun-dial, an invention, apparently, of great antiquity, in which the falling of a shadow, on a surface opposite to the sun, indicates the hour of the day. The sun-dial was known to the ancient Egyptians, Chinese, and Bramins, and was used, by the latter, for astronomical purposes. It appears, also, to have been known to the Jews, in the time of Ahaz, about seven hundred and forty years before Christ.

The first sun-dial at Rome was set up by Papirius Cursor, about three hundred years before Christ; previously to which time, Pliny tells us, there is no mention of any account of time, but by the sun's rising and setting.

At Athens, there is now standing an octagonal building, erected by Andronicus Cyrrhestes, and commonly called the Tower of the Winds. It is shown in Fig. 44 Vol. I. Upon each of the eight sides of this building, is a flying figure, carved in relief, representing the particular wind which blew against that side. Upon each side, was also placed a vertical sun-dial; the *gnomon*, or index, which cast the shadow, projecting from the side, while the lines, indicating the hour, were cut upon the wall. On the top, according to Vitruvius, was the figure of a Triton, which turned with the wind, in the same manner as a modern weathercock. The lines of the dial, upon the wall, are distinctly extant, at the present day; and, although the gnomons have disappeared, the places where they were inserted are still visible.

Clepsydra.—Since the sun-dial could be used, only in the day time, and in clear weather, a different instrument was invented by the ancients, to be used within doors, at all times; and to this was given the name of clepsydra. The clepsydra was formed by a vessel of water, having a minute perforation in the bottom, through which the water issued, drop by drop. It fell into another vessel, in which a light body floated, having attached to it an index, or graduated scale. As the water increased in the receiving vessel, the floating body rose, and, by its regularly increasing height, furnished an approximation to the correct indication of time.*

The original clepsydra was but a rude instrument, and must have given imperfect indications of the true divisions of time. When the vessel was first filled, the drops must have fallen faster, owing to the greater height and pres-

* This instrument was invented in Egypt, but was brought into Rome from Athens. Pompey, while Consul, introduced it into the Roman Senate House; and the orators were obliged to limit the length of their speeches, by its divisions of time, so that Pompey is designated, by one of the historians, as the first Roman who put bridles upon eloquence.

sure of the fluid ; and, in proportion as it became empty, the dropping would be slower, in consequence of the diminution of this pressure. The disadvantage, however, was remedied, in various ways, by the employment of two vessels, one of which was kept constantly full, by a supply from the other ; and thus the water, being always at the same height, furnished its drops, under an equable pressure.

Water Clock.—An instrument, called a water-clock, was in use, at a much later date, and was a subject of extensive manufacture, in some parts of Europe, a few centuries ago. Several modes of constructing this instrument were devised ; but the following is one of the most ingenious. A tight, hollow cylinder, Pl. IV. Fig. 4, is suspended by cords, wound round its axis, which will unwind, as it runs down. It has its interior divided into several compartments, situated like the buckets of a water-wheel. These compartments communicate with each other, by a minute aperture, through which water can pass slowly, from one compartment to another. Before the machine is put in motion, a small quantity of water is introduced into the lower compartments. As the cylinder descends, by the unwinding of the cords, it is obliged to revolve on its axis, until the lower compartments, which contain the water, have risen so far on the ascending side, as to produce an equilibrium. It can then unwind no faster than the water escapes, from one compartment to another, through the minute apertures. As this requires a considerable time, the cylinder may occupy a day, if required, in descending from the top to the bottom of the frame, to which it is attached. And, if the sides of the frame be marked with the hours of the day, the axis of the cylinder, as it passes by them, will indicate the time of the day, with as much accuracy as so imperfect a machine permits.

Clock Work.—In modern days, all other methods of measuring time have given place to the equable motion, produced by the action of machinery on the pendulum and balance. Timekeepers, constructed on this principle, began to be known in Europe, about the fourteenth century, but were formed in a rude and imperfect manner, until the middle of the seventeenth. Since that period, the learning of philosophers, and the ingenuity of artists, have been extensively applied to their improvement; and few subjects, connected with the mechanic arts, have called forth more inventive acuteness, elaborate experiment, and exact calculation.

Before proceeding to a description of the entire mechanism of a clock, or watch, it will be useful to attend to some of the general principles, and essential parts, of a timekeeper. These will be most easily made intelligible, by directing the attention to the following subjects. 1. The maintaining power. 2. The regulating movement. 3. The method of connection.

Maintaining Power.—The force, which is employed to sustain the motions of timekeepers, does not require to be of a powerful kind. It must, however, be steady and uniform, in its action. Gravity and elasticity, applied through the medium of weights and springs, are the only means now employed, to communicate motion to these machines. In clocks, the maintaining force is usually derived from a *weight*. A weight acts with perfect uniformity, from the beginning to the end of its descent, provided the line, which suspends it, is of equal size throughout, and that this line is wound upon a true and perfect cylinder. In portable timekeepers, the weight, for obvious reasons, cannot be employed; and the *spring*, although a less perfect and equable power, is obliged to be substituted. From the oldest clocks which remain, it appears, that the spring was in use before the weight; and one of the first, ever made, is still preserved at Brussels, in which the spring is an old sword-blade, from which a piece of catgut is wound upon the cylinder of the first wheel. The principal difficulty in the use of the spring is, that its action is unequal, and that the more it is bent, the greater force it exerts, to return to its natural situation. The spring of a watch, as it is now used, is a long plate of steel, coiled up into a spiral form. From the outside of this, proceeds a chain, which is attached, not to a cylinder, as is done with the weight, but to a spiral roller, called a fusee, which, by its conical form, gives to the spring an increased mechanical advantage, in proportion as its power diminishes. The fusee has already been described, on page 62.

In some of the watches which are now made, the fusee and the chain are dispensed with. The barrel, which incloses the spring, has a toothed circle on its outside, which turns round, as the spring unwinds, and gives motion to the machinery. But, in this case, the spring is made larger than common, and only the middle part of its action is used, it being never wound up so far, as to call forth its greatest strength, nor suffered to run down, so far as to be materially weakened.

Regulating Movement.—In the mechanism of clocks and watches, it is necessary, so far to retard the movement of the maintaining force, i. e., of the weight or spring, that it may be hours and days in expending itself, and that the timekeeper may require to be wound up, only at distant and convenient periods. This is, in part, effected, by the successive combination of wheels and pinions, the last of which turns round many hundred times, while the first turns round once. But, if a timekeeper possessed only wheels and pinions, it would run down, with a rapidly accelerated motion, in the course of a few seconds. It becomes, therefore, necessary, to connect with it another motion, which cannot be accelerated, beyond a certain degree, by any given force. This motion is obtained, in clocks, from the *pendulum*, and, in watches, from the *balance*; and it is the one which it was proposed to consider, as the second head, under the name of the regulating movement.

Pendulum.—A pendulum is a weight, capable of vibrating about a point, from which it is suspended. If the curve, in which the pendulum moves, be a circular arc, it is necessary, that the length of the vibrations should be exactly equal; otherwise, the pendulum will not keep true time. But, if the curve be a cycloidal one, the pendulum will move, back and forward, in equal times, whatever be the length of its vibrations. In practice, it is found difficult to make a pendulum move in a cycloidal path, without too much friction. It is, therefore, customary, in clocks, to use pendulums, moving in circular arcs, these arcs being made to approximate to cycloids, by being as short as possible.

Pendulums, when set in motion, would continue to vibrate forever, were it not for the retarding effect of friction, and the resistance of the atmosphere. The former of these is partly obviated, by hanging the pendulum upon a thin spring, and the latter, by forming it with a sharp edge. Still, a considerable force is requisite to sustain the motion, and this force, in clocks, is derived from the weight.

That pendulums may vibrate in equal periods, and thus furnish a correct measure of time, it is necessary, that they should always be of uniform length; for pendulums of different lengths differ in their vibrations, as the square roots of their lengths. Now, such is the effect of heat, in expanding all known substances, particularly metals, that the same pendulum is always longer in summer than it is in winter, and sufficiently so, to affect the correctness of the timepiece, to which it is attached. To remedy this difficulty, various ingenious contrivances have been resorted to, the most common of which are, combinations of metals, so connected, as to expand in opposite directions, counterbalancing each other, so as to keep the centre of oscillation in one place. This is sometimes effected, in the gridiron pendulum, by combining bars, or rods, of steel and brass; and, in the mercurial pendulum, by enclosing a quantity of quicksilver, in a tube, near the bottom of the pendulum.

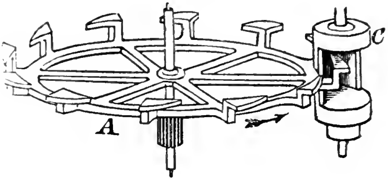
Balance—As the pendulum depends upon the force of gravity, for its motions, it obviously cannot be employed for watches, or portable timekeepers, which are liable to change their position. A substitute is found in the *balance*, which is commonly a wheel, moving on an axis, and which, when thrown, backward and forward, by opposite applications of the moving force, performs its vibrations in equal times. The balance is liable to the same irregularities, from expansion and contraction, as the pendulum, and is corrected in a similar manner; and watches go best, when they are kept in the uniform heat of the body.

The quantity of matter, accumulated in the balance-wheel of a common watch, is so extremely small, that it seems impossible, that it should exert a perfect regulating power. The want of weight, however, is, in some measure, made up, by causing it to perform large vibrations, and to move with great velocity. The rim of the balance-wheel, in a good watch, frequently moves through ten inches in every second. This velocity is produced by the hair-spring, which throws the balance back to the point of equilibrium, as fast as it is thrown out, in either direction, by the moving force; thus performing for the balance, what gravity does for the pendulum. If the hair-spring be taken away, a watch will lose more than twelve hours in twenty-four, and go much more irregularly. The operation of the common *regulator* of a watch is, to tighten, or relax, this hair-spring, by making its effective part longer or shorter, thus accelerating, or retarding, the speed of the balance.

Scapement.—It remains to consider the third part, or *scapement*, by which the rotary motion of the wheels is converted into the reciprocating one of the pendulum and balance. In the scapement, a certain part, connected with the pendulum, or balance, is put in the way of the last, or most rapid, wheel, so that only one tooth of this wheel can escape by it, during each vibration. Thus, the pendulum, or balance, while it receives its motion from this wheel, becomes, in its turn, the regulator of its velocity.

The crutch, or anchor-scapement, used in clocks, and the common pallet-scapement with a contrate-wheel, which is the kind most extensively used in watches, have been already explained, under the head of *Machinery*, page 72. The *horizontal* scapement, Fig. 183, consists of a wheel, A, with elevated teeth, the outer surface of which is curved obliquely. These teeth act upon the edges of a hollow half cylinder, C, the axis of which is parallel to that of the wheel, and carries the balance upon one of its extremities. When a tooth of the scape-wheel

Fig. 183



strikes the first edge of the cylinder, it causes it to recede, moving the balance in one direction. The tooth then enters the hollow part of the cylinder, and strikes upon the opposite side. Before it can escape, the cylin der is obliged to turn in the opposite direction, and thus a vibrating movement is kept up, in the cylinder and balance.

A multitude of other scapements have also been in troduced, by different artists, varying from each other, in the complication of their structure, and accuracy of their movements. But these must, necessarily, be omitted. The operation of the simpler forms, already described, will be more intelligible, taken in connexion with the wheel-work, next to be noticed.

Description of a Clock.—In Pl. IV. several views are given of the mechanism of a clock, consisting of the *going part*, which moves constantly, and carries the hands; and the *striking part*, which announces the hour. Fig. 1, Pl. IV. is an elevation of the clock, with the wheels seen edgewise, showing the going part; the striking movements being omitted, in this figure, to avoid confusion. Fig. 2, is a front view of the *wheel-work* of both going and striking parts; and Fig. 3, is the *dial-work*, or mechanism, immediately under the dial, or face of the clock, and is that part which puts the striking train in motion, every hour. A clock of this kind contains two independent trains of wheel-work, each with its separate first mover. One is constantly going, to indicate time, by the hands on the dial-plate; the other is put in motion, once in an hour, and strikes a bell, to tell the hour at a distance. The part, marked [*a*,] in Figs. 1 and 2, is the *barrel* of the going part; it has a catgut band, [*b*,] wound round it, suspending the weight, which keeps the clock in motion. The part, marked 96, is a wheel, called the first, or great wheel, of ninety-six teeth upon the end of a barrel, turning a pinion, 8, of eight leaves, on an arbor,* which carries the minute-hand; also, 64, is a wheel of sixty-four teeth, on the same arbor, called the centre-wheel, turning the wheel, 60, by a pinion of eight leaves on its arbor. This last wheel gives motion to the pinion of eight, on the arbor of the swing-wheel, 30, which has thirty teeth. The parts [*dh*] are the pallets of the scapement, fixed on an arbor, [*e*,] Fig. 1, going through the back plate of the clock's frame, and carrying a long lever, [*f*.] This lever has a small pin, projecting from its lower end, going into an oblong hole, made in the rod, B, of the pendulum.

The pendulum consists of an inflexible metallic rod, sus pended by a very slender piece of steel spring, D, from a brass bar, E, screwed to the frame of the clock, having a weight at its lower end, not seen in the figure; in the present case, thirty-nine and one eighth inches from the suspension, D. When this pendulum is moved from the perpendicular line, in either direction, and suffered to fall back again, it swings nearly as much beyond the perpendicular, on the contrary side, and then returns. This it will continue to do, for some time; and each of these vibrations will be performed in one second of time, when the pendulum is of the above length. This is the measurer of the time; and the office of the clock is only to indicate the number of vibrations it has made, and to give it a small impulse, each time, to keep it going, as the resistance of the air, and elasticity of the spring, D, would otherwise, in a short time, cause it to stop. By the action of the weight, applied to the cord, [*b*,] which is called the maintaining power, the wheels are all turned round;

* The terms *arbor*, *shaft*, *axle*, and *axis*, are synonymously used by mechanics, to express the bar, or rod, which passes through the centre of a wheel. The terminations of a horizontal arbor are called *gudgeons*, and of an upright one, frequently, *pivots*. The term *axis*, in a more exact sense, may mean merely the longest central diameter, or a diameter about which motion takes place.

and if the pallets [*d* and *h*] were removed, the swing-wheel, 30, would revolve, with great velocity, in the direction from 30 to [*d*,] until the weight reached the ground. The teeth of these pallets are so placed, that one of them always engages the wheel, and prevents it from turning more than half a tooth at a time. In the figure, the pallet [*d*] has the nearest tooth of the wheel resting on it, and the pendulum is on the side [*h*] of the perpendicular. When it returns, it moves the pallet, [*d*,] so as to allow the tooth of the wheel to slip off; but, in the mean time, the pallet [*h*] has interposed its point, in the way of the tooth next it, and stops the wheel, till the next vibration, or second. The distance between the two pallets [*d* and *h*] is so adjusted, that only half a tooth of the wheel escapes, at each vibration; and, as the wheel has thirty teeth, it will revolve once in sixty vibrations, of one second each, or in one minute; consequently, a hand, on the arbor of this wheel, will indicate seconds, on the dial-plate, F, which is a circle, divided into sixty. The pinion of eight, on its arbor, is turned by a wheel of sixty, which, consequently, will turn once in seven turns and a half of the other, or in seven minutes and thirty seconds, or, in one eighth of an hour. Its pinion of eight is moved by a wheel of sixty-four, or eight times itself, which will turn in one eighth part of the time. This will be an hour; and, therefore, the arbor of this wheel carries the minute-hand of the clock. The great wheel of 96, being twelve times the number of the pinion eight, will turn once in twelve hours, and the barrel, [*a*,] with it. The cord of catgut goes round sixteen times, so that the clock will go eight days.

The hour-hand of the clock is turned by the wheel-work, shown in Figs. 1 and 3. On the end of the arbor of the centre wheel, 64, a tube is fitted, so as to go round with it, by friction. This carries the minute-hand; and, if the clock should require correction, the hand may be slipped round, without moving the wheels. This tube has a pinion of forty teeth on its lower end, indicated by a dotted circle. This turns another wheel, 40, of forty teeth, which has a pinion of six teeth on its arbor, turning a wheel, 72, of seventy-two teeth. The two wheels, 40, will both turn in an hour; and 72, in twelve hours. The arbor of this wheel has the hour-hand, and is a tube, going over the arbor of the minute-hand, so that the two hands are concentric. The barrel [*a*] is fitted to an arbor, coming through the plate of the clock, and filed square, to put on a key, to wind up the weight. The great wheel, 96, is not fixed fast to the arbor, but has a click on it, which takes the teeth of a ratchet-wheel, cut on the barrel; so that the barrel may be turned in one direction, to wind up the weight, without the wheel; but, by the descent of the weight, the wheels will be turned with the barrel, by the click.

Striking Part.—Having now considered the going part of the clock, it remains to describe the mechanism by which the hour is struck. In Fig. 2, 78, is a great wheel of seventy-eight teeth, provided with a barrel and click, as in 96; it turns a pinion of eight. On the same arbor is a wheel, 64, turning a pinion of eight, on the arbor of the wheel [*o*] of forty-eight. This turns another pinion of eight, and wheel [*p*] of forty-eight, which turns a pinion of six, on the same arbor, with a thin vane of metal, seen edgewise, which is called the *fly*, and which, by the resistance of the air to its motion, regulates the velocity of the wheels.

The wheel, 64, has eight pins projecting from it, which raise the tail [*n*] of the hammer, as they revolve. The hammer is returned, violently, when the pins leave its tail, by a spring, [*m*,] pressing on the end of a pin, put through its arbor, and strikes the bell. The hammer and bell are behind the plate, and, therefore, unseen. There is a short spring, [*l*,] which the other end of the pin through the arbor touches, just before the hammer strikes the bell. Its use is, to lift the hammer off the bell, the instant it has struck, that it may not stop the sound, The pins in the wheel, 64, must pass by the hammer-tail seventy-eight times, in striking the twelve hours, $1+2+3+4+5+6+7+8+9+10+11+12=78$; and, as its pinion has eight leaves, each leaf of the pinion answers to a pin in the wheel, 64. Now, as the great wheel has seventy-eight teeth, it will turn once in twelve hours, the same as the other great wheel, 96. In the wheel, 64, eight of its teeth correspond to one of the pins of the hammer, and, as the pinion of the wheel [*o*] has eight teeth, it (wheel *o*) will turn once, for each stroke of the hammer. By the remaining wheels, one, [*o*,] multiplying six times, and the other, [*p*,] eight times, the fly will turn $6\times8=48$ times, for one turn of [*o*,] which answers to one stroke of the hammer.

Fig. 3, is also mechanism, relating to the striking part. Behind [*r*,] there is a small pinion, of one tooth, called the *gathering-pallet*, on the arbor of the wheel, [*o*,] which, consequently, turns once, for each stroke of the hammer. The part, marked [S*rx*,] is a portion of a large wheel, and is called the *rack*. The part [*t*] is an arm attached to the rack, whose end rests against a spiral plate, V, called the *snail*, which is fixed on the tubular arbor, before described, of the hour-hand and wheel, 72, and turns round with it once in twelve hours. The snail is divided into twelve equal angles, of thirty degrees each, and, as it turns, each of these answers to an hour. The circular arcs, forming the circumference of the snail, are struck from the centre of the arbor, between each division, with a different radius; decreasing a certain quantity, each time, in the order of the hours. The circular part of the rack, 14, is cut into teeth, each of which is of such a length, that every step upon the snail shall answer to one of them. At [*w*,] is a spring, pressing against the tail of the rack, and acting to throw the arm of the rack against the snail. The part [*g*] is a click, called the hawk's-bill, taking into the teeth of the rack, and holding it up, in opposition to the spring, [*w*.] The part [*ik*] is a three-armed detent, called the *warning-piece*. The arm [*k*] is bent at its end, and passes through a hole, in the front plate of the clock, so as to catch a pin, placed in one of the arms of the wheel, [*p*,] Fig. 2, and which describes the dotted circle, in Fig. 3. The other arm [*i*] stands, so as to fall in the way of a pin, in the wheel, 40. In the present position of the figure, the wheels of the striking train are in motion, and would continue turning, until the gathering-pallet at [*r*] which turns once, at each stroke of the hammer, by its tooth lifts the rack, [*s*,] in opposition to the spring, [*w*,] one tooth, each turn; and the hawk's-bill [*g*] retains the rack, until a pin, in the end of the rack, is brought in the way of the lever of the gathering-pallet, [*r*,] and stops the wheels from turning any further. It is in this position, with the rack wound up, till its pin arrests the tail, [*r*,] that we shall begin to describe the operation of the striking of the clock.

The wheel, 40, as has been said before, turns once in an hour; and, consequently, at the expiration of every hour, the pin in it takes the end, [*i*,] and moves it towards the spring near it. This depresses the end, [*k*,] until it falls in the circle of the motion of the pin, in the wheel, [*p*,] Fig. 2. At the same time, the short tail depresses one end of the hawk's-bill, and raises the other, [*g*,] so as to clear the teeth of the rack, [*s*.] Immedidiately, the spring [*w*] throws the rack back, until the end of its tail [*t*] touches that part of the snail which is nearest it. When the rack falls back, the pin in it is moved clear of the gathering-pallet, [*r*,] and the wheels are set at liberty. The maintaining power puts them in motion; but, in a very short time, before the hammer has struck, the pin in the wheel [*p*] falls against the end of [*k*,] and stops the whole. This operation happens, a few minutes before the clock strikes, and this noise of the wheels turning is called the warning. When the hour is expired, the wheel, 40, has turned so far, as to allow the end of [*i*] to slip over its pin, as in the figure. The small spring, pressing against it, raises the end, [*k*,] so as to be within the circle of the pin, in the wheel, [*p*,] Fig. 2. Every obstacle is now removed, and the wheels run on the pinion; the wheel, 64, raises the hammer, [*r*,] and it strikes on the bell; the gathering-pallet [*r*] takes up the rack, one tooth at each turn, the hawk's-bill [*g*] retaining it, until the pin [*x*] in the rack, comes under the gathering-pallet, [*r*,] and stops the motion of the whole machine, till the pin in the wheel, 40, at the next hour, takes the warning piece, [*ik*,] and repeats the operation we have now described. As the gathering-pallet turns once, for each blow of the hammer, and its tooth gathers up one tooth of the rack, at each turn, it is evident, that the number of teeth, which the rack is allowed to fall back, limits the number of strokes the hammer will make. This is done by the rack's tail, [*t*,] resting on the snail. Each step of the snail answers to one tooth of the rack, and one stroke of the hammer. At each hour, a fresh step of the snail is turned to the tail of the rack, and, by this means, the number of strokes is made to increase one, at each time, from one to twelve.

Description of a Watch.—In Pl. V., several views are given of the construction of a common portable watch. Fig. 1, represents the wheel-work, immediately beneath the dial-plate, and also its hands, the circles of hours and minutes being marked, though the dial, on which these are engraved, is removed. Fig. 2, is a plan of the wheel-work, all exhibited at one view, for which purpose, the upper plate of the watch is removed. Fig. 3, is a plan of the balance, and the work situated upon the upper plate. Fig. 4, shows the great wheel, and the pottance-wheel, detached. Fig. 5, the spring-barrel, chain, and fusee, detached; and Fig. 6, is an elevation of all the movements together, the works being supposed to be opened out into a straight line, to exhibit them all at once. Fig. 7, is a detached view of the balance, together with the scapement, in action.

The principal frame, for supporting the acting parts of the watch, consists of two circular plates, marked C and D, in the figures. Of these, the former is called the upper plate, and the latter, the pillar-plate, from the circumstance that the four pillars, EE, which unite the two plates, and keep them a proper distance asunder, are fastened firmly into the lower plate; while the other ends pass through holes, in the upper plate, C, and have small pins put through the ends of the pillars, to keep the whole together. By drawing out these pins, the watch may be taken to pieces. The pivots of the several wheels being received in small holes, made in these plates, they, of course, fall to pieces, as soon as the plates are separated.

The maintaining power is a spiral steel spring, which is coiled up close, by a tool used for the purpose, and put into a brass box, called the *barrel*. It is marked A, in all the figures, and is shown separate, in Fig. 5, with the spring in it. The spring has a hook, at the outer end of its spiral, which is put through a hole, [*a*,] Fig. 5, in the side of the barrel, and riveted fast to it. The inner end of the spiral has an oblong opening, cut through it, to receive a hook upon the barrel arbor, B, Fig. 5. The pivots of this arbor pass through the top and bottom of the barrel, and one of them is filed square, to hold a ratchet-wheel, [*b*,] Figs. 1 and 6, which has a click, and keeps the arbor from turning round, except in one direction. The two pivots of the arbor are received in pivot-holes in the plates, CD, of the watch, and the pivot, which has the ratchet-wheel upon it, passes through the plate. The wheel marked [*b*,] Figs. 1 and 6, with its click, is, therefore, on the outside of the pillar-plate, D, of the watch. The top of the barrel has a cover, or lid, fitted into it, through which the upper pivot of the arbor projects; thus, the arbor of the barrel is to be considered as a fixture, the click of the ratchet-wheel preventing it from turning round, while the interior end of the spiral spring, being hooked, assists in rendering it stationary. The barrel, thus mounted, has a small steel chain, [*d*,] Figs. 2 and 6, coiled round its circumference, and attached to it by a small hook of the chain, which enters a little hole, made in the circumference of the barrel, at its upper end. The other extremity of this chain is hooked to the lower part of the fusee, marked F, Figs. 2, 5, and 6, and the chain is disposed, either upon the circumference of the barrel, or in the spiral groove, cut round the fusee for its reception, the arbor of which has pivots at the ends, which are received into pivot-holes, made in the plates of the watch. One pivot is formed square, and projects through the plate, to fit the key, by which the watch is wound up.

It is evident, that, when the fusee is turned by the watch-key, it will wind the chain, off the circumference of the barrel, on itself; and, as the outer end of the spring is fastened to the barrel, and the other is hooked to the barrel-arbor, which, as before mentioned, is prevented from turning, by the click of the ratchet-wheel, [*ab*,] the spring will be coiled up into a smaller compass than before. Its reaction, therefore, when the key is taken off, will turn the barrel, and, by the chain, turn the fusee, and give motion to the wheels of the watch. The fusee has a spiral groove cut round it, in which the chain lies ; this groove is cut by an engine, in such a form, that the chain shall pull from the smallest part, or radius, of the fusee, when the spring is quite wound up, and, therefore, acts with its greatest force on the chain. From this point, the groove gradually increases in diameter, so that, as the spring unwinds, and acts with less power, the chain operates on a larger radius of the fusee ; and the effect, upon the arbor of the fusee, or the toothed wheel attached to it, will always be equal, and cause the watch to go with regularity.

To prevent too much chain being wound upon the fu see, and, by that means, breaking the chain, or overstraining the spring, a contrivance, called a *guard-gut*, is added. It is a small lever, [*e*,] Fig. 2, moving on a stud, fixed to the upper plate, C, of the watch, and pressed downwards by a small spring, [*f*.] As the chain is wound up, upon the fusee, it rises in the spiral groove, and lifts up the lever, until it touches the upper plate. It is then in a position to intercept the edge, or tooth, [*g*,] of the spiral piece of metal, seen on the top of the fusee, and thus stops it from being wound up any further.

The power of the spring is transmitted to the balance, by means of several toothed wheels, which multiply the number of revolutions, which the chain makes on the fusee, to such a number, that, though the last, or balance-wheel, turns nine and one half times every minute, the fusee will, at the same time, turn so slowly, that the chain will not be drawn off from it, in less than twenty-eight or thirty hours, and it will make only one turn, in four hours This assemblage of wheels is called the *train* of the watch. The first toothed wheel, G, is attached to the fusee, and is called the great wheel. It is shown separated from the fusee, in Fig. 4, having a hole through the centre, to receive the arbor of the fusee, and a projecting ring upon its surface. The under surface of the base of the fusee is shown in Fig. 5, at F, having a circular cavity cut in it, to receive the corresponding ring upon the great wheel, G, Fig. 4. A ratchet-wheel [*i*] is fixed fast upon the fusee arbor, and sunk within the cavity, excavated in the lower surface of the fusee. When the wheel and fusee are put together, a small click, [*h*,] Fig. 4, takes into the teeth of the ratchet, [*i*.] As the fusee is turned by the watch-key, to wind up the watch, this click slips over the sloping slides of the teeth, without turning the great wheel ; but, when the fusee is turned the other way, by drawing the chain from the spring-barrel, the click catches the teeth of the ratchet-wheel, and causes the toothed wheel to turn with the fusee.

The great wheel, G, has forty-eight teeth on its circumference, which take into, and turn, a pinion of twelve teeth, fixed on the same arbor with the

Centre-wheel, H, so called, from its situation in the centre of the watch ; it has fifty-four teeth, to turn a pinion of six leaves, on the arbor of the

Third wheel, I, which has forty-eight teeth. It is sunk in a cavity, formed in the pillar-plate, and turns a pinion of six, on the arbor of the

Contrate-wheel, K, which has forty-eight teeth, cut parallel with its axis, by which it turns a pinion of six leaves, fixed to

The balance-wheel, L. One of the pivots of the arbor of this wheel turns in a frame, M, called the *pottance*, or *potence*, fixed to the upper plate, and shown separately, in Fig. 4. The other pivot runs in a small piece, fixed to the upper part, called the counter pottance, not shown in any of the figures ; so that, when the two plates are put together, the balance-wheel pinion may work into the teeth of the contrate-wheel, as shown in Fig. 6. The balance-wheel, L, has fifteen teeth, by which it impels the balance, [*op*.] The arbor of the balance, which is called the *verge*, has two small leaves, or pallets, projecting from it, nearly at right angles to each other. These are acted upon by the teeth of the balance-wheel, L, in such a manner, that, at every vibration, the balance receives a slight impulse to continue its motion ; and every vibration, so made, suffers a tooth of the wheel to escape, or pass by ; whence this part is called the scapement of the watch, and constitutes its most essential part. The wheel, L, is sometimes called the *scape-wheel*, or *crown-wheel*. Its action is explained by Fig. 7, which shows the wheel, and balance, detached. Suppose, in this view, the pinion [*h*] on the arbor of the balance-wheel, or crown-wheel, [*ik*,] to be actuated by the main-spring, which forms the maintaining power, by means of the train of wheel-work, in the direction of the arrow, while the pallets, [*m* and *n*,] attached to the axis of the balance, and standing at right angles to each other, or very nearly so, are long enough to fall in the way of the ends of the sloped teeth of the wheel, when turned round, at an angle of forty-five degrees, so as to point to opposite directions, as in the figure. Then a tooth in the wheel below, for instance, meets with the pallet, [*n*,] supposed to be at rest, and drives it before it, a certain space, till the end of the tooth escapes. In the meantime, the balance, [*ospr*,] attached to the axis of the pallets, continues to move in the direction [*rosp*,] and winds up the small spiral, or *hair-spring*, [*q*,] one end of which is fast to the axis, and the other to a stud, on the upper plate of the frame. In this operation, the spring opposes the momentum, given to the balance, by this push of the tooth upon the pallet, and prevents the balance going quite round ; but, the instant the tooth escapes, the upper pallet [*m*] meets with another tooth, at the opposite side of the wheel's diameter, moving in an opposite direction to that below. Here, this pallet receives a push, which carries the balance back again, its momentum, as yet, being small in the direction [*ospr*,] and aids the spring, which now unbends itself, till it comes to its quiescent position, then swings beyond that point, partly, by the impulse from the maintaining power on the pallet, [*m*,] and partly, by the acquired momentum of the moving balance, particularly when this pallet [*m*] has escaped. At length, the pallet [*n*] again meets with the succeeding tooth, and is carried backward by it, in the direction in which the balance is now moving, till the maintaining power and force of the unwound spring, together, overcome the momentum of the balance, during which time, the recoil of the balance-wheel is apparent, and, also, of the second-hand, if the watch has one, its place being on the arbor of the contrate-wheel. Then the wheel brings the pallet [*n*] back again, till it escapes; and the same process takes place with the pallet, [*m*,] as has been described with respect to pallet, [*n*.] Thus, two contrary excursions, or oscillations, of the balance take place, before one tooth has completely escaped; and, for this reason, there must always be an odd number of teeth in this wheel, that a space on one side of the wheel may always be opposite to a tooth on the other, in order that one pallet may be out of action, while the other is in action.

The upper pivot of the verge is supported in a cover, screwed to the upper plate, as shown at N, in Fig. 6, which extends over the balance, and protects it from violence. The lower pivot works in the bottom of the pottance, M, at [*t*,] Fig. 4. The socket, for the pivot of the balance-wheel, is made in a small piece of brass, [*v*,] which slides in a groove, made in the pottance, as shown in Fig. 4; so that, by drawing the slide in or out, the teeth of the balance-wheel shall just clear one pallet, before it takes the other; and, upon the perfection of this adjustment, which is called the scaping of the watch, the performance of it very greatly depends.

It now remains to show the communication of this motion to the hands of the watch, which indicate the time on the dial-plate. The hands are moved by the central arbor, which comes through the pillar-plate, and projects a considerable length. It has a pinion of twelve leaves, called

The common pinion, [*w*,] Fig. 6, fitted upon it, the axis of which is a tube, formed square at the end, to fix on the minute-hand, W. It fits tight upon the projecting arbor of the centre-wheel; and, therefore, turns with it, but will slip round to set the hands, when the watch is wrong, and requires to be rectified. The common pinion is situated close to the pillar-plate, and its leaves engage the teeth of

The minute-wheel, X, Figs. 1 and 6, of forty-eight teeth, which is fitted on a pin fixed in the plate, and its pinion, [x,] of sixteen leaves, which is fixed to it, turns

The hour-wheel, Y, of forty-eight teeth. The arbor of this is a tube, which is put over the tube of the *cannon-pinion*, carrying the minute-hand, and has the hour-hand, Z, fixed on it, to indicate the time upon the dial-plate. Thus, by the cannon-pinion, [w,] which is to the minute-wheel, X, as one is to four, and the pinion [x] of this, which is to the hour-wheel, Y, as one is to three, the hour-wheel, Y, and its hand, [z,] though concentric with the cannon-pinion and minute-hand, make but one revolution, during twelve revolutions of the other; therefore, one turns round in an hour, and the other turns round once in twelve hours, as the figures on the dial show.

It is necessary to have some *regulation*, by which the rate of the watch's movement may be adjusted; for, hitherto, we have only spoken of making the watch keep always to a uniform, or certain rate of, motion; but it is necessary to make it keep true time. This can be done by two means; either by increasing or diminishing the force of the main-spring, which increases or diminishes the arc which the balance describes; or it may be done, by strengthening or weakening the hair-spring, which will cause the balance to move quicker or slower.

The hair-spring, otherwise called the *pendulum-spring*, [q,] Fig. 3, is fixed to a stud, upon the plate, [c,] by one end, and is attached to the verge of the balance, by the other.

The regulation is effected by means of what is called the *curb*. This is a small lever, [z,] Fig. 3, projecting from a circular ring, [rr,] which may be considered as its centre of motion, but perforated with a hole through the centre, large enough to contain the hair-spring within it. A circular groove is turned out in the upper plate, nearly concentric with the balance, and the ring [rr] fits into this. Both are turned rather largest at the bottom, in the manner of a dove-tail; but the ring, being divided at the side, opposite to the lever, [z,] can be sprung up, and rendered so much smaller, as to get it into the groove; and, being once in, the elasticity of the ring expands it, so as to fill the groove completely. In this state, it may be considered as a lever, which describes a circuit round the verge, as a centre ; and the end of it points to a divided arc, engraved on the upper plate, one end of which is marked F, and the other, S, denoting that the index, or lever, [*z*,] is to be moved towards one or the other, to make the watch move faster or slower, as its regulation requires.

The manner of its operation is thus ; the end of the lever, or index, [*z*,] continues within the circle, a small distance towards its centre, and, passing beneath the outer turn of the spiral spring, [*q*,] has two very small pins rising up from it, which include the spring between them. The actual length of the hair-spring is, therefore, to be estimated from these pins, to the place of its connexion with the verge. Now, by altering the position of the index, this acting length can be regulated, at pleasure, to produce such vibration of the balance, as will make the watch keep true time. By shortening the length, the spring becomes more powerful, and returns the balance quicker, so that it will vibrate in less time. This is effected by moving the index towards F. On the other hand, turning the index towards S, lengthens the spring, by which it becomes more delicate, and less powerful, returning the balance slower than before.

Many watches, instead of the arc and index, have a circular curb, or regulator, which is turned by a central arbor, to which the watch-key is applied, when it is necessary to move it.

Delicate watches have jewelled pivot-holes, for the top and bottom of the verge, to diminish the friction. These jewels are diamonds, rubies, and other stones, which unite great hardness with durability. Each consists of two pieces, one of which has a cylindrical hole drilled through it, to receive the pivot, the other is a flat piece, making the rest, or stop, which forms the bottom of the hole Both stones are ground circular on the edge, and are fitted and burnished into small brass rings, which are fastened into the bearings, above and below, by two small screws, applied to each. The addition of jewels to a watch is a great advantage, as they do not tend to thicken the oil, which brass is apt to do, in consequence of the oxidation of the metal.

Mr. Dent, a lecturer before the Royal Institution, exhibited to his audience, a dissected watch, showing the complicated nature of this little machine. It appears, that the number of pieces, in a complete lever watch, is nine hundred and ninety-two, and the number of separate trades, employed in manufacturing these pieces, and in putting them together, is forty-three.

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CHAPTER XX.

ARTS OF METALLURGY.

Extraction of Metals, Assaying, Alloys. *Gold*, Extraction, Cupellation, Parting, Cementation, Alloy, Working, Gold Beating, Gilding on Metals, Gold Wire. *Silver*, Extraction, Working, Coining, Plating. *Copper*, Extraction, Working. *Brass*, Manufacture, Buttons, Pins, Bronze. *Lead*, Extraction, Manufacture, Sheet Lead, Lead Pipes, Leaden Shot. *Tin*, Block Tin, Tin Plates, Silvering of Mirrors. *Iron*, Smelting, Crude Iron, Casting, Malleable Iron, Forging, Rolling and Slitting, Wire Drawing, Nail Making, Gun Making. *Steel*, Alloys of Steel, Case Hardening, Tempering, Cutlery.

THE term metallurgy, in its most comprehensive sense, signifies the art of working metals, in every different way. In a more precise and limited sense, it is confined to the separating of metals from their ores, and assaying them, to ascertain their value. In the present chapter, it is proposed to make use of the term in its more general meaning ; so far, at least, as to comprehend certain processes in the management and manufacture of metals, which are sufficiently interesting, to merit the attention of the general student.

Extraction of Metals.—Metals are found in Nature, in various states. When uncombined, or when combined only with each other, they are said to be in a *native* state. When combined with other substances, so that the metallic properties are, in some measure, disguised, they are said to be mineralized, or in the state of *ore*. The substance, with which the metal is combined, is termed its *mineralizer*. The most common states of combination, in which the metallic ores are found, are oxides, combinations of oxides with carbonic, sulphuric, muriatic, and phosphoric, acids and sulphurets. These ores occur, under various forms, sometimes crystallized, and often destitute of any regular figure. They are met with, generally, in veins, penetrating the strata; and, in this case, are usually blended, or intermixed, with various earthy fossils, as calcareous spar, fluor spar, quartz, &c. The accompanying fossil is termed the *gangue*, or *matrix*, of the metal. Some metallic ores occur in beds, or in large insulated masses.

To separate the metal, after it is dug from the mine, the mass is broken up, and subjected to the operations of sorting, stamping, washing, roasting, smelting, and refining. *Sorting* consists merely in the separation of the different pieces of ore, into lots, according to the products they are expected to afford, and the treatment they are likely to require. After the ore is sorted, it is carried to the stamper, or stamping-mill, which has been described in a former chapter. The process of *stamping*, breaks and pounds up the ore, together with its gangue, into a coarse powder. From the stamping-mill, the pounded ore is conveyed to the *washing*; a process, in which advantage is taken of the difference of specific gravity. The operation of washing is sometimes performed by hand, in wooden vessels, or in troughs, which cross a current of water; and, sometimes, if the ore is rich, and valuable, upon inclined tables, covered with cloth. In this process, the heavier parts, consisting of the metallic ore, sink first to the bottom, while the stony matter, which is lighter than the ore, being longer in sinking, is carried further down the current, and thus separated from the rest.

The next operation, which is that of *roasting*, is employed to drive off the sulphur, arsenic, and other volatile parts, which the mineral may contain. It is performed in a variety of ways, and by different processes, according to the nature of the ore, and the degree of heat required. The roasting is sometime performed in the air, and sometimes, in furnaces, among the fuel. *Smelting* consists, in general, in fusing the roasted ore, with a view to extract the metal; though the term is sometimes applied to the melting of metal, in any state, especially iron The immediate object of this process is to *reduce* the metal, or to separate the oxygen, with which the metal has either been naturally combined, or has united, during the operation of roasting. This is done, by placing in a furnace, alternate layers of charcoal, or coke, and of the metallic matter; a strong heat is then excited by bellows; the carbonaceous matter attracts the oxygen, while the metal is reduced, melted, and run out, at the bottom of the furnace. The volatile metals are obtained by sublimation, or distillation. Even after these operations, the metal is seldom pure, but is combined with some other metal or metals, which have been present in the ore. If these are in small quantity, and do not injure the metal, they are in general disregarded. If it is necessary, however, to separate them, or if, from their value, the separation is an object of importance, different processes are followed, adapted to each particular metal. All the operations, subsequent to smelting, are comprehended under the general name of *refining*, because their effect is always to obtain a purer metal. The different metals are refined by different processes.

Assaying.—The art of assaying metallic ores is that of analyzing them, in small quantities, so as to discover their component parts. It requires a knowledge of the relations of the metals to the other chemical agents, and is varied, in its different stages, as applied to each. The general process consists, in selecting proper specimens of the ore, which is done, by taking equal portions of that which appears to be the richest, the poorest, and of medium value, and reducing these to coarse powder, which is washed, to carry off any earthy or stony matter. It is then roasted in a shallow earthen vessel, under a muffle, to expel the volatile principles. It is lastly reduced, by mixing it with fluxes, and applying a more or less intense heat, as the metal is more or less refractory. The metallic matter, existing in the ore, is thus obtained. This, it is obvious, may consist of various metals; and, if there is reason to believe this, and it be of importance to ascertain it, it is submitted to operations, adapted to the metals which may be supposed present. Sometimes, an accurate analysis is made, at once, of the metallic ore, in the humid way; the metal being dissolved by the different acids, and precipitated by the alkalis, earths, and other re-agents. The assaying of the precious metals is usually confined to ascertaining the quantity of gold or silver, in any alloy or compound, without regard to the other constituents.

Alloys.—The metals are capable of combining with each other, by fusion; and to these combinations, the name of *alloy* is given. They all retain the general metallic properties,—lustre, opacity, and density; and even, in the greater number of cases, the properties of the constituent metals remain in the combination, only somewhat modified. In general, alloys are more hard and brittle than the individual metals of which they consist, though this, as well as the other changes of properties, is considerably influenced by the proportions, in which the ingredients are combined. They have also, in general, a greater fusibility, than the mean fusibility of the respective metals. The alloys of quicksilver, called *amalgams*, are usually soft, or liquid, according to the proportions. The metals combined in alloys, are generally more susceptible of oxidizement, than in their separate state; owing, probably, to the diminution in the power of cohesion, by the combination, or, perhaps, to an electrical action. From their peculiar properties, some of the alloys are extensively used, as brass, which is an alloy of copper and zinc; and pewter, which is an alloy of tin and zinc or lead.

A degree of condensation usually attends these combinations, so that the specific gravity of the alloy is greater, than the mean specific gravity of its constituent metals. In brass, for example, it is one tenth greater, and, in some cases, the condensation is such, that the density is even greater than that of the heavier metals combined, as in the alloy of silver and quicksilver. Sometimes, however, the particles assume such an arrangement, that the density is less than the mean, as in the examples of the alloy of copper with silver, and of gold with tin, and gold with iron.

In these combinations, there exists a certain order of attractions, by which one metal is more disposed to unite with another, than a third is. The difference, however, is not very considerable; hence, three, four, or more, metals can be combined together. Some, however, are difficult to unite, as iron and lead, and iron and quicksilver. The combination seems to be, in some measure, regulated by the relations of fusibility and specific gravity; so that, the affinities being equal, the metals are less disposed to combine, as they differ more in their fusibility and specific gravity; and, where the affinity is weak, a considerable difference of this kind may prevent any combination whatever.

GOLD.

Gold exists in various minerals; but the greatest part of the gold, in the possession of mankind, has been found in the form of grains and small masses, among the alluvial sands, which constitute certain plains, and margins of rivers. In this state, it is usually alloyed with small portions of other metals, particularly silver and copper.

Extraction.—When native gold is found in a state of mixture with foreign matters, its extraction is commonly performed by *amalgamation* with quicksilver. After having been freed, by pounding and washing, from most of the stony matter mixed with it, it is triturated with ten times its weight of quicksilver, until an amalgam is formed. This is separated from any superfluous earthy matter, and subjected to pressure, enclosed in leather, by which the more fluid part is separated, and forced through the leather, while the more consistent amalgam, containing the greater part of the gold, remains. It is then subjected to distillation, in retorts of earthen ware, to separate the quicksilver, and the remaining gold is afterwards fused. When the gold is contained in other ores, the ore is roasted, to drive off the more volatile principles, and to oxidize the other metals. The gold is then extracted, by amalgamation, by liquefaction with lead, by the action of nitric acid, or other methods, adapted to each ore, according to its constituent parts.

Cupellation.—Gold, obtained in any of these ways, is always more or less alloyed, particularly with silver or copper. The first step in its purification is the process of *cupellation.* To explain the nature of this, it is necessary to observe, that lead is a metal very fusible, and extremely easy of oxidizement, forming an oxide, which easily vitrifies, and which favors the oxidizement and vitrification of other metals. A portion of lead, therefore, is added to the impure gold, more or less, according to the quantity of alloy which it contains, of which the workman judges by the color, hardness, elasticity, and specific gravity, of the gold. They are melted together, and exposed to heat on a *cupel*, which is a vessel made of bone-ashes, or, sometimes, of wood-ashes, under a muffle, or, in the large way, on the hearth of a refining furnace. The lead passes to the state of oxide, is vitrified, and, at the same time, promotes the oxidizement and vitrification of the foreign metals. The vitrified oxide is absorbed by the porous cupel, or, in the large way, the greater part is driven off by the blast of bellows, and removed. When the greater part of the foreign metals is abstracted, the remaining fused metal exhibits various prismatic colors, which succeed each other quickly. It at length suddenly brightens, and its surface becomes highly luminous. This is regarded as the completion of the process. The metal is allowed to become solid, and, while yet hot, is detached.

Parting.—The gold, even after having been submitted to this process, may still be alloyed with silver, which, being nearly as difficult of oxidizement, is not removed by the action of the lead. It is, therefore, lastly subjected to the operation of *parting*. The metal is rolled out thin, and cut into small pieces. These are digested with a moderate heat, in diluted nitric acid, which dissolves the silver, leaving the gold, undissolved, in a porous mass. It has been found, however, that, when the proportion of silver is small to that of gold, the latter protects the former from the action of the acid. The previous step of *quartation*, as it is named, is therefore employed, which consists in fusing three parts of silver with one of the gold, and then subjecting this alloyed metal, rolled out, to the operation of the acid. These are the operations employed in commerce. To obtain gold, perfectly pure, still another process is, perhaps, necessary,—dissolving it in nitro-muriatic acid, and adding to the solution, a solution of sulphate of iron, which, attracting the oxygen, precipitates the gold, in the metallic state.

Cementation.—The process of *cementation* is performed, by beating the alloy into thin plates, and placing these in alternate layers, with a cement, containing nitrate of potass, and sulphate of iron. The whole is then exposed to heat, until a great part of the alloying metals are removed, by the action of the nitric acid, which is liberated by the nitre. Cementation is sometimes employed, by goldsmiths, to refine the surface of articles, in which gold is alloyed with baser metals.

Alloy.—There is a peculiar language, established in commerce, and often referred to, by writers, to denote the purity of gold, or the degree of its alloy with other metals. The mass is supposed to consist of twenty-four equal parts, these imaginary parts being termed *carats*. If perfectly pure, or unalloyed, it is said to be gold twenty-four carats fine; if alloyed with one part of any other metal, or mixture of metals, it is said to be twenty-three carats fine. In this way, the proportion of alloy is expressed. The standard gold coin of the United States, and Great Britain, is twenty-two carats fine; or contains one twelfth part of alloy.

Gold, when perfectly pure, is not so fit for coin, on account of its softness, in consequence of which, the impression is soon obliterated, and it sustains loss from friction. Hence, it is always alloyed, to give it hardness. The metals, that have been used for this purpose, are silver or copper. Gold, made standard by an alloy, consisting of equal parts of silver and copper, has a color, approaching more to that of pure gold, than any other alloy. This color also remains uniform, while that with copper, after a certain degree of wear, becomes unequal.*

Working.—Common goldsmiths' work is performed, by casting in moulds, beating with hammers, and rolling between polished steel rollers. Works, that have raised or embossed figures, are commonly cast in moulds, and afterwards polished; or, they are struck in dies, cut for the purpose. Vessels, both of gold and silver, are beat out from flat plates. When the form is difficult, they are made of several plates, and soldered together. The solder used for this purpose, is an alloy of gold with silver, copper, or brass. Small ornamental works are commonly executed, by *enchasing*. This process is performed upon thin plates of gold, with a block and hammer. It consists, in driving in portions of the metal, on one side, in such a manner, that they stand in relief, forming the figures required, on the opposite side. Many small articles are also made from gold wire, variously wrought and ornamented.

Gold Beating.—The great utility of gilding, in the arts, in furnishing an incorruptible covering to various

* Mr. Hatchet, with Mr. Cavendish, subjected the different alloys that have been used as coin, to friction, as similar as possible to that to which they must be subjected, in the course of circulation. The loss was by no means considerable; and it appeared, as the general result, that the present standard of gold, or an alloy of one part in twelve, is, all circumstances considered, the best, or at least, as good as any, that could be chosen. If the copper be in larger proportions, more loss is sustained, from friction. The same alloy is employed in the fabrication of plate, and of trinkets, and lace, and, by other additions, various shades of color are obtained. Its alloy with a fifth of silver forms the green gold of the jewellers, and the addition of iron gives a blue tint.

substances, has given rise to an extensive consumption of *gold-leaf*, which is formed, by beating the metal to a state of extreme tenuity. The gold is first forged into plates, on an anvil, and then reduced, by passing it between polished steel rollers, till it becomes a riband, as thin as paper. This riband is divided into small pieces, which are again beat upon an anvil, till they are about an inch square, after which, they are thoroughly annealed.* Two ounces of gold make one hundred and fifty of these squares. All these squares are interlaid with leaves, first of vellum, and afterwards, of gold-beater's skin, a thin membraneous substance obtained from the intestines of animals. The whole is then beaten with a heavy hammer, till the gold is extended to the same size as the pieces of skin. The gold leaves are then taken out, and each cut into four parts; and the six hundred pieces, thus produced, are again interlaid, in the same manner, with skins, and the beating repeated, with a lighter hammer. They are afterwards re-divided, as before, and formed into parcels, which are separately beat, at one or more operations, until the leaf has attained the requisite thinness. The use of the membranes, which are interposed between the leaves, is, to prevent them from cohering together, at the same time that they are permitted to expand; and, also, to soften the blows of the hammer. Notwithstanding the vast extent, to which gold is beaten between these skins, and the great tenuity of the skins themselves, yet they are said to sustain continual repetitions of the process, for a long time, without receiving injury. The kind of leaf, called *party-gold*, is formed, by laying a thin leaf of gold upon a thicker one of silver. They are then heated, and pressed together, till they unite and cohere; after which, they are beaten into leaves, as before.

Gilding on Metals.—Gilding on copper is commonly performed with an amalgam of gold and mercury. The surface of the copper, being freed from oxide, is covered

* The process of *annealing* is applied to metals, and some other substances, to diminish their brittleness, or increase their flexibility and ductility. It is performed, by heating the substance, and suffering it to cool, in a very gradual manner.

with the amalgam, and afterwards exposed to heat, till the mercury is driven off, leaving a thin coat of gold. It is also performed, by dipping a linen rag in a saturated solution of gold, and burning it to tinder. The black powder, thus obtained, is rubbed on the metal to be gilded, with a cork dipped in salt water, till the gilding appears. Iron or steel is gilded, by applying gold-leaf to the metal, after the surface has been well cleaned, and heated, until it has acquired the blue color, which, at a certain temperature, it assumes. The surface is previously burnished, and the process is repeated, when the gilding is required to be more durable. It is also performed, by diluting the solution of gold in nitro-muriatic acid, with alcohol, and applying it to the clean surface.*

Gold Wire.—The common gold or gilt wire is, in reality, silver wire covered with gold. In making it, a silver rod is enclosed in thick leaves of gold. It is then drawn, successively, through conical holes, of different sizes, made in plates of steel, in a manner similar to that pursued in making iron wire. The wire may thus be reduced to an extreme degree of fineness, the gold being drawn out with the silver, and constituting a perfect coating to the wire. When it is intended to be used in forming *gold-thread*, the wire is flattened, by passing it between rollers of polished steel. The coating of gold remains unbroken, though so far reduced, by these processes, as not to occupy the millionth part of an inch in thickness. The gold-thread, commonly used in embroidery, consists of threads of yellow silk, covered by flattened gilt wire, closely wound upon them by machinery.

SILVER.

Extraction.—Silver is, in general, extracted without

* This last process has been improved by Mr. Stoddart. A saturated solution of gold in nitro-muriatic acid, being mixed with three times its weight of sulphuric ether, dissolves the muriate of gold, and the solution is separated from the acid beneath. To gild the steel, it is merely necessary to dip it, the surface being previously well polished and cleaned, in the etherial solution, for an instant; and, on withdrawing it, to wash it instantly, by agitation in water. By this method, steel instruments are very commonly gilt.

much difficulty. When native, it is separated from the earthy matter, by washing, and amalgamation with mercury; the latter being separated again, by distillation. When alloyed with antimony, or arsenic, or when mineralized, the ore is roasted, to expel these metals, with the sulphur, or other volatile principles; and the residual matter is fused with lead, and refined by cupellation, in a manner similar to that described under the head of gold; the alloy of lead and silver being exposed to heat, on the hearth of the refining furnace, the lead being oxidized along with the foreign metals, the oxidizement and vitrification of which it promotes, and the vitrified oxide being, in part, absorbed, and, in part, driven off by the blast of the bellows. The appearance of a vivid incandescence, or brightening, denotes when the silver has become sufficiently pure. It retains a little gold in combination, but this does not alter its qualities; and the quantity is seldom such, as to render its separation, by the operation of parting, an object of importance.

If the ore which is wrought contain only a small portion of silver, the previous operation of *eliquation* is sometimes performed on it. This consists in adding a certain portion of lead to the metallic matter which remains, after roasting, and fusing the ore. This alloy is then exposed to a degree of heat, just sufficient to melt the lead, which runs out, and, from its affinity to the silver, carries it along with it, leaving the copper, or other metals, with which the silver had been combined. The alloy of silver and lead is then subjected to the usual refining process.

Working.—Silver is cast into bars, or ingots, and afterwards wrought, by hammering and rolling. The bars are beaten upon anvils, being heated, from time to time, to render them more ductile. The hammering is conducted, while the heat is below redness. They are then passed between polished steel rollers, until they are reduced to plates of a suitable thickness. To form utensils of different kinds, these plates are hammered in moulds, till they acquire the proper shape. Vessels are often made in pieces, which are afterwards united by sol dering. The solder, used for silver, consists of an alloy of silver, with more than an equal part of copper or brass. Figures, which are raised upon the silver, are produced by hammering the metal upon steel dies, in which the figure is cut, or by passing it through engraved rollers. Silver is polished, by burnishing it with steel instruments, or with hard polished stones ; and by rubbing it with the oxide of iron, called *colcothar*, in fine powder.

Silver, in the arts, is usually alloyed with a little copper, which increases its hardness, and renders it more sonorous, without debasing its color. The standard silver of the British coins contains eighteen pennyweights of copper, in a pound Troy of silver ; and, in the United States, sixteen hundred and sixty-four grains of silver contain one hundred and seventy-nine grains of copper.

Coining.—The coining of silver, and other metals, was originally performed by the hammer, in matrices, or dies, engraved for the purpose. At the present day, coins, of every description, are more commonly *milled.* In coining by the mill, the bars or ingots, of gold or silver, after having been cast, are taken out of the moulds, and their surfaces cleaned. They are then flattened by rollers, and reduced to the proper thickness, to suit the species of money, about to be coined. To render the plates more uniform, they are sometimes wire-drawn, by passing them through narrow holes, in a steel plate. The plates, whether of gold, silver, or copper, when reduced to their proper thickness, are next cut out into round pieces, called *blanks*, or *planchets.* This cutting is performed by a circular steel punch, of the size of the coin, which is driven downward, by a powerful screw, and passes through a corresponding circular hole, carrying before it the piece of metal which is punched out. The pieces, which are thus cut, are brought to the standard weight, if necessary, by filing or rasping ; and the deficient pieces, together with the corners, and pieces of the plates, left by the circles, are returned to the melter.

The milling, by which the inscription, or other impression, is given to the edge of the coin, is performed, by rolling the coin edgewise, between two plates of steel, in the form of rulers, each of which contains half of the en graved edging. One of these plates is fixed, and the other is movable, by a rack and pinion. The coin, being placed between them, is carried along by the motion of the rack, till it has made half a revolution, and received the whole impression on its edge. The most important part of the coining still remains to be done, and consists in stamping both sides, with the appropriate device, or figure, in relief. For this purpose, the circular piece is placed between two steel dies, upon which the figures to be impressed are *sunk*, or engraved, in the manner of an *intaglio*. The two dies are then forcibly pressed together, by the action of a powerful screw, to which is attached a heavy transverse beam, which serves the purpose of a fly, and concentrates the force at the moment of the impression. The coin is now finished, and is thrown out, when the screw rises.

In the coining machinery erected by Boulton and Watt, and introduced at the mint in England, the process is performed by steam-power, and both the edges and faces of the money are coined at the same time.* By means of this machinery, eight presses, attended by boys, can strike nineteen thousand pieces of money in an hour, and an exact register is kept by the machine, of the number of pieces struck.

For the coining of medals, the process is nearly the same as for that of money. The principal difference consists in this, that money, having but a small relief, receives its impressions at a single stroke of the engine; whereas, in medals, the high relief makes several strokes necessary; for which purpose, the piece is taken out from between the dies, heated, and returned again. This process for medallions is sometimes repeated, as many as a dozen or more times, before the full impression is given them. Some medallions, in a very high relievo, are obliged to be cast in sand, and afterwards perfected by being sent to the press.

Plating.—The great value of silver, and the useful

* A particular account of this machinery is given in the London Mechanic's Magazine, vol. iii.

property which it possesses, of resisting oxidation, has given rise to the art of *plating*, in which vessels and utensils of other metals, but, chiefly, of copper, are covered with a thin coating of silver, so as to protect them from the influence of the atmosphere. Plating is sometimes executed by heating the articles, which are to be coated, and rubbing on them portions of leaf-silver, with a steel burnisher, till it adheres. But it is performed, in a better manner, by plating solid ingots of copper, and afterwards working these into any shape desired. The ductility of the coating of silver causes it to be extended, and drawn out with the copper, so that the latter metal never appears at the surface. The copper, used in plating, is alloyed with a little brass. Great care is taken, in casting, to form the ingots sound, and free from pores, or flaws. The surface of the ingot is cleaned with a file, and a thin plate of silver is applied to one or to both sides, according to the article to be manufactured. A saturated solution of borax is then insinuated between the edges, the object of which is, to protect the copper from oxidation, which would otherwise prevent the silver from adhering. The ingot is then carried to the furnace, and exposed to heat, until the metals adhere to each other. Their adhesion is owing to the formation of an alloy between the silver and copper, which, being fusible at a lower temperature than either of the metals, acts as a solder, to unite them together. The ingot is then rolled into sheets, by passing it, repeatedly, between iron rollers, annealing it, from time to time, as it becomes hard and brittle.

The plated sheets, which are thus obtained, are formed into articles of different kinds, by hammering them in moulds, corresponding to the intended shape. When vessels are to be made, they are formed in pieces of a convenient shape, and these are soldered together, with an alloy of silver, copper, and brass. Mouldings, and other ornamental parts, are made by hammering the metal in steel dies, or rolling it between steel rollers, upon which the pattern is cut. As the edges of plated ware are most liable to be injured by wear, they are commonly protected by what are called *silver edges*. These are formed of a shell of silver, rolled out, or hammered in dies, and having its inside filled up with a mixture of tin and lead. When finished, these edges are soldered to the vessel. The handles, feet, and solid parts, of vessels are often made in the same way. *Plated baskets*, and other light articles, are made from copper cylinders, covered with silver, and afterwards drawn into wire.

Plating on iron, as it is used for the buckles of harnesses, and other ornaments, is executed, by first covering the iron with a coating of tin, and then applying, closely to the surface, a thin plate of silver. The union is effected by a moderate heat, sufficient to melt the tin, and form an alloy ; and it is aided by the use of a resinous flux.

COPPER.

Extraction.—The various sulphurets of copper are the most abundant of its ores ; and of these, the most so is copper pyrites. The malachite, red copper ore, and others, are generally associated with these, in small quantities. Copper mines are wrought in many countries, but those of Sweden are said to furnish the purest copper of commerce. The sulphurets are the ores from which copper is usually extracted. The ore is roasted by a low heat, in a furnace, with which flues are connected, in which the sulphur, that is volatilized, is collected. The remaining ore is then smelted, in contact with the fuel. The iron present in the ore, not being so easily reduced, or fused, as the copper, remains in the scoria, while the copper is run out. It often requires repeated fusions ; and, even after these, it may be still alloyed with portions of metals, which are not volatile, and are of easy fusion. Hence, the copper of commerce is never altogether pure, but generally contains a little lead, and a smaller portion of antimony.

The carbonates of copper, reduced by fusion, in contact with the fuel, afford a purer copper, as does also the solution of sulphate of copper, which is met with in some mines, the copper being precipitated in its metallic state, by immersing iron in the solution. The precipitate, which is thus formed, is afterwards fused.

Working.—Copper, being ductile and easily wrought, is applied to many useful purposes. It is formed into thin sheets, by being heated in a furnace, and subjected to pressure between iron rollers. These sheets, being both ductile and durable, are applied to a variety of uses, such as the sheathing of the bottoms of ships, the coverings of roofs and domes, the constructing of boilers and stills, of a large size, &c. Copper is also fabricated into a variety of household utensils, the use of which, however, for preparing or preserving articles of food, is by no means free from danger, on account of the oxidizement, to which copper is liable. It has been attempted to obviate this danger, by *tinning* the copper, or applying to its surface a thin covering of tin. This method answers the purpose, as long as the coating of tin remains entire.

Copper may be forged into any shape, but will not bear more than a red heat, and, of course, requires to be heated often. The bottoms of large boilers are frequently forged with a large hammer, worked by machinery. The bolts of copper, used for ships, and other purposes, are either made by the hammer, or cast into shapes, and rolled. The copper cylinders, used in calico printing, are either cast solid, upon an iron axis, or are cast hollow, and fitted upon the axis. The whole is afterwards turned, to render the surface true.

BRASS.

Brass is an alloy of copper and zinc. The proportions of these two metals differ, in almost every place in which brass is manufactured; and the proportion of zinc is found, in different specimens, to vary from twelve to twenty-five parts, in a hundred. The alloy is commonly made from the ores of zinc mixed with copper, and with a sufficient quantity of charcoal, to reduce them to a metallic state. The volatility of the zinc gives it a tendency to escape in vapor, on which account, the combination is effected at a lower heat, than that which would be necessary to melt the copper. Several other alloys, of the same metals, are also known in the arts, differing in the proportions of the ingredients; such as ***pinch-beck***, ***prince's-metal***, ***tombac***, ***Bath-metal***, &c.

Manufacture.—The value of brass, in the arts, consists, in its bright color, in its being more fusible than copper, and in its being more easily wrought with common tools. In the working of brass, the larger articles, as well as those of complicated forms, are cast in moulds. When it is intended, for economy of the metal, that the article shall be hollow, as in the case of andirons, &c., it is cast in halves, or pieces, which are afterwards soldered together, and turned in a lathe, or otherwise polished. Brass is also rolled into thin sheets, and drawn into wire. A variety of figured and ornamental articles are made, by stamping it in dies, or moulds. Brass knobs and similar implements, if large, are made in pieces, and soldered. The wheel-work of time-pieces, and of other machinery, which is not subjected to great strain or wear, is usually made of brass. The comparative softness of this alloy permits it to be cut with thin saws, and to be turned in a lathe, with much greater ease than iron.

Buttons are either struck out of sheets of brass, with a circular punch, driven by a fly-press, or they are cast. in large numbers at once, in a mould, or flask of sand. The *eye*, or *shank*, of the button, is made separately, by a machine, and soldered on, if the button has been cut out by the punch. If the button is cast, the eye is previously placed in the mould, so that its extremity is immersed in the centre of the melted metal. If the button is to be plain, its surface is planished by the stroke of a smooth die; and, if figured, it is stamped with an engraved die. The edges are afterwards turned off, in a lathe. The gilding of brass buttons is performed, by covering them with an amalgam of gold and mercury, from which the mercury escapes, when heated, and leaves the gold. *White-metal* buttons are made of an alloy of brass and tin, and subsequently coated with tin. The brass eyes of *pearl buttons* are inserted, by drilling a conical hole, which is largest on the inside, in the mother of pearl, or shell, of which the button is made. The eye, having an extremity like a hollow cone, is then driven in, till it spreads, and fills the cavity.

Pins are made of brass wire, cut into proper lengths. The pieces are pointed, by turning them with the fingers, upon stones or steel mills. The heads are cut from a spiral coil of wire, in pieces of a suitable length; and, after being placed upon the pins, are shaped and fastened, by the stroke of an instrument like a hammer. Several machines have been invented for this manufacture, one of which makes a solid head, from the body of the pin itself. Pins are whitened, by immersing them in a vessel, containing tin and lees of wine, and are polished, by agitating them with bran, in a revolving cask.

Bronze.—A series of alloys is formed, from the combination of copper with tin. The combination appears to have a tendency to form in certain proportions, regulated, in some measure, by the specific gravities and fusibilities of the metals; for, when kept in fusion, and allowed to cool without agitation, two alloys are formed, the under part of the mass being one of copper, with a small portion of tin, and the upper part tin, with a small proportion of copper, while, between these, there is, probably, a gradation. By agitation, this separation is counteracted. In general, tin lessens the ductility of copper, while it renders it more hard, rigid, and sonorous; these qualities being possessed, in various degrees, by the different alloys, according to their proportions; the hardness and brittleness being greater, as the tin predominates. The density of the compound is, also, always greater than the mean density; the contraction, from the combination, being about one eighth. The principal of these alloys are *bronze*, *gun-metal*, from which pieces of artillery are cast, *bell-metal*, and *speculum-metal*, which has been used for the mirrors of reflecting telescopes. Bronze is one of those, in which the proportion of tin is least, not exceeding ten or twelve parts in one hundred. It is of a grayish yellow color, harder than copper, less liable to rust, and more fusible, so as to be easily cast in moulds. Hence it is employed in the casting of statues. The metal, from which pieces of artillery are cast, is of a similar composition, containing rather less tin. It appears that an alloy, very similar to bronze, was much in use among the ancients ; and swords, darts, and other warlike instruments, were formed of it, as were also various utensils.*

When the proportion of tin is increased, the alloy is rendered more brittle and elastic, and, at the same time, highly sonorous. *Bell-metal* is an alloy of this kind, in which the proportion of tin varies from one third to one fifth of the weight of the copper, according to the size of the bell, and the sound required.

When the proportion of tin is still greater, an alloy is formed, called *speculum-metal*, which is of a white color, and which, from the closeness of its texture, and its susceptibility of a fine polish, exceeds most metals in the property of reflecting light. Hence it is used in forming the speculum of reflecting telescopes. It has, also, the advantage of not being liable to tarnish, on exposure to the air. The proportion in which these qualities were best attained, appeared, from the experiments of Mr. Mudge, to be a little less than one part of tin, with two parts of copper. The Chinese *pakfong*, or white copper, which is sometimes imported from that country, is an alloy, according to Dr. Fyfe, of copper, zinc, nickel, and iron. The article used in this country, and in Europe, under the name of *German silver*, is essentially an alloy of copper, zinc, and nickel.

LEAD.

Extraction.—Lead, mineralized by sulphur, forms by far the most abundant ore of the metal, and has been long known to mineralogists by the name of *galena*. This is the ore which is generally wrought, and from which nearly

* According to Dr. Pearson's experiments, made on various instruments of this kind, the alloy appears to have consisted of about eight or nine parts of copper, with one of tin ; and, as he justly remarks, this alloy still affords the best substitute for iron or steel. While the art, therefore, of manufacturing malleable iron was imperfectly known, and difficult to be practised, it must have been much used. The hardness of this alloy, observed in ancient arms, had even given rise to an opinion, that the ancients were acquainted with a method of hardening copper, which had been lost. Of this alloy, medals and coins were also often formed, as appears from the experiments of Dize, on several Greek, Roman, and Gallic coins, which consisted of copper and tin alone.

all the lead of commerce is procured. The ore, after being pounded, and freed from the admixture of any stony matter, by washing, is fused in a furnace, with the addition of lime, which combines with the sulphur of the sulphuret; the lead is melted, and run out by an aperture, towards the bottom of the furnace. When the native salts of lead are found with the galena, so as to render it of importance to work them, they are selected, until a sufficient quantity be obtained. They are then roasted, to expel the volatile matter, and are afterwards fused, in contact with the fuel, with an addition of lime. The lead obtained from galena, sometimes contains so much silver, as to be subjected to an additional process to separate the silver. In this case, the lead is oxidized in a furnace; a current of air being directed on its surface, when in fusion, by bellows. Towards the end of the operation, the silver remains, with a small portion of lead, from which it is freed, by cupellation; and the oxide of lead is either applied to the purposes for which it is used, or is reduced to the metallic state.

Manufacture.—Lead, being fusible at a low temperature, requires only to be cast in smooth moulds, to form weights, bullets, and other articles of small size. The linings of cisterns, and the coverings of roofs, gutters, &c., are made of sheet-lead; pumps, and aqueducts, of leaden pipes.

Sheet Lead, of the thicker kinds, is cast upon large tables, covered with sand, and having an elevated rim. The melted lead is poured upon the surface, out of a box, which moves upon rollers across the table, and is spread out with a uniform thickness, by passing over it a straight piece of wood, called a *strike*. The sheets, thus cast, are afterwards rendered thinner, by reducing them between rollers. The sheet-lead with which tea-chests are lined, is an alloy of lead and tin, and is made by the Chinese, by suddenly compressing the melted metal between flat, polished stones.

Lead pipes, for conveying water, may be made in various ways. They were at first formed of sheet lead, bent round a cylindrical bar, or mandrel, and soldered; but these pipes are liable to crack and leak, especially when bent. A second method is, to cast a short tube of lead in a cylindrical mould, with a core. This tube, when cold, is drawn nearly out of the mould, and a fresh portion of melted lead poured in, at apertures in the sides of the mould. The melted lead unites with the tube, previously formed, so as to increase its length; and by repeating the process, any length of pipe may be produced. But pipes, cast in this manner, are found to have imperfections, arising from flaws and air bubbles. A third method, which is now most commonly practised, is to cast a short, thick tube of lead, upon one end of a long, polished, iron cylinder, or mandrel, of the size of the bore of the intended pipe. The lead is then reduced in size, and drawn out in length, either by drawing it on the mandrel, through circular holes, of different sizes, in a steel plate; or by rolling it between contiguous rollers, which have a semi-circular groove, cut round the circumference of each. A fourth mode, invented by Mr. Bramah, consisted in forcing melted lead, by means of a pump, into one end of a mould; while it was discharged, in the form of a pipe, at the opposite end. Care was taken, so to regulate the temperature, that the lead should chill, just before it left the mould.

Leaden shot consist of drops of metal, which are discharged, in a melted state, from small orifices, and cool in falling. The best shot are cast in high towers, built for the purpose. The lead is previously alloyed with a portion of arsenic, which increases the cohesiveness of its particles, and causes it to assume, more readily, the globular form. It is melted, at the top of the tower, and poured into a vessel, which is perforated at bottom, with numerous small holes. The lead, after running through these perforations, immediately separates into drops, which cool, in falling through the height of the tower, and are received in a reservoir of water, at bottom, to break the force of the fall. The shot are then proved, by rolling them down an inclined board. Those which are irregular in shape roll off at the sides, or stop, while the spherical ones continue to the end. They are then assorted, by passing them through wire sieves of different fineness. The glazing is given, by agitating them with small quantities of black lead.

Shot is sometimes made, mechanically, by cutting sheets of lead into cubes, and agitating these, for a long time, in a cylindrical vessel, turned upon an axis. The attrition, thus produced, communicates a globular form to the cubes.

TIN.

Native oxide of tin, or *tinstone*, as it is commonly named, is the only ore that is wrought, to obtain this metal. Being freed, by washing, from the intermixture of any stony matter, it is roasted, and then fused, in contact with the fuel, by a moderate heat. The tin of Cornwall is supposed to be purer than the German tin, though it is still inferior to the tin from India.

Block-tin, consisting of the metal in its solid state, is used for vessels which are not exposed to a temperature much exceeding that of boiling water. Vessels of this kind, being not readily tarnished, form a cheaper substitute for silver and plated ware. A kind of ware, denominated *Biddery ware*, consists of tin vessels, alloyed with a little copper, and having their surface made black by the application of substances, containing nitre, com mon salt, with sal ammoniac. *Tin-foil* is made by rol ling, in the same way as the plates for tinned iron hereafter described. It is also sometimes hammered. The most extensive use, however, to which metallic tin is applied, is to form a coating for other metals, which are stronger than itself, but at the same time more liable to oxidation by exposure to the air.

Tin plates, which constitute the material of the common tin ware, so extensively used, are thin sheets of iron, coated with tin. The mode of rolling these sheets will be described under the head of *Iron*. To prepare them for tinning, they are steeped in water, acidulated with muriatic acid, and then heated, scaled, and rolled, to remove all oxide, and enable the tin to adhere to the iron. The tin is kept melted in oblong, rectangular vessels, and to preserve its surface from oxidation, a quantity of melted fat and oil is kept floating upon it. The iron plates are taken up with pincers, and immersed in the tin for some time. When withdrawn, they are found to have acquired a bright coating of the tin, which adheres closely, owing to the formation of an intermediate alloy. The dipping is repeated twice, or more times, according to the thickness of the coat intended to be given, and also to produce a smooth surface, and, between these processes, the tin is equalized with a brush.*

Various other articles of iron, such as spoons, nails, bridle-bits, small chains, &c. are coated with tin, by immersing them in that metal, while in a state of fusion. From the affinity between tin and copper, a thin layer of the former metal can be easily applied to the surface of the latter; and this practice of tinning, as it is named, is often employed, to prevent the erosion, or rusting, of copper vessels, and the noxious impregnation which they would otherwise communicate to liquors kept in them. The surface of the copper is polished, so as to be quite bright; sal-ammoniac is applied to it, when hot, by which the oxidation appears to be prevented; or pitch is sometimes used, for the same purpose. The melted tin, or, sometimes, an alloy of tin and lead, is then applied to the surface of the copper, to which it readily adheres.

Silvering of Mirrors.—The surfaces, best adapted for reflecting light, are those of polished metals. To constitute a good reflector, it is necessary that a metal should be susceptible of an equal, unbroken, and exquisite, polish, and that it should retain this polish, without being tarnished by the atmosphere. Speculum-metal is, chiefly, employed for reflecting surfaces, in telescopes; but, for common purposes, an amalgam of tin and mercury is used, in a state of adhesion to glass. The use of the glass is, in the first place, to produce a smooth surface, in the amalgam; and, afterwards, to protect it from oxidation by the atmosphere.

In the silvering of plain looking-glasses, a flat, hori-

* For a full account of the present mode of manufacturing tin plate, see Parkes's Chemical Essays, vol. ii.

zontal slab of stone is used, as a table. This is smoothly covered with paper, and a sheet of tin-foil, equal to the size of the glass, is extended over it. A quantity of mercury is then laid upon the tin-foil, and immediately spread over it, with a roll of cloth, or a hare's foot. Afterwards, as much mercury, as the surface will hold, is poured on. While this mercury is yet in a fluid state, the plate of glass is slid on, at the edge of the table, so as to pass over the tin-foil, driving the superfluous mercury before it. In this way, any bubbles of air and particles of dust are prevented from getting between the glass and the metal, and an uninterrupted coating is formed. In order to force out the remaining liquid mercury, the glass is placed in a sloping position, to allow the mercury to drain off, after which, heavy weights are placed upon the glass, and suffered to remain, for some time. The portion, which is left, amalgamates with the tin, and forms a permanent reflecting surface, the smoothness and perfection of which depend upon the degree of regularity and polish, which the glass possesses.

In silvering concave and convex mirrors, instead of a stone table, the tin-foil is spread upon a plaster mould, previously cast on the surface of the glass itself. The inside of *glass globes* is silvered, by pouring into them a fusible alloy of tin, lead, bismuth, and mercury, the heat of which, when liquid, is not sufficient to break the glass By turning the globe about, a thin metallic coating is deposited on the whole interior surface.

IRON.

The properties which iron possesses, in its various forms, render it the most useful of all the metals. The toughness of malleable iron adapts it to purposes, where great strength is required ; while its combination of difficult fusibility with the property of softening by heat, so as to admit of forging and welding, renders it capable of being easily worked, and of withstanding an intense heat. Cast-iron, from its cheapness, and the facility with which its form is changed by fusion, is made the material of numerous structures and machines. Steel, which is the most important compound of iron, exceeds all other metals, in the combination of hardness and tenacity; and hence, it is particularly adapted to the fabrication of cutting instruments. It is equally superior in elasticity, a quality by which it is suited to be the spring of motion, in various machines.

Smelting.—The principal ores, which are wrought for the extraction of iron, are the different species of the native oxides. The process is somewhat different, as carried on, in different countries, and as adapted to different ores; but the following is the general outline of it, as it is conducted on the hæmatite bog-ores, and other oxides of iron.

The *blast-furnace*, in which the operation is *conducted*, is a large pyramidal stack, made of brick or hewn stone, from twenty to sixty feet high, having its internal cavity shaped like an egg, with its large end downwards, and lined with fire-brick or stone.

The ore is first roasted, with a strong heat, to expel the carbonic acid, and any portion of sulphur, or other volatile matter, that may be present. The remaining ore is put into a furnace, of a conical form, with charcoal, or with coke, and exposed to a heat, rendered sufficiently intense by a blast of air, urged through the furnace. A quantity of lime is, at the same time, added to the ore and fuel; the advantage of which appears to be, that in combination with the argillaceous and silicious substances, generally contained in the iron ores, it acts as a flux, to vitrify the foreign matter, and thus facilitate the separation of the melted metal. The proportions of these are extremely various, according to the nature of the ore. When the furnace is once charged, the charge is renewed at the upper part, as fast as the materials sink, and the process is carried on, for a long time, without interruption. During this process, the oxygen of the oxide of iron unites with one portion of the carbon, and the metal with another, producing carbonic acid, and carburet of iron; while the earthy substances, together with a little oxide of iron, enter into combination, forming a vitreous substance called *slag*, or *scoria*, and which, being lighter than the me tal, rises upon its surface. The slag is drawn off, by an opening, and the melted metal is collected in a cavity, at bottom, from which, as it accumulates, it is conveyed off, at intervals, into moulds.

A vast improvement, in regard to the saving of fuel, has been produced, in late years, by the introduction of the *hot blast*, in smelting furnaces. The fire, in this case, is blown by air, previously heated ; the combustion becomes more effective ; and a saving of two thirds of the fuel is said to be produced.

Crude Iron.—The metal thus obtained, is named *pig-iron*, and *crude*, or *cast-iron*. It is far from being pure, containing, always, more or less oxygen and carbon ; and, often, several other heterogeneous ingredients, such as manganese, and the metallic bases of lime, clay, and silex, with portions of unreduced ore and charcoal. The oxygen is, partly, a portion of what was originally combined with the metal, in the ore, and partly, perhaps, derived from the blast of air, which is driven through the furnace, and necessarily presented to the metal, in a state of fusion Hence, the qualities of cast-iron are very various, accord ing as one or other of the principles predominates.

Iron, in this state, is readily capable of being fused, and cast into moulds. It is, however, much more brittle, than when pure, and cannot be wrought or flattened, under the hammer. Hence, it is altogether unfit for many purposes, to which pure or malleable iron is, from its tenacity and softness, well adapted.

Casting.—Iron, as well as brass, and other metals, which melt at temperatures above ignition, is cast in moulds, made of sand. The kind of sand, most employ ed, is loam, which possesses a sufficient portion of argillaceous matter, to render it moderately cohesive, when damp. The mould is formed, by burying in the sand, a wooden pattern, having exactly the shape of the article to be cast. The sand is most commonly enclosed in flasks, which are square frames, resembling wooden boxes, open at top and bottom. If the pattern be of such form, that it can be lifted out of the sand, without deranging the form of the mould, it is only necessary to make an impression of the pattern, in one flask; and articles of this kind are sometimes cast in the open sand, upon the floor of the foundry. But when the shape is such, that the pattern could not be extracted, without breaking the mould, two flasks are necessary, having half the mould formed in each. The first flask is filled with sand, by ramming it close, and is smoothed off, at the top. The pattern is separated into halves, one half being imbedded in this flask. A quantity of white sand, or burnt sand, is sprinkled over the surface, to prevent the two flasks from cohering. The second flask is then placed upon the top of the first, having pins to guide it. The other half of the pattern is put in its place, and the flask is filled with sand, which, of course, receives the impression of the remaining half of the pattern, on its under side. After one or more holes are made in the top, to permit the metal to be poured in, and the steam and air to escape, the flasks are separated, and the pattern withdrawn. When the flasks are again united, a perfect cavity, or mould, is formed, into which the melted metal is poured.

The arrangement of the mould is, of course, varied, for different articles. When the form of the article is complex and difficult, as in some hollow vessels, crooked pipes, &c., the pattern is made in three or more pieces, which are put together, to form the moulds, and afterwards taken apart, to extract them. In some other irregular articles, as andirons, one part is cast first, and afterwards inserted in the flask which is to form the other part.

The metal for small articles is usually dipped up, with iron ladles coated with clay, and poured into the moulds. In large articles, such as cannon, the mould is formed in a pit, dug in the earth, near the furnace, and the melted metal is conveyed to it, in a continued stream, through a channel communicating with the bottom of the furnace.

Cannon balls are sometimes cast in moulds, made of iron; and to prevent the melted metal from adhering, the inside of the mould is covered with powder of black lead. Rollers for flattening iron are also cast in iron cases. This method is called *chill-casting*, and has, for its ob ject, the hardening of the surface of the metal, by the sudden reduction of temperature, which takes place in consequence of the superior conducting power of the iron mould. These rollers are afterwards turned smooth, in a powerful lathe, which has a slow motion, that the cutting tool may not become heated by the friction.

Malleable Iron.—To obtain pure iron, that is, to free crude iron from the oxygen, carbon, and other foreign substances, contained in it, it is subjected to two operations,—melting, and forging. The fusion is performed in different furnaces. The melted metal is, in some cases, run out, to free it from the scoria which has separated; and this process is repeated, until the iron attains a degree of consistence, sufficient to be submitted to the action of the forge-hammer. But, more commonly, the metal is kept in fusion, in a reverberatory furnace, called a *puddling-furnace*, where it is raised to a very high temperature. The liquid is stirred frequently, to facilitate the combination of the carbon and oxygen. At length, a lambent blue flame appears on its surface, probably from the formation and disengagement of carbonic oxide; and, after some time, the fluidity of the metal diminishes, until it, at length, assumes the consistence of a stiff paste. It is then subjected to the action of a very large hammer, or to the more equable pressure of rollers, by which a portion of oxide of iron, carbon, and other heterogeneous substances, not consumed during the fusion, are forced out. The iron, in this state, is no longer granular in its texture, but is soft, ductile, and malleable, and much less fusible. It is then named *wrought-iron*, *forged*, or *bar iron*, as it is generally formed into long bars. A considerable loss of weight attends the process, from the dissipation of the foreign substances, contained in the crude iron, and from the oxidation of the surface of the metal. The operation is generally performed on the varieties called white, or gray, crude iron.

Forging.—Forging consists in changing the form of iron, and other malleable metals, by percussion, applied to them, while they are softened by heat. Iron, when exposed to the action of great heat, becomes highly malleable and ductile. It is also capable of welding, at a sufficiently high temperature. Most other metals have their malleability improved, by a certain degree of heat, but become brittle, if the heat is carried near to their fusing point. The strength and quality of iron, on the contrary, are improved, by forging at a strong white heat, since the parts become consolidated, and the flaws obliterated, by hammering, at a welding temperature.

The joint action of the heat and current of air, used in forges, tends to oxidate, rapidly, the surface of iron. The oxide which is formed has some tendency to vitrification when combined with silicious matter. Hence it is a common practice among workmen, to immerse the iron in sand, when it is near to a welding heat. A vitreous coating is, by this means, formed, which protects the surface of the iron from further oxidation. This coating would prevent the different pieces from uniting, by welding, were it not that its fluidity causes it to escape, while under the action of the hammer.

The forging, at the furnaces, of large masses of iron, called *blooms*, is performed by the aid of tilt-hammers, as is also that of anchors, and various other massive implements, and parts of machines. Bars of iron are commonly rolled, and when heavier articles, such as anchors, are to be made, a sufficient number of bars, for the purpose, are welded together.

A tilt-hammer, of the kind used in iron-works, is shown in Pl. III., Fig. 2. AB, is the hammer, which turns upon the fulcrum, C. At D, is a wheel, or cylinder, furnished with wipers, [*abc*, &c.,] each of which, as it passes, strikes the end, A, of the helve, and causes the hammer-end, B, to rise. The hammer then descends, with its own weight, and is accelerated by the recoil of the end, A, from the fixed obstacle, E. The wipers may be indefinitely varied, in number and position, and are sometimes applied, on the other side of the fulcrum. The recoil, likewise, is sometimes produced by a spring, placed over the end, B, of the hammer. The motion of these engines is extremely rapid, and is commonly regulated by a fly-wheel.

Rolling and Slitting.—Malleable iron is commonly wrought into those shapes which have flat, parallel surfaces, by submitting it to compression, between rollers. Bars, plates, and sheets, of iron are formed, in this way. A pair of heavy cylindrical rollers, made of iron, chill-cast, and turned smooth, are connected together by strong iron bearings, a space being left between them, equal to the intended thickness of the metal, which is to be rolled. This distance is varied, by adjusting it with powerful screws. The iron, which is to be rolled, is prepared, by heating it red hot, and, in this state, it is presented to the rollers. As soon as any part has entered, so as to fill the space between the rollers, the friction, or adhesion, becomes sufficient to draw in the remainder, in opposition to the force with which the metal resists compression. The iron, in passing through, is compressed into a uniform plate, of equal thickness, and is, at the same time, extended in length, but is very little increased in breadth. As the rollers usually move with considerable velocity, the heated iron may be passed, several times, between different pairs of rollers, before it cools. To prevent the rollers from becoming heated, a continual stream of water is let fall upon their surface.

As the principal extension, which plates receive, is in a longitudinal direction, it is necessary to vary their position, when it is desired to increase their width. This is sometimes done, by passing them in an oblique direction; but, in making sheet-iron and wide plates, it is necessary to pass the pieces through the rollers, in the direction of their breadth, as well as length, that they may be extended in both directions. Very thin plates, like those used for tinned iron, are repeatedly doubled, and passed between the rollers, so that, in the thinnest plates, sixteen thicknesses are rolled, together, care being taken to change their relative positions, and to interpose oil, to prevent them from cohering. The last rollings are performed, while the metal is cold. Bars which are square, round, and of various other shapes, are formed, between rollers which have grooves cut upon their circumferences, corresponding, in shape, to half the bar to be made. Even rails of malleable iron, for rail-roads, have lately been made between rollers, formed for the purpose. And, at some furnaces, where malleable iron is made, the forge-hammer is dispensed with, and reliance is placed on the rollers, alone, to consolidate and equalize the masses of metal.

Slitting rollers, or those intended for dividing plates of iron into narrow rods, are formed with elevated rings upon their circumferences, which reciprocally enter between each other, their edges being angular, and passing in close contact with each other, so as to cut like shears. These rings are separately made, so that they can be removed from the rollers, for the purpose of sharpening them, when necessary.

Wire Drawing.—The manufacture of wire consists, in drawing a piece of metal through a conical hole in a steel plate, which forms it into a regular cylindrical filament. The size of this filament may be reduced, and the length extended, indefinitely, by passing it through successive holes, which gradually diminish in diameter.

To prepare the iron for drawing, it is first subjected to the action of the hammer, till it is reduced to a size that will admit of its being drawn through the plate. Sometimes, the iron is prepared by rolling; but the best wire is produced, when the metal has been thoroughly hammered.

The rod of iron which has been prepared, in this manner, is next drawn through one of the larger holes in the steel plate. Various machines are employed, to overcome the resistance which the plate opposes to the compression and passage of the wire. In general, the end of the wire is held by pincers, and as fast as the wire is drawn through the plate, it is wound upon a roller, by the action of a wheel and axle, or other power. Sometimes, a rack and pinion is employed, for this purpose, and sometimes, a lever, which acts at intervals, and takes fresh hold of the wire, each time that the force is applied.

The finer kinds of wire are made from the larger, by repeated drawings, each of which is performed through a smaller hole than the preceding. As the metal becomes stiff and hard, by the repetition of this process, it is necessary to anneal it, from time to time, to restore its ductility. It is also occasionally immersed in an acid liquid, to loosen the superficial oxide which is formed, in the process of annealing.

Nail Making.—Nails are made, both by hand, and by machinery. *Wrought-nails* are made, singly, at the forge and anvil, by workmen who acquire, from practice, great despatch in the operation. Machines have been made, for making these nails perfectly, and with rapidity; yet they have not come into general use, owing to the cheapness of the product by manual labor. *Cut-nails* are made, almost wholly, by machinery, invented in this country. The iron, after having been rolled, and slit into rods, is flattened into plates, of the thickness intended for the nails, by a second rolling. The end of this plate is then presented to the nail-machine, by a workman, who turns the plate over, once, for every nail. The machine has a rapid reciprocating motion, and cuts off, at every stroke, a wedge-shaped piece of iron, constituting a nail without a head. This is immediately caught, near its largest end, and compressed between *gripes.* At the same time a strong force is applied to a die, at the extremity, which spreads the iron, sufficiently to form a head to the nail. Some nails are made of cast-iron, but these are always brittle, unless afterwards converted into malleable iron, by the requisite process.

Gun Making.—Cannon, carronades, &c., whether of iron or brass, are cast in sand, and afterwards bored. Muskets and fowling-pieces are forged from bars of malleable iron. The bar is first flattened by hammering, till it attains the requisite width. It is then made into a tube, by turning it over a mandrel, or cylindrical rod, of a size which is smaller than that of the intended bore. The edges are made to overlap each other, about half an inch, and are firmly welded together. The whole is then consolidated and strengthened, by hammering it, for some time, in semi-circular grooves, on a swage, or anvil, which is furrowed for the purpose. To render the barrel smooth, on the inside, and perfectly true, it is afterwards bored out, with an instrument somewhat larger than the man drel; and several such instruments, of different sizes, are employed, in succession. The breech of the barre is closed, by a strong plug, which is firmly screwed in, at the extremity. The projecting parts of the barrel, such as the *sight*, and the loops which confine it to the stock, are soldered on. The construction of the lock, and other appendages, is readily understood, from inspection.

Steel.—When malleable iron is re-combined with carbon, in a much smaller proportion, it forms *steel.* Different methods are followed, to form this combination. The product varies, according to the method pursued, and is also effected, by the introduction of other substances into the combination. The best steel is made from Swedish and Russian iron.

The general method of forming steel is, by the process of *cementation.* A furnace is constructed, of a conical form, in which are two large cases, or troughs, of fire-brick, capable of holding some tons of iron. Beneath these, is a long grate, on which the fuel is placed. On the bottom of the case, is placed a layer of charcoal dust; over this, a layer of bars of malleable iron; over this, again, a layer of charcoal powder; and the series of alternate layers of charcoal and iron is thus raised to a considerable height. The whole is covered with clay, to exclude the air; and flues are carried through the pile from the furnace, so as to communicate the heat more completely and equally. The fire is kept up, for eight or ten days. The progress of the cementation is discovered, by withdrawing a bar, called the *test-bar*, from an aperture in the side. When the conversion of iron into steel appears to be complete, the fire is extinguished; the whole is left to cool, for six or eight days longer, and is then removed.

The iron, prepared in this manner, is named *blistered-steel*, from the blisters which appear on its surface. To render it more perfect, it is subjected to the action of the hammer, in nearly the same manner which is practised with forged iron; it is beat very thin, and is thus renered more firm in its texture, and more convenient in its form. In this state it is often called *tilted-steel.* When the bars are exposed to heat, in a furnace sufficient to soften them, and afterwards doubled, drawn out, and welded, the product is called *shear-steel*. *Cast-steel* is made, by fusing bars of common blistered-steel, with a flux of carbonaceous and vitreous substances, in a large crucible, placed in a wind-furnace. When the fusion is complete, it is cast into small bars, or ingots. Cast-steel is harder and more elastic, has a closer texture, and receives a higher polish, than common steel. It is capable of still further improvement, by being subjected to the action of the hammer.*

Steel is generally prepared from malleable iron. It can also be formed from crude cast-iron, as in Mr. Lucas's method, hereafter described. Several varieties of cast-iron have been used for this purpose. The crude iron from certain ores, as the *sparry* iron ore, is capable of this conversion. The steel, thus obtained, is named *natural steel*, but is inferior to that obtained by cementation.

Alloys of Steel.—Messrs. Stodart and Faraday have succeeded in making some useful alloys of steel with other metals.† Their experiments induced them to believe, that the celebrated Indian steel, called *wootz*, is an alloy of steel with small quantities of silicium and aluminum; and they succeeded in preparing a similar compound, possessed of all the properties of *wootz*. They ascertained that silver combines with steel, forming an alloy, which, although it contains only one five hundredth of its weight of silver, is superior to wootz, or to the best cast-steel, in hardness. The alloy of steel with one hundredth part of platinum, though less hard than that with silver, possesses a greater degree of toughness, and is, therefore, highly valuable, when tenacity, as well as hardness, is required. The alloy of steel with rhodium even ex-

* Writers differ, in regard to the proportion of carbon contained in cast-steel. Mr. Buttery, in Ure's Dictionary, states, that the amount is less than in common steel, and that no charcoal is added, in making it. He also states, that it does not melt, at a welding temperature, but falls to pieces, like sand, under the hammer, and the parts refuse to become again united.

† Philosophical Transactions, for 1822.

ceeds the two former, in hardness. The compound of steel with palladium, and of steel with iridium and osmium, is likewise exceedingly hard ; but these alloys cannot be applied to useful purposes, owing to the rarity of the metals of which they are composed. M. Berthier has also produced a useful alloy, by combining with the steel a small portion of chromium.

Case Hardening.—The process of case-hardening consists in converting the surface of iron into steel, and is used for giving a superficial hardness to various instruments. It is effected, by enclosing the article which is to be case-hardened, in a box, with some carbonaceous substance, usually animal charcoal, and exposing it to heat, until the surface is converted into steel. The same term is sometimes improperly applied to the method of chill-casting, which has been already mentioned.

Tempering.—The most remarkable, as well as the most useful, of the properties of steel is the power which it has of changing, permanently, its degree of hardness, by undergoing certain changes of temperature. No other metal, says Thenard, is known to possess this property, and iron itself acquires it, only when it is combined with a minute portion of carbon. If steel is heated to redness, and suddenly plunged in cold water, it is found to become extremely hard, but, at the same time, it is too brittle for use. On the other hand, if it be suffered to cool very gradually, it becomes more soft and ductile, but is deficient in strength. The process of tempering is intended to give to steel instruments a quality, intermediate between brittleness and ductility, which shall insure them the proper degree of strength, under the uses to which they are exposed. For this purpose, after the steel has been sufficiently *hardened*, it is partially softened, or let down to the proper temper, by heating it again, in a less degree, or to a particular temperature, suited to the degree of hardness required ; after which, it is again plunged in cold water.

Different methods have been pursued, for determining the temperature, proper for giving the requisite temper to different instruments. One method is, to observe the shades of color which appear on the surface of the steel and succeed each other, as the temperature increases. Thus, at four hundred and thirty degrees of Fahrenheit, the color is pale, and but slightly inclining to yellow. This is the temperature at which lancets are tempered. At four hundred and fifty degrees, a pale straw-color appears, which is found suitable for the best razors and surgical instruments. At four hundred and seventy degrees, a full yellow is produced, suitable for penkives, common razors, &c. At four hundred and ninety degrees, a brown color appears, which is used to temper shears, scissors, garden-hoes, and chisels intended for cutting cold iron. At five hundred and ten degrees, the brown becomes dappled with purple spots, which show the proper heat for tempering axes, common chisels, plane-irons, &c. At five hundred and thirty degrees, a purple color is established; and, at this degree, the temper is given to table-knives and large shears. At five hundred and fifty degrees, a bright blue appears, used for swords and watch-springs. At five hundred and sixty degrees, the color is a full blue, and is used for fine saws, augers, &c. At six hundred degrees, a dark blue, approaching to black, has become settled, and is attended with the softest of all the grades of temper, used only for the larger kinds of saws.

Another method of giving the requisite temper has been practised upon various articles. The pieces of steel are covered with oil or tallow, or put into a vessel containing either of these ingredients, and heated over a moderate fire. The appearance of the smoke, from the oil or tallow, indicates the degree of heat. If the smoke just appear, the temper corresponds with that indicated by the straw-color, when the metal is heated alone. If so much heat is applied, that a black smoke arises, this points out a different degree of hardness; and so on, till the vapor catches flame. By this method, a number of pieces may be done, at once, with comparatively little trouble, and the heat is also more equally applied.

A still more accurate method of producing any desired degree of temper is, to immerse the steel in some fluid medium, the temperature of which is kept regulated, by the thermometer. Thus oil, which boils at about six hundred degrees, may be used, for this purpose, at any degree of heat which is below that number of degrees. Mr. Parkes has recommended the employment of metallic baths, chiefly composed of lead and tin, in different proportions, which pass into fusion, at definite temperatures, and which can be used for tempering steel, as soon as they arrive at their melting points.* †

* The following table of metallic baths is given, in Parkes's Chemical Essays, Appendix to vol. ii.

No.	Edge Tools to be tempered in the various Baths.	Composition of the Bath.	Temper. Fahren.
1	Lancets, in a bath, composed of	7 lead 4 tin	420°
2	Other surgical instruments,	7½ lead 4 tin	430
3	Razors, &c.,	8 lead 4 tin	442
4	Penknives, and some implements of surgery,	8½ lead 4 tin	450
5	Larger penknives, scalpels, &c.,	10 lead 4 tin	470
6	Scissors, shears, garden-hoes, cold chisels, &c.,	14 lead 4 tin	490
7	Axes, firmer chisels, plane-irons, pocket-knives, &c.,	19 lead 4 tin	509
8	Table-knives, large shears, &c.,	30 lead 4 tin	530
9	Swords, watch-springs, &c.,	48 lead 4 tin	550
10	Large springs, daggers, augers, small fine saws, &c.,	50 lead 2 tin	558
11	Pit-saws, band-saws, and some particular springs,	Boiling linseed oil	600
12	Articles which require to be still somewhat softer,	Melting lead	612

† Formerly, no man in Great Britain knew how to temper a sword in such a way, that it would bend, for the point to touch the heel and spring back again uninjured, except one Andrew Ferrara, who resided in the Highlands of Scotland. The demand which this man had for his swords was so great, that he employed workmen to forge them, and spent all his own time in tempering them; and found it necessary, even in the day time, to work in a dark cellar, that he might be better able to observe the progress of the heat, and that the darkness of his workshop might favor him in the nicety of the operation.

The swords, which were formerly in the highest repute, were made at Damascus, in Syria. The method, by which these were made, has long been lost, or perhaps it was never thoroughly known to Europeans; but from their striated appearance, it has been supposed that they were formed by alternate layers of extremely thin plates of iron and steel, bound together with iron wire, and then firmly cemented together by welding. These weapons never broke, even in the hardest conflict, and retained so powerful an edge, as to be capable of cutting through armor. Various other explanations have been given in regard to the character and structure of the Damascus, or damasked steel.

Cutlery.—Under the head of cutlery, are comprehended numerous instruments, designed for cutting or penetration, and which are made of steel, mostly, by the processes of forging, tempering, grinding, and polishing. The inferior kinds of cutlery are made of blistered-steel, welded to iron. Tools of a better quality are manufactured from shear-steel, while the sharpest and most delicate instruments are formed of cast-steel.

The first part of the process consists in forging, and is varied, according to the kind of article to be formed. Common *table-knives*, have the blade forged of steel, and welded to a piece of iron, out of which the shoulder, and part which enters the handle, are made, the shape being given to them by hammering in a die and swage. They are afterwards tempered and ground. *Forks* are made by forging the shank, and flattening the other end to the length intended for the prongs. The prongs are made, by stamping the metal, at a white heat, between two dies, the uppermost of which is attached to a heavy weight, and falls from a height. The shape is thus given to the fork, leaving, however, a flat thin piece of metal between the prongs, which is afterwards cut out with a fly-press. They are subsequently filed, bent, hardened, and polished.

Blades of *penknives* are forged from the end of a rod of steel, and cut off, together with metal enough to form the joint. The small recess, in which the nail is inserted, to open the knife, is made with a curved chisel, while the steel is hot. *Razors* are forged from cast-steel, much in the same manner as knives. The anvil is commonly a little rounded, at the sides, for the purpose of making the sides of the razor a little concave, and the edge thinner. In forging *scissors*, the shape is given to the different parts, by hammering them upon different indented surfaces, called *bosses*. The bows which receive the finger and thumb are made, by punching a hole in the metal, and enlarging it, by hammering it round a tool, called a *beak* iron. The halves are finished by filing and grinding, and afterwards united by a joint. *Saws* are made from steel-plates, rolled for the purpose, and have their teeth cut and finished by filing, and set by a suitable instrument. *Axes*, *adzes*, and other large tools, are forged from iron, and have a steel piece welded on, of the proper size, to form the edge.

To enable the steel to be wrought, it is brought to its softest state ; but after the shape is given to the instrument, the steel is hardened and tempered, by the methods already described. The remaining part of the manufacture consists in grinding, polishing, and setting the instrument, to produce a smooth surface and a sharp edge. The grinding is performed upon stones, of various kinds, among which, freestone is, perhaps, the most common. These stones are made to revolve by machinery, and move with prodigious velocity, so that the surface, in some cases, passes over six or seven hundred feet, in a second, and stones have been burst by their own centrifugal force. For grinding flat surfaces, like those of saws, the largest stones are used ; while, for concave surfaces, like the sides of razors, smaller stones are used, on account of their greater convexity. The internal surfaces of scissors, forks, &c., which cannot be applied to the stone, are ground with sand and emery, applied with instruments of wood, leather, and other elastic substances. The last polish is given by the impure oxide of iron, called *colcothar-crocus*, and by the French, *Rouge d' Angleterre*. The edges are lastly *set* with hones and whetstones, according to the degree of keenness required. The test, used by cutlers, for determining the goodness of the edge and point of a lancet, is, that it shall pass through a piece of soft leather, without sensible resistance. *Needles* are polished, by tying them in large bundles, with emery and oil, and rolling them under a heavy plank, till they become smooth, by mutual attrition. The shape is previously given, and the eye made with a steel punch.

A process has been invented by Mr. Lucas, for converting edge-tools, nails, &c., made of cast-iron, into good steel. It consists in stratifying the cast articles, in cylindrical metallic vessels, with native oxide of iron, and then submitting the whole to a regular heat, in a furnace built for the purpose. It is not, however, necessary that the oxide employed should be a native oxide, any artificial oxide being equally effectual.

The cast-iron, of which this cutlery is made, is brittle, in the first instance, like other cast-iron, in consequence of the carbon contained in it; but the great heat which it undergoes, aided by the pulverized oxide, separates a part of the carbon. This, uniting with the oxygen of the ground oxide of iron, is dissipated in the state either of carbonic oxide, or carbonic acid gas, and the articles are then converted into a state nearly similar to that of good cast-steel cutlery. They do not, however, receive so fine an edge, and do not bear hardening and tempering, in the common manner.

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CHAPTER. XXI.

ARTS OF VITRIFICATION.

Glass, Materials, Crown Glass, Fritting, Melting, Blowing, Annealing, Broad Glass, Flint Glass, Bottle Glass, Cylinder Glass, Plate Glass, Moulding, Pressing, Cutting, Stained Glass, Enamelling, Artificial Gems, Devitrification, Reaumur's Porcelain, Crystallo-Ceramie, Glass Thread, Remarks.

A GREAT number of earths, and other mineral bodies, after being fused, do not resume their original character, upon cooling, but pass into a dense, hard, shining, and brittle, state, having the character of glass ; and are thus said to be *vitrified*. Most of these substances do not immediately become hard, upon the reduction of their temperature, but go through an intermediate, or ductile, state, in which a combination of softness with tenacity, enables them to be wrought into articles of use and ornament. Of these, common glass is the most important, while enamels, artificial gems, &c., belong to the same species of manufacture.

Glass.—Glass is a compound substance, artificially produced, by the combination of silicious earth with alkalies, and, in some cases, with other metallic oxides. These substances, being melted together at a high temperature, unite, lose their opacity, and are fused into a homogeneous mass, which, on cooling, has the properties of hardness, transparency, and brittleness.

*Materials.**—The most important ingredient, and, in fact, the basis, of transparent glass, is silica, or oxide of silicium. This earth, nearly in a state of purity, is found in the sand of certain situations, and also in common flint, and quartz pebbles. Sand has the advantage of being already in a state of minute division, not requiring to be pulverized. Pure silicious sand, proper for the glass furnace, is found in many localities. A great portion of that used in the United States is taken from the banks of the Delaware. When flints, or quartz, are employed, they must be first reduced to powder, which is done by heating them red hot, and plunging them in cold water. This causes them to whiten and fall to pieces ; after which, they are ground and sifted, before they are ready for the furnace.

An alkaline substance, either potash or soda, is the second ingredient in glass. For the finer kinds of glass, pure pearlash is used, or soda, procured by decomposing

* The term *metals*, which appears to be a corruption of *materials*, is in common use, among glass-manufacturers, to express the ingredients, or substances, upon which their operations are performed. The same term is employed, in a similar sense, by other manufacturers and artists, and by some writers on road-making. The term *metal*, in the singular, is applied to glass, in a state of fusion

sea-salt ; but, for the inferior sorts, impure alkalies, and even wood-ashes, are made to answer the purpose. Lime is often employed, in small quantities ; also borax, a salt which facilitates the fusion of the silica.

Instead of the common alkalies, the sulphate of soda may be employed, in glass-making. But, in this case, it is necessary to liberate the alkali, by decomposing the sulphuric acid of the salt. This may be done, by charcoal, or, in flint-glass, by metallic lead. Lime is also used with this salt.

Of the metallic oxides, which are added in different cases, the deutoxide of lead (red lead) is the most common. This substance renders flint-glass more fusible, heavy, and tough, and more easy to be ground and cut. At the same time, it imparts to it a greater brilliancy, and refractive power. Black oxide of manganese, in small quantities, has the effect of cleansing the glass, or of rendering it more colorless and transparent. This effect it seems to produce, by imparting oxygen to the carbonaceous impurities, thus forming with them carbonic acid, which subsequently escapes. Common nitre produces a similar effect. If too much manganese be added, it communicates a purple tinge to the glass, which, however, may be destroyed, by a little charcoal or wood. Arsenious acid, (white arsenic,) in small quantities, promotes the clearness of glass ; but, if too much be used, it communicates a milky whiteness. Its use, in drinking-vessels, is not free from danger, when the glass contains so much alkali, as to render any part of it soluble in acids.

Crown Glass.—Glass is of various kinds, which are named, not only from the character of their ingredients, but from the mode in which they are wrought. The name of *crown-glass* is given to the best kind of window-glass, that which is hardest, and most free from color. It is made almost entirely of sand and alkali, and a little lime, without lead, or any other metallic oxide, except a minute quantity of manganese, and sometimes of cobalt, which are added, to counteract the effect of any impurities, in giving color to the glass. Crown-glass requires a greater heat, to melt its ingredients, than those kinds, which contain a larger quantity of metallic oxide, especially of lead.

Fritting.—After the materials have been intimately mixed, they are subjected to the operation, called *fritting*. This consists in exposing them to a dull, red heat, which is not sufficient to produce their fusion. The use of this process is, to drive off the carbonic acid, and other gaseous and volatile matters, which would otherwise prove troublesome, by causing the materials to swell up in the glass-pots. The heat is gradually increased, and the materials constantly stirred, for some hours, until they unite into a soft, adhesive mass; the alkali having gradually combined with the silicious earth. The reason why the fritting is conducted at a low heat is, that, if a high temperature were applied, at once, the alkali would be driven off, before it had time to combine with the silica.

Melting.—The homogeneous mass, or *frit*, is next transferred to the glass-pots of the melting furnace. These are crucibles, made of the most refractory clays and sand. A quantity of old glass is commonly placed upon the top of the frit, and the heat of the furnace is raised to its greatest height, at which state it is continued for thirty or forty hours. During this time, the materials become perfectly united, and form a transparent, uniform, mass, free from specks and bubbles. The whole is then suffered to cool a little, by slackening the heat of the furnace, until it acquires sufficient tenacity to be wrought.

Blowing.—The formation of window-glass is effected, by blowing the melted matter, or *metal*, as it is called, into hollow spheres, which are afterwards made to expand into circular sheets. The workman is provided with a long, iron tube, one end of which he thrusts into the melted glass, turning it round, until a certain quantity, sufficient for the purpose, is *gathered*, or adheres to the extremity. The tube is then withdrawn from the furnace, the lump of glass, which adheres, is rolled upon a smooth iron table, and the workman blows strongly, with his mouth, through the tube. The glass, in consequence of its ductility, is gradually inflated, like a bladder, and is prevented from falling off, by a rotary motion, constantly communicated to the tube. The inflation is assisted by the heat, which causes the air and moisture of the breath to expand, with great power. Whenever the glass becomes so stiff, from cooling, as to render the inflation difficult, it is again held over the fire to soften it, and the blowing is repeated, until the globe is expanded to the requisite thinness. It is then received, by another workman, upon an iron rod,* while the blowing-iron is detached. It is now opened at its extremity, and, by means of the centrifugal force, acquired from its rapid whirling, it spreads into a smooth, uniform sheet, of equal thickness throughout, excepting a prominence at the centre, where the iron rod was attached.

Annealing.—After the glass has received the shape which it is to retain, it is transferred to a hot chamber, or annealing furnace, in which its temperature is gradually reduced, until it becomes cold. This process is indispensable to the durability of glass; for, if it is cooled too suddenly, it becomes extremely brittle, and flies to pieces, upon the slightest touch of any hard substance. This effect is shown, in the substances called *Rupert's-drops*, which are made, by suddenly cooling drops of green glass, by letting them fall into cold water. These drops fly to pieces, with an explosion, whenever their smaller extremity is broken off. The *Bologna-phials*, and some other vessels of unannealed glass, break into a thousand pieces, if a flint, or other hard and angular substance, is dropped into them. This phenomenon seems to depend upon some permanent and strong inequality of pressure; for when these drops are heated so red as to be soft, and left to cool, gradually, the property of bursting is lost, and the specific gravity of the drop is increased.

Broad Glass.—This is a coarser kind of window-glass, and is made from sand, with kelp and soap-boilers' waste It is blown into hollow cones, about a foot in diameter, and these, while hot, are touched on one side with a cold iron, dipped in water. This produces a crack, which runs through the length of the cone, nearly in a right line

* Called a *punt*, or *punting-iron*.

The glass then expands into a sheet, in its form resembling, somewhat, the shape of a fan. This appears to have been one of the oldest methods of manufacturing glass.

Flint Glass.—Flint-glass, so called, from its having been originally made of pulverized flints, differs from window-glass, in containing a large quantity of the red oxide of lead. The proportions of its materials differ; but, in round numbers, it consists of about three parts of fine sand, two of red lead, and one of pearlash, with small quantities of nitre, arsenic, and manganese. It fuses at a lower temperature than crown-glass, has a beautiful transparency, a great refractive power, and a comparative softness, which enables it to be cut and polished, with ease. On this account, it is much used for glass vessels, of every description, and especially those which are intended to be ornamented, by cutting. It is also employed for lenses, and other optical glasses. Flint-glass is worked, by blowing, moulding, pressing, and grinding. Articles of complex form, such as lamps and wine-glasses, are formed in pieces, which are afterwards joined, by simple contact, while the glass is hot. It appears, that the red lead, used in the manufacture of flint-glass, gives up a part of its oxygen, and passes to the state of a protoxide.

Bottle Glass.—Common green glass, of which bottles are made, is the cheapest kind, and formed of the most ordinary materials. It is composed of sand, with lime, and sometimes clay, and alkaline ashes, of any kind, such as kelp, barilla, or even wood-ashes. The green color is owing to the impurities in the ashes, but chiefly, to oxide of iron. This glass is hard, strong, and well vitrified. It is less subject to corrosion, by strong acids, than flint-glass; and is superior to any cheap material, for the purposes to which it is ordinarily applied.

Cylinder Glass.—The plates of crown-glass, which are obtained in the common manner, by blowing them in circular plates, afford the common material for window-glass; being cut into squares, by first marking the surface deeply, with a diamond, and then breaking the glass, in the same directions; the crack always following the exact course of the incision, made by the diamond. But there is always a loss, or waste, in cutting squares, from a circular plate; besides which, they can never be very large, owing to the protuberance, or *bull's-eye*, which fills the centre of the plate; so that a square can never be larger, than can be described within less than half the circle. To remedy this disadvantage, plates for looking-glasses, and others, of large size, are executed in a different way, either by blowing them in cylinders, or by casting them in plates, at first.

Cylinder glass is blown, at first, in spheres, like window-glass. These are elongated into spheroids, by a swinging motion, which the workman gives to his rod. The ends of this spheroid are successively perforated, thus converting it into an irregular cylinder. One side of this cylinder is cut through, with shears, and the glass is laid upon a flat surface, where it expands into a uniform plate, without any protuberance. It is then annealed, by diminishing the heat, in the common way. When the plates are intended for looking-glasses, the finest materials are used, and the heat kept at its greatest height, for a long time, to dissipate all impurities, and remove any specks or bubbles.

Plate Glass.—Looking-glass plates may be blown in cylinders, when they do not exceed about four feet in length. But they cannot well be blown, of a larger size than this, from such a quantity of glass as the rod will take up, without becoming too thin to bear polishing. Plates, however, may be made of more than double this size, by another process, which is called *casting*, and which is the only mode by which very large plates are produced.

When glass is to be cast, it is melted, in great quantities, in large pots, or reservoirs, until it is in a state of perfect fusion, in which state it is kept for a long time. It is then drawn out, by means of iron cisterns, of considerable size, which are lowered into the furnace, filled, and raised out, by machinery. The glass is poured out from these cisterns, upon tables of polished copper, of a large size, having a rim elevated as high as the intended thickness of the plate. In order to spread it perfectly, and tc make the two surfaces parallel, a heavy roller of polished copper, weighing five hundred pounds, or more, is rolled over the plate, resting upon the rim, at the edges. The glass, which is beginning to grow stiff, is pressed down, and spread equally, the excess being driven before the roller, till it falls off at the extremity of the table. The plate is then ready to be annealed.

As the plates, which are cast for looking-glasses, are always uneven and dull, at their surface, it is necessary to grind and polish them, before they are fit for use. The process, employed for producing a perfectly even and smooth surface, is very similar to that employed in polishing marble; except that the glass, being the harder substance, requires more labor and nicety, in the operation. The plate to be polished is first cemented to a table of wood or stone, with plaster of Paris. A quantity of wet sand or emery is spread upon it, and another glass plate, similarly cemented to another wooden surface, is brought in contact with it. The two plates are then rubbed together, until the surfaces have become mutually smooth and plane. The emery, which is first used, is succeeded by emery of a finer grain, and the last polish is given by colcothar or putty. When one surface has become perfectly polished, the cement is removed, the plate turned, and the opposite side polished in the same manner.

As the grinding of glass causes an expenditure of a considerable portion of its substance, a great waste of glass takes place, when foreign materials are employed, in the manner which has been described. To prevent this loss, a more economical mode has been introduced, in which the glass is ground with pure *flint*, reduced to powder. The mixture of glass and flint, which is left, after the operation, is valuable, for forming fresh glass.

Moulding.—A variety of ornamental forms are produced, upon the surface of glass vessels, by impressions given to them with a metallic mould, while the glass is in a hot state. Flint-glass is the kind which is used for articles, intended to possess much brilliancy; but coarser kinds, even of colored glass, are also subjected to the same process. The simplest manner, in which the operation is conducted, consists, in blowing the glass into the mould, till it receives the impression, on its outside. For this purpose, a quantity of glass, sufficient to form the intended vessel, is taken up on the end of a pipe, and inserted at the top of the mould. The workman then blows, with his mouth, till a hollow portion of glass is driven into the mould, and expands, so as to fill every part, and receive an impression on its outside. The mould is usually made of copper, with the figure cut on its inside, and opens with hinges, to permit the glass to be inserted, and taken out. As the mould is, of necessity, much colder than the glass, the latter substance is chilled, at its surface, as soon as it comes in contact with the copper; hence its ductility is impaired, and the impression given is never so sharp as that which is obtained with substances, which are nearly at the same temperatures. Moulded bottles, phials, decanters, &c., are made in this way.

Pressing.—An improvement has been made, in the process of moulding glass, by subjecting the material to pressure, on the inside and outside, at the same time, by different parts of a mould, which are brought suddenly together, by mechanical power. This process has been carried to great perfection, in several of the manufactories in this country,* and produces specimens, which compare with cut glass, in the accuracy and beauty of the workmanship. It is applied only to solid articles, and to vessels which are not contracted at top. The hot glass being dropped into the mould, a part, called the *follower*, answering to the inside or top of the vessel, or other article, is immediately pressed down upon it, by a lever, and the glass is thus stamped with a very distinct impression of the figure, on both sides at once. The glass vessel is sometimes transferred from the mould to another receptacle, called the *receiver*, in order to preserve its shape, till it is cool enough to stand.

Cutting.—The name of *cut-glass* is given, in com

* Particularly, at Lechmere's Point, and Sandwich

merce, to glass which is ground and polished, in figures, with smooth surfaces, appearing as if cut by incisions of a sharp instrument. This operation is chiefly confined to flint-glass, which, being more tough, soft, and brilliant, than the other kinds, is more easily wrought, and produces specimens of greater lustre. An establishment for cutting glass, contains a great number of small wheels, of stone, metal, and wood, which are made to revolve rapidly, by a steam-engine or other power. The cutting of the glass consists entirely, in grinding away successive portions, by holding them upon the surface of these wheels. The first, or rough cutting, is sometimes given by wheels of stone, resembling grindstones. Afterwards, wheels of iron are used, having their edges covered with sharp sand, or with emery, in different states of fineness. The last polish is given by brush-wheels, covered with putty, which is an oxide of tin and lead. To prevent the friction from exciting so much heat, as to endanger the glass a small stream of water continually drops upon the sui face of the wheel.

Stained Glass.—The name of *staining* has been ap plied to the process, by which painting, with vitrifiable colors, is executed upon the surface of glass. The pigments used are, chiefly, metallic oxides, which do not exhibit their full color, until they have been exposed to the heat of the furnace. This art has been repeatedly described, as being no longer known ; but this is not the fact, except in respect to some particular colors, which are found in the windows of the ancient cathedrals.

The metallic oxides, used in staining glass, are difficult of fusion ; on which account, it is necessary to mix them with a flux, composed of glass, with lead or borax. This renders the oxide fusible, at a temperature which does not injure its color ; also, by enveloping the particles, it causes them to adhere to the glass, and afterwards protects them from the atmosphere.

A very beautiful violet, but liable to turn blue, is made from a flux, composed of borax and flint-glass, colored with one sixth part of the purple of *Cassius*, precipitated from muriate of gold, by protomuriate of tin.

A fine red is made from red oxide of iron, prepared by nitric acid and heat, mixed with a flux of borax, and a small proportion of red lead.

A yellow, equal in beauty to that produced by the ancients, may be made from muriate of silver, oxide of zinc, white clay, and the yellow oxide of iron, mixed together, without any flux. A powder remains on the surface, after the glass has been baked ; but this is easily cleaned off.

Blue is produced by oxide of cobalt, with a flux, composed of fine sand, purified pearlash, and red lead.

Black is produced, by mixing the composition for blue, with the oxides of manganese and iron.

To stain glass green, it may be painted blue, on one side, and yellow, on the other.

The colors, ground with water, being laid upon the glass, must be exposed to heat, under a muffle, so as to be heated equally, until the color is melted upon the surface. To prevent the panes of glass from bending, they are placed upon a bed of bone-ashes, of quicklime, or of unglazed porcelain. A bed of gypsum has been recommended ; but the sulphuric acid, exhaling from it, is apt to injure the glass.

Among ancient specimens of painted glass, some pieces have been found, in which the colors penetrate through the glass, so that the figure appears in any section, made parallel to the surface. It is supposed, that such pieces can only have been made in the manner of mosaic, by accumulating transverse filaments of glass, of different colors, and uniting them by heat, the process being one of great labor. They are described by Winckelmann, and Caylus, from some specimens brought from Rome.

Enamelling.—Enamels are compositions of various substances, which, when vitrified upon the surface of opaque bodies, communicate their colors, and produce the effect of painting. Enamels differ from stained glass, as a common picture differs from a transparency ; the former producing its effect, when viewed by reflected, and the latter by transmitted, light. Enamels are executed upon the surface of copper, and other metals, by a method, similar to painting. One coat, or color, often requires to be vitrified, before another is laid upon it; and thus the plate, to be enamelled, is obliged to be exposed to heat, several successive times.

Transparent enamels are usually rendered opaque, by adding putty, or the white oxide of tin, to them. The basis of all enamels is, therefore, a transparent and fusible glass. The oxide of tin renders this of a beautiful white, the perfection of which is greater, when a small quantity of manganese is likewise added. If the oxide of tin be not sufficient to destroy the transparency of the mixture, it produces a semi-opaque glass, resembling the opal.

The metals, employed as coloring materials, are, 1. Gold. The purple of Cassius imparts a fine ruby tint. 2. Silver. Oxide, or phosphate, of silver, gives a yellow color. 3. Iron. The oxides of iron produce green, yellow, and brown, depending upon the state of oxidizement, and quantity. 4. Copper. The oxides of copper give a rich green; they also produce a red, when mixed with a small proportion of tartar, which tends, partially, to reduce the oxide. 5. Antimony imparts a rich yellow. 6. Manganese. The black oxide of this metal, in large quantities, forms a black glass; in smaller quantities, various shades of purple. 7. Cobalt, in the state of oxide, gives beautiful blues, of various shades; and, with the yellow of antimony, or lead, it produces green. 8. Chrome produces fine greens and reds, depending upon its state of oxidizement.

Artificial Gems.—The great value of the precious stones has led to artificial imitations of their color and lustre, by compositions in glass. In order to approximate, as near as possible, to the brilliancy, and refractive power, of native gems, a basis, called a *paste*, is made from the finest flint-glass, composed of selected materials, combined, in different proportions, according to the preference of the manufacturer. This is mixed with metallic oxides, capable of producing the desired color. A great number of complex recipes are in use, among manufacturers of these articles.

Devitrification.—It is found, that, if certain kinds of glass be exposed to heat, sufficient to keep them in a soft state, for some hours, and are suffered to cool, gradually, they lose their transparency, and pass into the state of an opaque substance, of a grayish white color. M. Dartrigues,* who has examined the cause of this change, asserts, that it is owing to a real crystallization of the vitreous silicate. Common bottle-glass is most easily changed, in this manner ; while those varieties, which contain neither lime, nor alumina, are the most difficult to devitrify. In all cases, glass, which has undergone this change, requires a stronger heat to melt it, than before.

Reaumur's Porcelain.—It has been frequently observed, that, during the annealing of green glass, some parts of it become white, and opaque. M. Reaumur made experiments on this apparent devitrification of glass, and found it was owing to the alkali flying off, by the too long continuance, or too great degree, of the heat, and that the opaque, changed glass, had acquired the quality of bearing sudden transitions of heat and cold, as well as the best porcelain.

For the purpose of making vessels, of this kind, common bottle-glass is chosen, and blown into the proper form. The vessel is then to be filled to the top, with a mixture of white sand and gypsum, and is set in a large crucible, upon a quantity of the same mixture, with which the glass vessels must also be surrounded, and covered over, and the whole pressed down, rather hard. The crucible is then to be covered with a lid, the junctures well luted, and put into a potter's kiln, where it remains, during the whole time that the pottery is baking ; after which, the glass will be found changed into a milk-white porcelain.

An imitation of porcelain, which is lately introduced into our shops, and which combines whiteness with a beautiful semi-transparency, is made of flint-glass, containing a portion of white arsenic, on which its opacity depends.

* Journal de Physique, 1804.—Thenard, Chimié, ii. 473

Crystallo Ceramie.—This name is given to an elegant, but difficult, species of manufacture, in which medallions, portraits, and other subjects, executed in an opaque material, are enclosed, or encrusted, with glass. This art was first attempted, by enclosing, in glass, small figures, made of a peculiar kind of clay ; but these experiments were only in few instances successful, owing to the unequal expansion and contraction of the two substances, and their consequent fracture. More recently, a composition has been employed, for the opaque figure, which is less liable to these accidents. It is necessary, that the substance, employed in these devices, should be less fusible than glass, incapable of generating air, and, at the same time, susceptible of expansion and contraction, as the glass becomes hot or cold. The ornamental figures are introduced into the glass while hot, and thus become incorporated with it.

Glass Thread.—The great ductility of glass is one of its most remarkable properties. When heated to a sufficient degree, it may not only be moulded, into any possible form, with the utmost facility, but it can be drawn out into the finest fibres. The method of spinning glass is very simple. The operator holds a piece of glass over the flame of a lamp, with one hand ; he then fixes a hook to the melted mass, and, by withdrawing it, obtains a thread of glass, attached to the hook. The hook is then fixed in the circumference of a cylindrical drum, which can be turned round by the hand ; and a rapid, rotary motion being given to the drum, the glass is drawn in the finest threads, from the fluid mass, and coiled round the cylindrical circumference. M. Reaumur supposed, with great reason, that the flexibility of glass increased with the fineness of the threads, and he therefore conjectured, that, if they were drawn to a sufficient degree of fineness, they might be used in the fabrication of stuffs. He succeeded in making them as fine as a spider's web ; but he was never able to obtain them of a sufficient length, when their diameter was so much reduced. The circumference of these threads is generally a flat oval, about three or four times as broad as it is thick. By using opaque and transparent glass, of different colors, artists have been able to produce many beautiful ornaments. M. Bonnet, and others, have succeeded in obtaining glass fibres, of such fineness and flexibility, as to admit of being woven into cloth, of a very brilliant, silvery appearance.

Remarks.—Pure glass possesses the remarkable property, of suffering no change by the application of an intense heat. The effect of great heats is only to melt the glass, or to dissipate it in vapor ; but, as long as any of the glass remains, it still preserves its transparency, and other distinguishing properties.

Of all the solid substances, whose expansibility has been accurately examined, glass possesses the property of being least affected by heat or cold. Its expansion, according to General Roy, with an increase of heat, equal to one hundred and eighty degrees of Fahrenheit's thermometer, is only 0.000776, while that of platina is 0.000856, and that of hammered zinc, 0.003011. On account of this property, glass is peculiarly fitted for containing fluids, whose expansions are under examination, as its own change of form may, in ordinary cases, be neglected. For the same reason, it is better than any other substance, for the simple pendulum of a clock.

The invention of glass seems to have been extremely ancient, and some curious specimens are found, in the sarcophagi of Egyptian mummies. Glass windows appear not to have been in use, among the Romans of the Augustan age ; though vessels and plates of glass are found at Herculaneum, and Pompeii. Most of the important improvements, in the manufacture of this substance, have been made by the moderns.

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CHAPTER XXII.

ARTS OF INDURATION BY HEAT.

Bricks, Pressed Bricks, Tiles, Terra Cotta, Crucibles, Pottery, Operations, Stone Ware, White Ware, Throwing, Pressing, Casting, Burning, Printing, Glazing, China Ware, European Porcelain, Etruscan Vases.

COMMON clay, with its varieties, consisting essentially of alumina and silica, also, the artificial imitations of clay, into which these earths enter, possess properties, adapted to render them highly useful in the arts. When mixed with water, they form a ductile and tenacious paste, capable of being moulded into various forms, and of acquiring, when exposed to the heat of a furnace, a durable and stony hardness. These compounds are used in different states, to form the materials, both for the largest structures, and the most delicate ornaments; and they are surpassed by few substances, in the power of resisting the effects of exposure and time. Bricks, tiles, terra-cotta, pottery, and porcelain, are the most noticeable products of the branch of industry, in the operations of which indurated clay is the material.

Bricks.—The use of bricks, in building, may be traced to the earliest ages, and they are found among the ruins of almost every ancient nation. The walls of Babylon, some of the ancient structures of Egypt, and Persia, the walls of Athens, the Rotunda of the Pantheon, the Temple of Peace, and the Thermæ, at Rome, were all of brick. The earliest bricks were dried in the sun, and were never exposed to great heat, as appears from the fact, that they contain reeds and straws, upon which no mark of burning is visible. These bricks owe their preservation to the extreme dryness of the climate, in which they have remained; since the earth, of which they are made, often crumbles to pieces, when immersed in water, after having kept its shape for more than two thousand years. This is the case, with some of the Babylonian bricks, with inscriptions in the arrow-headed character, which have been brought to this country. The ancients, however, at a later period, burnt their bricks ; and it is these, chiefly, which remain at the present day. The antique bricks were larger than those employed by the moderns, and were almost universally of a square form. Besides bricks made of clay, the ancients also employed a kind of factitious stone, composed of a calcareous mortar.*

Modern bricks receive their hardness from exposure to heat, in the process of burning. The common clay, of which they are made, consists of a mixture of argillaceous earth, and sand. Most of our common clays contain, also, oxide of iron, which causes the bricks to turn red, in burning. Pure clays become white in the furnace, such as that of which pipes are made, and common crockery-ware. Clay, after it is taken from the earth, requires to be thoroughly mixed, incorporated, and mellowed, before it is fit for the manufacture of bricks. For this purpose, it is to be dug in the summer, or autumn, and exposed to the influence of the frost, through the winter. It should be worked over repeatedly, with the spade, and not made into bricks, till the ensuing spring, previously to which, it is well tempered, either by treading it, with oxen, or by a horse-mill, till it is reduced to a tough, homogeneous paste. In proportion to the labor bestowed on this process, the bricks become solid, hard, and strong. The clay, after being thus prepared, is forced into moulds, to receive the shape of bricks, and afterwards dried in the sun.

Pressed bricks, which are used to form the facing of walls, in the better kinds of structures, are finished in a machine. The roughness, and change of form, to which common bricks are liable, is owing, in part, to the evaporation of a portion of the water, which the clay contains. To remedy the difficulty, arising from this cause, the bricks, after being moulded, in the common manner, are exposed to the sun, till they are nearly dried ; retaining, however, sufficient plasticity, to be still capable of a

* Some travellers have even advanced an opinion, that the Py amids of Egypt are constructed with an artificial stone.

slight change of form. In this state, they are placed in an iron mould, and subjected to a strong pressure, by which they become regular in shape, and very smooth. A machine usually contains a number of moulds, arranged in a circle, or otherwise; so that the power is applied to them in succession, and the bricks pressed with rapidity.

The burning of bricks is commonly performed, in this country, by forming them into large, square piles, denominated *clamps*, or, with us, *kilns*, having flues, or cavities, at the bottom, for the insertion of the fuel, and interstices between the bricks, for the fire and hot air to penetrate. A fire is kindled in these cavities, and gradually increased, for the first twelve hours, after which, it is kept up, at a uniform height, for several days and nights, till the bricks are sufficiently burned. Much care and experience are necessary, in regulating the fire, since too much heat vitrifies them, and too little, leaves them soft and friable. In some places, the burning of bricks is conducted in permanent kilns, erected for the purpose.

Tiles.—Tiles are plates of burnt clay, resembling bricks, in their composition and manufacture, and used for the covering of roofs. They are necessarily made thicker than slates or shingles, and thus impose a greater weight upon the roofs. Their tendency to absorb water promotes the decay of the wood-work beneath them. Tiles are usually shaped in such a manner, that the edge of one tile receives the edge of that next to it, so that water cannot percolate between them.* Tiles, both of burnt clay, and marble, were used by the ancients; and the former continue to be employed in various parts of Europe. Floors, made of flat tiles, are used in many countries, particularly in Italy.

Terra Cotta.—The Italian name, *terra-cotta*, in French, *terre-cuite*, in its most general sense, implies clay, indurated by heat. In the arts, however, its use seems to be restricted to the finer clays, in which ornamental designs have been executed, both by the ancients and moderns. Not only vases, but imitations of sculpture, and

* For different forms of tiles, used at Florence, Trieste, &c., see Cadell's Journey in Italy, and Carniola, Plate X.

architectural decorations, are successfully made, from this material. Among other things, a complete restoration of the Choragic monument of Lysicrates, at Athens, has been made from terra-cotta, in the court of the Louvre, at Paris. From the facility with which it is moulded into any form, this substance would be of great use in architecture, were it not for the unequal shrinking of the clay, from heat, and the difficulty of preserving, accurately, the original proportions.

Crucibles.—Crucibles, melting-pots, and other vessels, intended for use in the furnace, require to be made of substances, which sustain a high temperature, without fusion. When they are made of about one part of pure clay, mixed with three of sand, and slowly dried, and annealed, they are found to bear a great heat, and will retain most of the metals which are melted for use in the arts. Such crucibles, however, are liable to be acted upon and destroyed, at high temperatures, if the metals are suffered to become oxidized, or if saline fluxes are used. To prevent this accident, some crucibles are made entirely of clay, which is burnt, coarsely powdered, and mixed with fresh clay. These are found very refractory in the furnace. Crucibles are also made of plain Stourbridge clay, of Wedgewood's ware, of graphite, and of platina.

Pottery.—In manufactures of vessels, from argillaceous compounds, the different degrees of beauty, and costliness, depend upon the quality of the raw material used, and upon the labor and skill, expended in the operation. The cheapest products of the art, are those made of common clay, similar to that of which bricks are formed, and which, from the iron it contains, usually turns red, in burning. Next to this, is the common crockery-ware, formed of the purer and whiter clays, in which iron exists, only in minute quantities. Porcelain, which is the most beautiful and expensive of all, is formed only from argillaceous minerals, of extreme delicacy, united with silicious earths, capable of communicating to them a semi-transparency, by means of its vitrification.

Clay, although it is a compound body, and possesses more silica than alumina, nevertheless, derives characters from the latter, which abundantly distinguish it from minerals, which are more purely silicious. The processes of its manufacture are, in most respects, the reverse of those applied to glass, that substance being softened by heat, and wrought at a high temperature, whereas, the clay is wrought while cold, and afterwards hardened by heat.

Operations.—Though the various kinds of pottery and porcelain differ from each other, in the details of their manufacture, yet there are certain general principles, and processes, which are common to them all. The first belongs to the preparation of the clay, and consists in dividing and washing it, till it acquires the requisite fineness. The quality of the clay requires the intermixture of a certain proportion of silicious earth, the effect of which is to increase its firmness, and render it less liable to shrink and crack, on exposure to heat. In common clay, a sufficient quantity of sand exists, in a state of natural mixture, to answer this purpose. But in the finer kinds, an artificial admixture of silica is necessary. The paste, which is thus formed, is thoroughly beaten and kneaded, to render it ductile, and to drive out the air. It is then ready to receive its form. The form of the vessel, intended to be made, is given to the clay, either by turning it on a wheel, or by casting it in a mould. When dry, it is transferred to the oven, or furnace, and there burnt, till it acquires a sufficient degree of hardness, for use. Since, however, the clay is still porous, and, of course, penetrable to water, it is necessary to glaze it. This is done, by covering the surface with some vitrifiable substance, and exposing it, a second time, to heat, until this substance is converted into a coating of glass.

In the coarse earthen ware, which is made of common clay, the clay, after being mixed and kneaded, until it has acquired the proper ductility, is transferred to a sort of revolving table, called the *wheel*. A piece of clay, of sufficient size, being placed in the centre of this table, a rotary motion is communicated to it, by the feet. The potter then begins to shape it, with his hands, which are previously wet, to prevent its adhering to the fingers

The rotary motion gives it a circular form, and it is gradually wrought up to the intended shape, a tool being occasionally used, to assist the finishing. The vessels are now set aside, to dry; after which, they are baked in the oven, or kiln. The glazing, of this kind of pottery, is given by metallic oxides, which vitrify at a low heat. A yellow glazing is communicated, by the oxide of lead; black, by the oxide of manganese; and white, by the oxide of tin. Unglazed ware is porous, and permeable to water, as is seen in common flower-pots, and coolers.

Stone Ware.—The kinds of pottery, denominated stone-ware, may be formed of the clays, which are used for other vessels, by applying to them a much greater degree of heat, the effect of which is, to increase, very much, their strength and solidity. These vessels do not require to be glazed, with any metallic oxides, but afford the material of their own glazing, by a vitrification of their surface. When the furnace, in which they are burnt, has arrived at its greatest heat, a quantity of muriate of soda, or common salt, is thrown into the body of the kiln. The salt rises in vapor, and envelopes the hot ware, and, by the combination of its alkali with the silicious particles on the surface of the ware, a perfect vitrification is produced. This glazing, consisting of an earthy glass, is insoluble in most chemical agents, and is free from the objections, to which vessels, glazed with lead, are liable, that of communicating an unwholesome quality to liquids contained in them, by the solution of the lead in common acids, which they frequently contain.

White Ware.—The better sorts of earthen ware are made of white clay, or of clay containing so little oxide of iron, that it does not turn red in burning, but, on the contrary, improves its whiteness in the furnace. This kind, commonly called *pipe* clay, is found very pure in Devonshire, and Dorsetshire, in England. In the manufactory of Mr. Wedgewood, to whose industry and ingenuity the public are indebted, for some of the finest specimens of the art, the clay is prepared, by first bringing it to a state of minute division, by the aid of machinery. This machinery consists of a series of iron blades, or knives, fixed to an upright axis, and made to revolve in a cylinder, and intersecting, or passing between, another set of blades, which are fixed to the cylinder. The clay, by the continual intersection of these blades, is minutely divided, and, when sufficiently fine, is transferred to a vat. It is here agitated, with water, until it assumes the consistence of a pulp, so thin, that the coarser or stony particles can subside to the bottom, after a little rest, while the finer clay remains in suspension. This last is poured off, and suffered to subside, after which it is passed through sieves, of different fineness, and becomes sufficiently attenuated for use.

To this clay is added a certain quantity of flint, reduced to powder, by heating it red hot, and throwing it into cold water, to diminish the cohesion of its parts. Afterwards, it is pounded by machinery, ground in a mill, sifted, and washed, precisely as the clay is treated, and made into a similar pulp. In this state, the two ingredients are intimately mixed together, in such quantities, that the clay bears to the flint the proportion of about five to one.

The object of adding flint to the clay is two-fold. It lessens the shrinking of the clay, in the fire, and thus renders it less liable to warp and crack, in the burning. At the same time, by its partial fusion, it communicates to the ware that beautiful translucency, which is so much admired in porcelain, and of which the simple clay-wares are destitute.

The fine pulp of flint and clay, being intimately mixed, is then exposed to evaporation, by a gentle heat, until the superfluous water is dissipated, and the mass reduced to a proper consistency to work. To produce a uniformity, in the thickness of the material, it is taken out, in successive pieces, which are repeatedly divided, struck, and pressed together, till every part becomes blended with the rest.

Throwing.—The formation of circular vessels is done by the process called *throwing*, performed on the potter's wheel, in the manner already described ; except that, in large manufactories, the wheel is not turned by the operator himself, but by an assistant, or a steam-engine. The handles, and similar appendages, are made, by forcing the clay with a piston, through an aperture, of the size and shape which it is desired to produce. When formed, the handles are cemented to the ware, by a thin mixture of the clay with water, which the workmen call *slip*. The vessels, when complete, are dried, with a gradual heat, in a room, heated to eighty or ninety degrees, and, after being smoothed from any irregularities of surface, they are conveyed to the kiln.

Pressing.—The only vessels which can be made in the wheel, or lathe, are those of a circular form. When the form is different, the vessel must be made, either by press-work, or casting. The press-work is executed in moulds, made of plaster of Paris, one half the figure being on one side of the mould, and the other half, on the other side. These fit accurately together. The clay is first made into two flat pieces, of the thickness of the articles; one of these is pressed into one side of the mould, and the other into the other side. The superfluous clay being cut away, the two sides of the mould are brought together, to unite the two halves of the vessel. The mould is now separated from the clay, and the article is finished, as to form. When dry, it is completed by the addition of handles or other parts, belonging to it. All vessels, of an oval form, or which have flat sides, may be made in this way.

Casting.—In the third method, called *casting*, the clay is used in the state of pulp, sufficiently thin to flow. It is poured into moulds, made of *plaster*, by which the superfluous water being rapidly absorbed, the clay is deposited, and acquires sufficient solidity to preserve the shape communicated by the mould. It is then taken out, and dried, and transferred to the kiln.

Burning.—All vessels, when formed, are in a very tender and frangible state, before they are submitted to the action of fire. The burning, or hardening, is performed in kilns; and to preserve the ware from injury, it is enclosed in cases, or boxes, of burnt clay, called *saggars*, in which it is heated red hot, by the flame cir culating among the cases. The fire is kept up, from twenty-four to forty-eight hours, and the saggars suffered to cool, before they are removed. The ware is then found to have acquired great hardness, and is converted into a dry, sonorous, and extremely bibulous, solid. In this state, it is called the *biscuit*. It adheres strongly to the tongue, and absorbs water in such quantities, that vessels, in this state, are used as coolers, being kept saturated with water, which, as it passes constantly to the outer surface, generates cold, by its evaporation.

Printing.—When colors, or designs, are to be impressed upon the vessels, it is necessary, in most cases, that it should be done, before the ware is glazed. In China, the drawings on the surface of porcelain, and other wares, are executed by hand, with the pencil; and the same method is pursued in Europe, in elaborate pieces of workmanship. But, in the common figured white-ware, the designs are first engraved upon copper, and an impression taken on thin paper, in the common mode of copperplate-printing, except that the color is a metallic oxide. The paper is then moistened, applied closely to the biscuit, and rubbed on; by which process, the coloring matter is absorbed, in consequence of the porosity of the earthen material. The paper is then washed off, leaving the printed figure transferred to the sides of the vessel. Blue and white ware is printed with oxide of cobalt,* and a black color is imparted, by an admixture with the oxides of manganese and iron.

Glazing.—To prevent the penetration of fluids, it is necessary, that vessels should be glazed, or covered, with a vitreous coating. The materials of common glass would afford the most perfect glazing to crockery-ware, were it not that the ratio of its expansion and contraction, is not the same with that of the clay; so that a glazing of this sort is liable to cracks and fissures, when exposed to changes of temperature. A mixture, of equal parts of oxide of lead and ground flints, is found to be a

* Mr. Parkes informs us, that such improvements are made in the manufacture of this article, that the Chinese potters are now supplied from England, with all the cobalt they consume.

durable glaze, for the common cream-colored ware, and is generally used for that purpose. These materials are first ground to an extremely fine powder, and mixed with water, to form a thin liquid. The ware is dipped into this fluid, and drawn out. The moisture is soon absorbed by the clay, leaving the glazing particles upon the surface. These are afterwards melted, by the heat of the kiln, and constitute a uniform and durable vitreous coating.

The English and French manufacturers find it necessary to harden their vessels, by heat, or to bring them to the state of biscuit, before they are glazed ; but the composition used by the Chinese resists water, after it has been once dried in the air, so as to bear dipping in the glazing liquid, without injury. This gives them a great advantage, in the economy of fuel.

China Ware.—The Chinese porcelain excels other kinds of ware, in the delicacy of its texture, and the partial transparency which it exhibits, when held against the light. It has been long known and manufactured, by the Chinese, but has never been successfully imitated, in Europe, until within the last century. In China, porcelain is made by the union of two earths, to which they give the name of *petuntze*, and *kaolin*, the former of which is fusible in the furnace, the latter, not. Both these earths are varieties of feldspar, the kaolin being feldspar, in a state of decomposition, and which is rendered infusible, by having lost the small quantity of potass, which originally entered into its composition. The petuntze is feldspar, undecomposed. These earths are reduced to an impalpable powder, by processes, similar to those already described, and intimately blended together. When exposed to a strong heat, the petuntze partially melts, and, enveloping the infusible kaolin, communicates to it a fine semi-transparency. The glazing is produced by the petuntze alone, applied in minute powder to the ware, after it is dry.

European Porcelain.—Since the nature of the Chinese earths has been understood, materials, nearly of the same kind, have been found, in different parts of Europe, and the manufacture of porcelain has been carried on in several countries, but particularly at Sevres, in France, with great success. The European porcelains, in the elegance and variety of their forms, and the beauty of the designs which are executed upon them, excel the manufactures of the Chinese. But the Oriental porcelain has not yet been equalled, in hardness, strength, durability, and the permanency of its glaze. Several of the processes, which are successfully practised by the Chinese, remain still to be learnt by Europeans. The manufacturers in Saxony are said to have approached most nearly, in their products, to the character of the Asiatic porcelain.

The porcelain earths are found in various parts of the United States, and will, doubtless, hereafter constitute the material of important manufactures.

The finer and more costly kinds of porcelain derive their value, not so much from the quality of their material, as from the labor bestowed on their external decoration. When the pieces are separately painted by hand, with devices of different subjects, their value, as specimens of art, depends upon the size of the piece, the number and brilliancy of the colors employed, and, more especially, upon the skill and finish exhibited by the artist, in the design. The manual part of the operation consists, in mixing the coloring oxide with a fluid medium, commonly an essential oil, and applying it with camels' hair pencils. The colors used are the same, as those employed in other kinds of enamelling. When one color requires to be laid over another, this is performed by a second operation; and it often happens, that a piece of porcelain has to go into the enamel-kiln, four or five times, when a great variety of colors is contained in the painting.

Gilding upon porcelain is performed, by applying the gold, after its solution in nitro-muriatic acid, ground up with oil of turpentine, and mixed with a flux. When exposed to heat, the oxygen, if any is present, escapes, and a coating of metallic gold remains fixed to the porcelain. This has, at first, the appearance of dead gold; but is subsequently burnished, with an instrument of polished steel, or with an agate, or blood-stone.

The articles, called *lustre-ware*, are of two kinds. The first of these, called *gold-lustre*, is made of red clay, and is brushed over with a thin coating of gold, obtained from its solution in nitro-muriatic acid, the acid being driven off by heat. The other kind is called *silver-lustre*, and is made of the cream-colored ware, covered, in the same manner, with a film of platinum.

Etruscan Vases.—This name is given to a kind of painted antique vases, of great beauty, lightness, and delicacy, which are dug up in the graves of lower Italy. Many of them are supposed to be of Grecian, and not of Etruscan, origin. Some of these vases are entirely black, and, in this case, there is no separate glazing; but the interior of the mass has the same appearance with the outside. Other vases are furnished with a simple black coating, but unlike the modern glazing. It appears, from analysis, that this black color is produced by a carbonaceous substance, perhaps bitumen; but the art of applying it is unknown to the moderns.

The celebrated Portland vase, discovered in the tomb of Alexander Severus, and for which the Dutchess of Portland paid a thousand guineas, is said to be made, not of porcelain, but of glass. The body of the urn consists of a deep-blue glass, over which is applied a coating of white semi-transparent glass. The white covering appears to have been cut away, by the lapidary, in the same way as the subjects of antique cameos on colored grounds. Mr. Wedgewood, at a great expense, produced imitations of this vase, in porcelain.

Among the curiosities of this art, may be mentioned the *magic porcelain* of the Chinese. The figures upon the surface of this ware are executed in such a manner, that they are said to be invisible, when the vessels are empty,* but become apparent, when the vessels are filled with water.

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* See the article *Porcelain*, in the Edinburgh Encyclopedia, ascribed to M. Brogniart.

APPENDIX.

I. — Artesian Wells.

Under this name, is designated a cylindrical perforation, bored vertically down through one or more of the geological strata of the earth, till it passes into a porous gravel bed, containing water placed under such incumbent pressure, as to make it mount up through the perforation, either to the surface, or to a height convenient for the operation of a pump. In the first case, these wells are called spouting, or overflowing. This property is not directly proportional to the depth, as might at first sight be supposed, but to the subjacent pressure upon the water. We do not know exactly the period, at which the borer, or sound, was applied to the investigation of subterranean fountains, but we believe the first overflowing wells were made in the ancient French province of Artois, whence the name of Artesian. These wells, of such importance to agriculture and manufactures, and which cost nothing to keep them in condition, have been in use, undoubtedly, for several centuries, in the northern departments of France, and in the north of Italy; but it is not more than fifty or sixty years, since they became known in England and Germany. There are now many such wells in London and its neighborhood, perforated through the immensely thick bed of the London clay, and even through some portions of the subjacent chalk. The boring of such wells has given much insight into the geological structure of many districts.

The formation of Artesian wells depends on two things, essentially distinct from each other; 1. On an acquaintance with the physical constitution, or nature, of the mineral structure of each particular country; and, 2. On the skilful direction of the processes, by which we can reach the water-level, and of those by which we can promote its ascent in the tube. We shall treat of the best method of making the well, and then offer some general remarks on the other subjects.

The operations employed for penetrating the soil are entirely similar to those daily practised by the miner, in boring to find metallic veins; but the well-excavator must resort to peculiar expedients to prevent the purer water, which comes from deep strata, mingling with the cruder waters of the alluvial beds near the surface of the ground, as also to prevent the small perforation getting eventually filled with rubbish.

The cause of overflowing wells has been ascribed to various circumstances. But, as it is now generally admitted, that the numerous springs which issue from the ground proceed from the infiltration of the waters, progressively condensed in rain, dew, snow, &c., upon the surface of our globe, the theory of these interior streamlets becomes by no means intricate; being analogous to that of syphons and water-jets, as expounded in the treatises of physics. The waters are diffused, after condensation, upon the surface of the soil, and percolate downwards through the various pores and fissures of the geological strata, to be again united subterraneously in veins, rills, streamlets, or expanded films, of greater or less magnitude or regularity. The beds traversed by numerous disjunctions will give occasion to numerous interior currents, in all directions, which cannot be recovered and brought to the day; but when the ground is composed of strata of sand or gravel very permeable to water, separated by other strata nearly impervious to it, reservoirs are formed to our hand, from which an abundant supply of water may be spontaneously raised. In this case, as soon as the upper stratum is perforated, the waters may rise, in consequence of the hydrostatic pressure upon the lower strata, and even overflow the surface in a constant stream, provided the level from which they proceed be proportionably higher.

The sheets of water occur, principally, at the separation of two contiguous formations; and, if the succession of the geological strata be considered, this distribution of the water will be seen to be its necessary consequence. In fact, the lower beds are frequently composed of compact sandstone or limestone, and the upper beds of clay. In level countries, the formations being almost always in horizontal beds, the waters which feed the Artesian wells must come from districts somewhat remote, where the strata are more elevated, as towards the secondary and transition rocks. The copious streams, condensed upon the sides of these colder lands, may be therefore regarded as the proper reservoirs of our wells.

The situation of the intended well being determined upon, a circular hole is generally dug in the ground, about six or eight feet deep, and five or six feet wide. In the centre of this hole, the boring is carried on by two workmen below, assisted by a laborer above.

The tools used are variously formed, in the shape of drills, chisels, picks, &c., screwed upon the end of a handle which is capable of being lengthened, as the work proceeds. The whole is suspended from an elastic horizontal pole, which is firmly fixed, at one end, while the other end can be moved, up and down, by a workman, producing a vibrating, or picking, motion. At the same time, other workmen turn or vary the position of the drill, by means of a cross-bar, so that it acts as in the common mode of drilling rocks. The dirt and broken stones are drawn up, by an instrument shaped somewhat like an auger, which is inserted, from time to time, when the drill is withdrawn.

It is obvious, that placing and displacing the lengths of rod, which is done every time that the auger is required to be introduced or withdrawn, must, of itself, be extremely troublesome, independent of the labor of boring; but yet the operation proceeds, when no unpropitious circumstance attends it, with a facility almost incredible. Sometimes, however, rocks intercept the way, which require great labor to penetrate; but this is always effected by pecking, which slowly pulverizes the stone. The most unpleasant circumstance attendant upon this business is the occasional breaking of a rod into the hole, which sometimes creates a delay of many days, and an incalculable labor in drawing up the lower portion.

When the water is obtained, in such quantities and of such quality as may be required, the hole is dressed or finished, by passing down it a diamond chisel, funnel-mouthed, with a triangular bit in its centre; this makes the sides smooth, previous to putting in the pipe. This chisel is attached to rods, and to the handle, as before described, and in its descent, the workmen continually walk round, by which the hole is made smooth and cylindrical. In the progress of the boring, frequent veins of water are passed through; but, as these are small streams, and perhaps impregnated with mineral substances, the operation is carried on, until an aperture is made into a main spring, which will flow up to the surface of the earth. This must, of course, depend upon the level of its source, which, if in a neighboring hill, will frequently cause the water to rise up, and produce a continued fountain. But, if the altitude of the distant spring happens to be below the level of the surface of the ground, where the boring is effected, it sometimes happens, that a well of considerable capacity is obliged to be dug down to that level, in order to form a reservoir, into which the water may flow, and whence it must be raised by a pump; while, in the former instance, a perpetual fountain may be obtained. Hence, it will always be a matter of doubt, in level countries, whether water can be procured, which would flow near to, or over, the surface; if this cannot be effected, the process of boring will be of little or no advantage, except as an experiment, to ascertain the fact.

In order to keep the strata pure, and uncontaminated with mineral springs, the hole is cased, for a considerable depth, with a metallic pipe, about a quarter of an inch smaller than the bore. This is generally made of tin, though sometimes of copper or lead, in convenient lengths; and, as each length is let down, it is held by a shoulder resting in a fork, while another length is soldered to it; by which means a continuous pipe is carried through the bore, as far as may be found necessary, to exclude land-springs, and to prevent loose earth or sand from falling in, and choking the aperture.—*Ure's 'Dictionary of Arts,'* &c.

II.—Mines.

Amidst the variety of bodies, apparently infinite, which compose the crust of the globe, geologists have demonstrated the prevalence of a few general systems of rocks, to which they have given the names of *formations*, or *deposits*. A large proportion of these mineral systems consists of parallel planes, whose length and breadth greatly exceed their thickness ; on which account, they are called stratified rocks ; others occur in very thick blocks, without any parallel stratification, or horizontal seams, of considerable extent.

The stratiform deposits are subdivided into two great classes ; the primary, and the secondary. The former seem to have been called into existence, before the creation of organic matter, because they contain no exuviæ of vegetable or animal beings ; while the latter are more or less interspersed, and sometimes replete, with organic remains. The primary strata are characterized, moreover, by the nearly vertical, or highly inclined, position of their planes ; the secondary lie, for the most part, in a nearly horizontal position.

Where the primitive mountains graduate down into the plains, rocks of an intermediate character appear, which, though possessing a nearly vertical position, contain a few vestiges of animal beings, especially shells. These have been called *transition*, to indicate their being the passing links between the first and second systems of ancient deposits. They are distinguished by the fractured and cemented texture of their planes, for which reason they are sometimes called, conglomerate.

Between these, and the truly secondary rocks, another very valuable series is interposed, in certain districts of the globe ; namely, the coal-measures, the paramount formation of Great Britain. The coal strata are disposed in a basin form, and alternate with parallel beds of sandstone, slate-clay, iron-stone, and occasionally limestone. Some geologists have called the coal-measures the medial formation.

In every mineral plane, the inclination and direction are to be noted ; the former, being the angle which it forms with the horizon, the latter, the point of the azimuth, or horizon, towards which it dips, as west, northeast, south, &c. The direction of the bed is that of a horizontal line drawn in its plane ; and which is also denoted by the point of the compass. Since the lines of direction and inclination are at right angles to each other, the first may always be inferred from the second ; for when a stratum is said to dip to the east or west, this implies, that its direction is north and south.

The smaller sinuosities of the bed are not taken into account, just as the windings of a river are neglected, in stating the line of its course.

Masses are mineral deposits, not extensively spread in parallel planes, but irregular heaps, rounded or oval, enveloped, in whole or in a great measure, by rocks of a different kind. Lenticular masses being frequently placed between two horizontal, or inclined, strata, have been sometimes supposed to be stratiform themselves, and have been accordingly denominated by the Germans, *liegende stocke*, *lying heaps*, or *blocks*.

The orbicular masses often occur in the interior of unstratified mountains, or in the bosom of one bed.

Nests, *concretions*, *nodules*, are small masses found in the middle of strata ; the first being commonly in a friable state ; the second often kidney-shaped, or tuberous ; the third nearly round, and encrusted, like the kernel of an almond.

Lodes, or large veins, are flattened masses, with their opposite surfaces not parallel, which consequently terminate like a wedge, at a greater or less distance, and do not run parallel with the rocky strata in which they lie, but cross them, in a direction not far from the perpendicular ; often traversing several different mineral planes. The *lodes* are sometimes deranged in their course, so as to pursue, for a little way, the space between two contiguous strata; at other times they divide, into several branches. The matter which fills the lodes is, for the most part, entirely different from the rocks they pass through; or, at least, it possesses peculiar features.

This mode of existence, exhibited by several mineral substances, but which has been long known with regard to metallic ores, suggests the idea of clefts, or rents, having been made in the stratum, posterior to its consolidation and of the vacuities having been filled with foreign matter, either immediately, or after a certain interval. There can be no doubt, as to the justness of the first part of the proposition, for there may be observed, round many lodes, undeniable proofs of the movement or dislocation of the rock; for example, upon each side of the rent, the same strata are no longer situated in the same plane as before, but make greater or smaller angles with it; or the stratum upon one side of the lode is raised considerably above, or depressed considerably below, its counterpart, upon the other side. With regard to the manner in which the rent has been filled, different opinions may be entertained. In the lodes which are widest, near the surface of the ground, and graduate into a thin wedge, below, the foreign matter would seem to have been introduced, as into a funnel, at the top, and to have carried along with it, in its fluid state, portions of rounded gravel and organic remains. In other cases, other conceptions seem to be more probable; since many lodes are largest, at their under part, and become progressively narrower, as they approach the surface; from which circumstance it has been inferred, that the rent has been caused by an expansive force, acting from within the earth, and that the foreign matter, having been injected in a fluid state, has afterwards slowly crystallized. This hypothesis accounts, much better than the other, for most of the phenomena observable in mineral veins, for the alterations of the rock at their sides, for the crystallization of the different substances interspersed in them, for the cavities bestudded with little crystals, and for many minute peculiarities. Thus, the large crystals of certain substances, which line the walls of hollow veins, have sometimes their under surfaces besprinkled with small crystals of sulphurets, arseniurets, &c., while their upper surfaces are quite smooth ; suggesting the idea of a slow sublimation of these volatile matters from below, by the residual heat, and their condensation upon the under faces of the crystalline bodies, already cooled. This phenomenon affords a strong indication of the igneous origin of metalliferous veins.

In the lodes, the principal matters which fill them are to be distinguished from the accessory substances ; the latter being distributed, irregularly, amidst the mass of the first, in crystals, nodules, veins, seams, &c. The non-metalliferous exterior portion, which is often the largest, is called *gangue*, from the German *gang*, *vein*. The position of a vein is denoted, like that of the strata, by the angle of inclination, and the point of the horizon towards which they dip, whence the direction is deduced.

Veins are merely small lodes, which sometimes traverse the great ones, ramifying, in various directions, and in different degrees of tenuity.

A metalliferous substance is said to be *disseminated*, when it is dispersed in crystals, spangles, scales, globules, &c., through a large mineral mass.

Certain ores, which contain the metals most indispensable to human necessities, have been treasured up by the Creator in very bountiful deposits ; constituting either great masses in rocks of different kinds, or distributed in lodes, veins, nests, concretions, or beds, with stony and earthy admixtures ; the whole of which become the objects of mineral exploration. These precious stones occur in different stages of the geological formations, but their main portion, after having existed, abundantly, in the several orders of the primary strata, suddenly cease to be found, towards the middle of the secondary. Iron ores are the only ones which continue among the more modern deposits, even so high as the beds immediately beneath the chalk, when they also disappear, or exist merely as coloring matters of the tertiary earthy beds.

The strata of gneiss and mica-slate constitute, in Europe, the grand metallic domain. There is hardly any kind of ore, which does not occur there in sufficient abundance, to become the object of mining operations, and many are found nowhere else. The transition rocks, and the lower part of the secondary ones, are not so rich, neither do they contain the same variety of ores. But this order of things, which is presented by Great Britain, Germany, France, Sweden, and Norway, is far from forming a general law ; since in Equinoctial America, the gneiss is but little metalliferous ; while the superior strata, such as the clay-schists, the sienitic porphyries, the limestones, which complete the transition series, as also several secondary deposits, include the greater portion of the immense mineral wealth of that region of the globe.

All the substances, of which the ordinary metals form the basis, are not equally abundant in Nature ; a great proportion of the numerous mineral species, which figure in our classifications, are mere varieties, scattered up and down in the cavities of the great masses, or lodes. The workable ores are few in number, being mostly sulphurets, some oxides, and carbonates. These occasionally form, of themselves, very large masses ; but, more frequently, they are blended with lumps of quartz, feldspar, and carbonate of lime, which form the main body of the deposit ; as happens, always, in proper lodes. The ores, in that case, are arranged in small layers, parallel to the strata of the formation, or in small veins, which traverse the rock in all directions, or in nests, or concretions, stationed irregularly, or finally disseminated, in hardly visible particles. These deposits sometimes contain, apparently, only one species of ore, sometimes several, which must be mined together, as they seem to be of contemporaneous formation ; whilst, in other cases, they are separable, having been probably formed at different epochs.

Lodes, or mineral veins, are usually distinguished, by English miners, into at least four species. 1. The rake-vein ; 2. The pipe-vein ; 3. The flat, or dilated, vein ; and 4. The interlaced mass, (*stock-werke*,) indicating the union of a multitude of small veins, mixed, in every possible direction, with each other and with the rock.

1. The *rake* vein is a perpendicular mineral fissure ; and is the form best known among practical miners. It

commonly runs in a straight line, beginning at the superficies of the strata, and cutting them downwards, generally further than can be reached. This vein sometimes stands quite perpendicular; but it more usually inclines, or hangs over, at a greater or smaller angle, or slope, which is called, by the miners, the *hade*, or *hading*, of the vein. The line of direction in which the fissure runs is called, the *bearing of the vein.*

2. The *pipe* vein resembles, in many respects, a huge, irregular cavern, pushing forward into the body of the earth, in a sloping direction, under various inclinations, from an angle of a few degrees to the horizon, to a dip of forty-five degrees, or more. The pipe does not, in general, cut the strata across, like the rake-vein, but insinuates itself between them; so that, if the plane of the strata be nearly horizontal, the bearing of the pipe-vein will be conformable; but if the strata stand up at a high angle, the pipe shoots down, nearly headlong, like a shaft. Some pipes are very wide and high, others are very low and narrow, sometimes not larger than a common mine, or drift.

3. The *flat*, or *dilated*, vein is a space or opening, between two strata or beds of stone, the one of which lies above, and the other below, this vein, like a stratum of coal between its roof and pavement; so that the vein and the strata are placed in the same plane of inclination. These veins are subject, like coal, to be interrupted, broken, and thrown up or down, by slips, dykes, or other interruptions of the regular strata. In the case of a metallic vein, a slip often increases the chance of finding more treasure. Such veins do not preserve the parallelism of their beds, characteristic of coal-seams; but vary, excessively, in thickness, within a moderate space. Flat veins occur, frequently, in limestone, either in a horizontal or declining direction. The flat, or strata, veins open and close, as the rake-veins also do.

To these may be added, the *accumulated* vein, or irregular mass, (*butzenwerke*,) a great deposit, placed, without any order, in the bosom of the rocks, apparently filling up cavernous spaces.

The interlaced masses are more frequent in primitive formations, than in the others, and tin is the ore which most commonly affects this locality.

These *gangues*, such as quartz, calcareous spar, fluor spar, heavy spar, &c., and a great number of other substances, although of little or no value in themselves, become of great consequence to the miner, either by pointing out, by their presence, that of certain useful minerals, or by characterising, in their several associations, different deposits of ores, of which it may be possible to follow the traces, and to discriminate the relations, often of a complicated kind, provided we observe assiduously the accompanying *gangues*.

Mineral veins are subject to derangements, in their course, which are called shifts, or faults. Thus, when a transverse vein throws out, or intercepts a longitudinal one, we must commonly look for the rejected vein on the side of the obtuse angle, which the direction of the latter makes with that of the former. When a bed of ore is deranged by a fault, we must observe, whether the slip of the strata be upwards or downwards ; for, in either circumstance, it is only by pursuing the direction of the fault, that we can recover the ore ; in the former case, by mounting, in the latter, by descending, beyond the dislocation.

When two veins intersect each other, the direction of the *offcast* is a subject of interest, both to the miner and the geologist. In Saxony, it is considered as a general fact, that the portion thrown out is always upon the side of the obtuse angle, a circumstance which holds also in Cornwall ; and the more obtuse the angle, the out-throw is the more considerable. A vein may be thrown out, on meeting another vein, in a line which approaches either towards its inclination, or its direction. The Cornish miners use two different terms, to denote these two modes of rejection ; for the first case, they say the vein is *heaved ;* for the second, it is *started.*

GENERAL OBSERVATIONS ON THE LOCALITIES OF ORES AND ON THE INDICATIONS OF METALLIC MINES.

1. *Tin* exists, principally, in primitive rocks, appearing

either in interlaced masses, in beds, or as a constituent part of the rock itself, and, more rarely, in distinct veins. Tin ore is found indeed, sometimes, in alluvial land, filling up low situations between lofty mountains.

2. *Gold* occurs either in beds, or in veins, frequently in primitive rocks; though, in other formations, and particularly in alluvial earth, it is also found. When this metal exists in the bosom of primitive rocks, it is particularly in *schists*; it is not found in serpentine, but it is met with in gray-wacke, in Transylvania. The gold of alluvial districts, called gold of washing, or transport, occurs, as well as alluvial tin, among the debris of the more ancient rocks.

3. *Silver* is found, particularly in veins and beds, in primitive and transition formations; though some veins of this metal occur in secondary strata. The rocks, richest in it, are, gneiss, mica-slate, clay-slate, gray-wacke, and old alpine limestone. Localities of silver ore itself are not numerous, at least in Europe, among secondary formations; but it occurs in combination with the ores of copper, or of lead.

4. *Copper* exists in the three mineral epochas: 1. in primitive rocks, principally in the state of pyritous copper, in beds, in masses, or in veins; 2. in transition districts, sometimes in masses, sometimes in veins of copper pyrites; 3. in secondary strata, especially in beds of cupreous schist.

5. *Lead* occurs, also, in each of the three mineral epochas; abounding, particularly, in primitive and transition grounds, where it usually constitutes veins, and occasionally beds, of sulphuretted lead, (galena.) The same ore is found in strata, or in veins, among secondary rocks, associated, now and then, with ochreous iron-oxide and calamine, (carbonate of zinc,) and it is sometimes disseminated, in grains, through more recent strata.

6. *Iron* is met with, in four different mineral eras, but in different ores. Among primitive rocks, magnetic iron ore and specular iron ore occur chiefly in beds, sometimes of enormous size; the ores of red, or brown, oxide of iron (hæmatite) are found generally in veins, or, occa-

sionally, in masses with sparry iron, both in primitive and transition rocks; as also, sometimes, in secondary strata; but, more frequently, in the coal-measure strata, as beds of clay-ironstone, of globular iron-oxide, and carbonate of iron. In alluvial districts, we find ores of clay-ironstone, granular iron-ore, bog-ore, swamp-ore, and meadow-ore. The iron ores, which belong to the primitive period, have almost always the metallic aspect, with a richness amounting even to eighty per cent. of iron, while the ores in the posterior formations become, in general, more and more earthy, down to those in alluvial soils, some of which present the appearance of a common stone, and afford not more than twenty per cent. of metal, though its quality is often excellent.

7. *Mercury* occurs principally among secondary strata, in disseminated masses, along with combustible substances; though the metal is met with, occasionally, in primitive countries.

8. *Cobalt* belongs to the three mineral epochas; its most abundant deposits are veins in primitive rocks. Small veins, containing this metal, are found, however, in secondary strata.

9. *Antimony* occurs in veins, or beds, among primitive and transition rocks.

10, 11. *Bismuth* and *nickel* do not appear to constitute the predominating substance of any mineral deposits; but they often accompany cobalt.

12. *Zinc* occurs in the three several formations; namely, as sulphuret or blende, particularly in primitive and transition rocks; as calamine, in secondary strata, usually along with oxide of iron, and sometimes with sulphuret of lead.

An acquaintance with the general results, collected and classified by geology, must be our first guide in the investigation of mines. This enables the observer to judge, whether any particular district should, from the nature and arrangement of its rocks, be susceptible of including within its bosom, beds of workable ores. It indicates, also, to a certain degree, what substances may probably be met with in a given series of rocks, and what locality these substances will preferably affect For want of a knowledge of these facts, many persons have gone blindly into researches, equally absurd and ruinous.

Formerly, indications of mines were taken from very unimportant circumstances ; from thermal waters, the heat of which was gratuitously referred to the decomposition of pyrites ; from mineral waters, whose course is, however, often from a far distant source ; from vapours incumbent over particular mountain groups ; from the snows melting faster in one mineral district than another ; from the different species of forest trees, and from the greater or less vigor of vegetation, &c. In general, all such indications are equally fallacious with the divining rod, and the compass made of a lump of pyrites, suspended by a thread.

Geognostic observation has substituted more rational characters of metallic deposits, some of which may be called *negative*, and others *positive*.

The *negative* indications are derived from that peculiar geological constitution, which, from experience, or general principles, excludes certain metallic matters ; for example, granite, and, in general, every primitive formation, forbids the hope of finding within them combustible fossils, (pit-coal,) unless it be beds of anthracite ; there also it would be vain to seek for sal gem. It is very seldom that granite rocks include silver ; or limestones, ores of tin. Volcanic territories never afford any metallic ores worth the working ; nor do extensive veins usually run into secondary and alluvial formations. The richer ores of iron do not occur in secondary strata ; and the ores of this metal, peculiar to these localities, do not exist among primary rocks.

Among *positive* indications, some are proximate, and others remote. The proximate are, an efflorescence, so to speak, of the subjacent metallic masses ; magnetic attraction, for iron ores ; bituminous stone, or inflammable gas, for pit-coal ; the frequent occurrence of fragments of particular ores, &c. The remote indications consist in the geological epocha and nature of the rocks. From the examples previously adduced, marks of this kind acquire new importance, when, in a district susceptible of including deposits of workable ores, the *gangues*, or vein-stones, are met with, which usually accompany any particular metal. The general aspect of mountains, whose flanks present gentle and continuous slopes, the frequency of sterile veins, the presence of metalliferous sands, the neighborhood of some known locality of an ore, for instance, that of iron-stone, in reference to coal; lastly, the existence of salt springs and mineral waters may furnish some indications.

In speaking of remote indications, we may remark, that, in several places, and particularly near Clausthal, in the Hartz, a certain ore of red oxide of iron occurs above the most abundant deposits of the ores of lead and silver; whence it has been named by the Germans, the *iron-hat*. It appears that the iron ore, rich in silver, which is worked in America, under the name of *pacos*, has some analogy with this substance; but iron ore is, in general, so plentifully diffused on the surface of the soil, that its presence can be regarded as only a remote indication, relative to other mineral substances, except in the case of clay-iron-stone with coal.

Of the instruments and processes of subterranean operations.—It is by the aid of geometry, in the first place, that the miner studies the situation of the mineral deposits, on the surface, and in the interior, of the ground; determines the several relations of the veins and the rocks; and becomes capable of directing the perforations towards a suitable end.

The instruments are, 1. The magnetic compass, which is employed to measure the direction of a metallic ore, wherever the neighborhood of iron does not interfere with its functions. 2. The graduated semicircle, which serves to measure the inclination, which is also called the clinometer. 3. The chain, or cord, for measuring the distance of one point from another. 4. When the neighborhood of iron renders the use of the magnet uncertain, a plate, or plane table, is employed.

The dials of the compasses, generally used in the most celebrated mines, are graduated into hours; most commonly into twice twelve hours. Thus the whole limb is divided into twenty-four spaces, each of which contains fifteen degrees, equal to one hour. Each hour is subdivided into eight parts.

Means of penetrating into the interior of the earth.—In order to penetrate into the interior of the earth, and to extract from it the objects of his toils, the miner has at his disposal several means, which may be divided into three classes; 1. *manual tools*, 2. *gunpowder*, and 3. *fire*. The tools used by the miners of Cornwall and Devonshire are the following:

The *pick*. It is a light tool, and somewhat varied in shape, according to circumstances One side, used as a hammer, is called the *poll*, and is employed to drive in the *gads*, or to loosen and detach prominences. The *point* is of steel, carefully tempered, and drawn under the hammer to the proper form. The French call it *pointerolle*.

The *gad*. It is a wedge of steel, driven into crevices of rocks, or into small openings made with the point of the pick.

The *miner's shovel*. It has a pointed form, to enable it to penetrate among the coarse and hard fragments of the mine rubbish. Its handle being somewhat bent, a man's power may be conveniently applied, without bending his body. The *blasting*, or *shooting*, tools are, a sledge or mallet, borer, claying-bar, needle or nail, scraper, tamping-bar. Besides these tools, the miner requires a powder-horn, rushes to be filled with gunpowder, tin cartridges, for occasional use in wet ground, and paper rubbed over with gunpowder, or grease, for the *smifts*, or fuses.

The *borer* is an iron bar, tipped with steel, formed like a thick chisel, and is used by one man holding it straight in the hole, with constant rotation on its axis, while another strikes the head of it, with the iron sledge, or mallet. The hole is cleared out, from time to time, by the scraper, which is a flat iron rod, turned up at one end. If the ground be very wet, and the hole gets full of mud, it is cleaned out by a stick, bent at the end into a fibrous brush, called a *swab-stick*.

The hole must be rendered as dry as possible, which is effected very simply, by filling it partly with tenacious clay, and then driving into it a tapering iron rod, which nearly fills its calibre, called the *claying-bar*. This being forced in with great violence condenses the clay into all the crevices of the rock, and secures the dryness of the hole. Should this plan fail, recourse is had to tin cartridges, furnished with a stem, or tube, through which the powder may be inflamed. When the hole is dry, and the charge of powder introduced, the *nail*, a small taper rod of copper, is inserted, so as to reach the bottom of the hole, which is now ready for *tamping*. By this difficult and dangerous process, the gunpowder is confined, and the disruptive effect produced. Different substances are employed for *tamping*, or cramming the hole, the most usual one being any soft species of rock, free from silicious, or flinty, particles. Small quantities of it only are introduced at a time, and rammed very hard, by the *tamping-bar*, which is held steadily by one man, and struck with a sledge by another. The hole being thus filled, the nail is withdrawn, by putting a bar through its eye, and striking it upwards. Thus, a small perforation, or vent, is left for the rush which communicates the fire.

Besides the improved tamping-bar, faced with hard copper, other contrivances have been resorted to, for diminishing the risk of those dreadful accidents that frequently occur in this operation. Dry sand is sometimes used as a tamping material; but there are many rocks, for the blasting of which it is ineffective. Tough clay will answer better, in several situations. For conveying the fire, the large and long green rushes, which grow in marshy ground, are selected. A slit is made in one side of the rush, along which the sharp end of a bit of stick is drawn, so as to extract the pith, when the skin of the rush closes again, by its own elasticity. This tube is filled up with gunpowder, dropped into the vent-hole, and made steady with a bit of clay. A paper *smift*, adjusted to burn a proper time, is then fixed to the top of the rush tube, and kindled, when the men of the mine retire to a safe distance.

Gunpowder is the most valuable agent of excavation, possessing a power which has no limit, and which can act every where, even under water. Its introduction, in 1615, caused a great revolution in the mining art.

It is employed in mines, in different manners, and in different quantities, according to circumstances. In all cases, however, the process resolves itself into boring a hole, and enclosing a cartridge in it, which is afterwards made to explode. The hole is always cylindrical, and is usually made by means of the borer, a stem of iron terminated by a blunt-edged chisel. It sometimes ends in a cross, formed by two chisels set transversely. The workman holds the stem in his left hand, and strikes it with an iron mallet, held in his right. He is careful to turn the punch a very little round, at every stroke. Several punches are employed, in succession, to bore one hole; the first shorter, the latter ones longer, and somewhat thinner. The rubbish is withdrawn, as it accumulates at the bottom of the hole, by means of a picker, which is a small spoon, or disc of iron, fixed at the end of a slender iron rod. When holes of a large size are to be made, several men must be employed; one, to hold the punch, and one or more, to wield the iron mallet. The perforations are seldom less than an inch in diameter, and eighteen inches deep; but they are sometimes two inches wide, with a depth of fifty inches.

The gunpowder, when used, is most commonly put up in paper cartridges. Into the side of the cartridge, a small cylindrical spindle, or *piercer*, is pushed. In this state, the cartridge is forced down to the bottom of the hole, which is then stuffed, by means of the tamping-bar, with bits of dry clay, or friable stones coarsely pounded. The peircer is now withdrawn, which leaves in its place a channel, through which fire may be conveyed to the charge. This is executed, either by pouring gunpowder into that passage, or by inserting into it, reeds, straw-stems, quills, or tubes of paper, filled with gunpowder. This is exploded by a long match, which the workmen kindle, and then retire to a place of safety.

As the *piercer* must not only be slender, but stiff, so as to be easily withdrawn when the hole is tamped, iron spindles are usually employed, though they occasionally give rise to sparks, and, consequently, to dangerous accidents, by their friction against the sides of the hole. Brass piercers have been sometimes tried, but they twist and break too readily

Each hole bored in a mine should be so placed, in reference to the schistose-structure of the rock, and to its natural fissures, as to attack and blow up the least resisting masses. Sometimes, the rock is prepared, beforehand, for splitting in a certain direction, by means of a narrow channel, excavated with the small hammer.

The quantity of gunpowder should be proportional to the depth of the hole, and the resistance of the rock ; and merely sufficient to split it. Any thing additional would serve no other purpose than to throw the fragments about the mine, without increasing the useful effect. Into the holes of about an inch and a quarter diameter, and eighteen inches deep, only two ounces of gunpowder are put.

It appears, that the effect of the gunpowder may be augmented, by leaving an empty space above, in the middle of, or beneath, the cartridge. In the mines of Silesia, the consumption of gunpowder has been eventually reduced, without diminishing the product of the blasts, by mixing sawdust with it, in certain proportions. The hole has also been filled up with sand, in some cases, according to Mr. Jessop's plan, instead of being packed with stones, which has removed the danger of the tamping operation. The experiments, made in this way, have given results very advantageous, in quarry blasts, with great charges of gunpowder ; but less favorable, in the small charges employed in mines.

Water does not oppose an insurmountable obstacle to the employment of gunpowder ; but when the hole cannot be made dry, a cartridge bag, impermeable to water, must be used, provided with a tube, also impermeable, in which the *piercer* is placed.

After the explosion of each mining charge, wedges and levers are employed, to drag away, and break down, what has been shattered.

Wherever the rock is tolerably hard, the use of gunpowder is more economical, and more rapid, than any tool-work, and is, therefore, always preferred. A gallery, for example, a yard and a half high, and a yard wide, the piercing of which, by the hammer, formerly cost from five to ten pounds sterling the running yard, in Germany, is executed, at the present day, by gunpowder, at from two to three pounds. When, however, a precious mass of ore is to be detached; when the rock is cavernous, which nearly nullifies the action of gunpowder; or when there is reason to apprehend that the shock, caused by the explosion, may produce an injurious fall of rubbish, hand-tools alone must be employed.

In certain rocks and ores, of extreme hardness, the use, both of tools and gunpowder, becomes very tedious and costly. Examples to this effect are seen in the mass of quartz, mingled with copper pyrites, worked at Rammelsburg, in the Hartz; in the masses of stanniferous granite of Geyer and Altenberg, in the Erzgebirge of Saxony, &c. In these circumstances, fortunately very rare, the action of fire is used with advantage, to diminish the cohesion of the rocks and the ores. The employment of this agent is not necessarily restricted to these difficult cases. It was formerly applied, very often, to the working of hard substances; but the introduction of gunpowder into the mining art, and the increase in the price of wood, occasion fire to be little used as an ordinary means of excavation, except in places, where the scantiness of the population has left a great extent of forest-timber, as happens at Kongsberg in Norway, at Dannemora in Sweden, at Felsobanya in Transylvania, &c.

The action of fire may be applied to the piercing of a gallery, or to the advancement of a horizontal cut, or to the crumbling down of a mass of ore, by the successive upraising of the roof of a gallery already pierced. In any of these cases, the process consists in forming bonfires, the flame of which is made to play upon the parts to be attacked. All the workmen must be removed from the mine, during, and even for some time after, the combustion. When the excavations have become sufficiently cool to allow them to enter, they break down with levers and wedges, or even by means of gunpowder, the masses which have been rent and altered by the fire.

To complete our account of the manner in which man may penetrate into the interior of the earth, we must point out the form of the excavations that he should make in it.

In mines, three principal species of excavations may be distinguished, viz.; *shafts*, *galleries*, and the *cavities* of greater or less magnitude, which remain in the room of the old workings.

A *shaft*, or *pit*, is a prismatic, or cylindrical, hollow space, the axis of which is either vertical, or much inclined to the horizon. The dimension of the pit, which is never less than thirty-two inches in its narrowest diameter, amounts,sometimes,to several yards. Its depth may extend to one thousand feet, and more. Whenever a shaft is opened, means must be provided to extract the rubbish, which continually tends to accumulate at its bottom, as well as the waters, which may percolate down into it; as also to facilitate the descent and ascent of the workmen For some time a wheel and axle, erected over the mouth of the opening, which serve to elevate one or two buckets, of proper dimensions, may be sufficient for most of these purposes. But such a machine becomes, ere long, inadequate. Horse-whims, or powerful steam-engines, must then be had recourse to; and effectual methods of support must be employed, to prevent the sides of the shaft from crumbling, and falling down.

A *gallery* is a prismatic space, the straight or winding axis of which does not usually deviate much from the horizontal line. Two principal species are distinguished; the galleries of *elongation*, which follow the direction of a bed, or a vein; and the *transverse* galleries, which intersect this direction under an angle, not much different from ninety degrees. The most ordinary dimensions of galleries are a yard wide, and two yards high; but many, still larger, may be seen, transversing thick deposites of ore. There are few, whose width is less than twenty-four inches, and height less than forty; such small drifts serve merely as temporary expedients in workings. Some galleries are several leagues in length. We shall cescribe, in the sequel, the means which are, for the most part, necessary to support the roof and the walls. The rubbish is removed by wagons, or wheel-barrows, of various kinds

It is impossible to advance the boring of a shaft, or gallery, beyond a certain rate ; because only a limited set of workmen can be made to bear upon it.

There are some galleries which have taken more than thirty years to perforate. The only expedient for accelerating the advance of a gallery, is, to commence, at several points of the line to be pursued, portions of galleries, which may be joined together on their completion.

Whether tools, or gunpowder, be used, in making the excavations, they should be so applied, as to render the labor as easy and quick as possible, by disengaging the mass out of the rock, at two or three of its faces. The effect of gunpowder, wedges, or picks, is then much more powerful. The greater the excavation, the more important is it to observe this rule. With this intent, the working is disposed in the form of *steps*, (*gradins*,) placed like those of a stair ; each step being removed, in successive portions, the whole of which, except the last, are disengaged on three sides, at the instant of their being attacked.

The substances to be mined occur in the bosom of the earth, under the form of alluvial deposits, beds, pipe-veins or masses, threads or small veins, and rake-veins.

When the existence of a deposit of ore is merely suspected, without positive proofs, recourse must be had to labors of research, in order to ascertain the richness, nature, and disposition, of a supposed mine. These are divided into three kinds ; *open workings*, *subterranean workings*, and *boring operations*.

1. The *working by an open trench* has for its object to discover the outcropping, or basset edges of strata, or veins. It consists in opening a fosse of greater or less width, which, after removing the vegetable mould, the alluvial deposits, and the matters disintegrated by the atmosphere, discloses the native rocks, and enables us to distinguish the beds, which are interposed, as well as the veins which traverse them ; the trench ought always to be opened in a direction perpendicular to the line of the supposed deposit. This mode of investigation costs little

but it seldom gives much insight. It is chiefly employed for verifying the existence of a supposed bed, or vein.

The *subterranean workings* afford much more satisfactory knowledge. They are executed by different kinds of perforations; viz. by *longitudinal galleries*, hollowed out of the mass of the beds or veins themselves, in following their course; by *transverse galleries*, pushed at right angles to the direction of the veins; by *inclined shafts*, which pursue the slope of the deposits, and are excavated in their mass; or, lastly, by *perpendicular pits*.

If a vein or bed unveils itself on the flank of a mountain, it may be explored, according to the greater or less slope of its inclination, either by a longitudinal gallery, opened in its mass from the outcropping surface, or by a transverse gallery, falling upon it in a certain point, from which either an oblong gallery, or a sloping shaft, may be opened.

If our object be to reconnoitre a highly inclined stratum, or a vein in a level country, we shall obtain it, with sufficient precision, by means of shafts, eight or ten yards deep, dug at thirty yards distance from one another, excavated in the mass of ore, in the direction of its deposit. If the bed is not very much inclined, only forty-five degrees, for example, vertical shafts must be opened in the direction of its roof, or of the superjacent rocky stratum, and galleries must be driven from the points in which they meet the ore, in the line of its direction.

When the rocks, which cover valuable minerals, are not of very great hardness, as happens generally with the coal formation, with pyritous and aluminous slates, sal gem, and some other minerals of the secondary strata, the *borer* is employed with advantage, to ascertain their nature. This mode of investigation is economical, and gives, in such cases, a tolerably exact insight into the riches of the interior. The method of using the borer has been described under *Artesian Wells.—Ure's* '*Dict. of Arts*,' *&c.*

III.—Depth of Mines.

At the third meeting of the British Association, Mr. Taylor exhibited a section, showing the depths of shafts of the deepest mines in the world, and their position in relation to the level of the sea.

The absolute depths of the principal ones were:

		Feet.
1.	The shaft, called Roehrobichel, at the Kitspühl mine, in the Tyrol,	2764
2.	At the Sampson mine, at Andreasberg, in the Hartz,	2230
3.	At the Valenciana mine, at Guanaxuato, Mexico,	1770
4.	Pearce's shaft, at the Consolidated mines, Cornwall,	1464
5.	At Wheal Abraham mine, Cornwall,	1452
6.	At Dolcoath mine, Cornwall,	1410
7.	At Ecton mine, Staffordshire,	1380
8.	Woolf's shaft, at the Consolidated mines,	1350

These mines are, however, very differently situated, with regard to their distance from the centre of the earth; as the last on the list, Woolf's shaft, at the Consolidated mines, has twelve hundred and thirty feet of its depth below the surface of the sea; while the bottom of the shaft of Valenciana, in Mexico, is near six thousand feet in absolute height above the tops of the shafts in Cornwall. The bottom of the shaft, at the Sampson mine, in the Hartz, is but a few fathoms under the level of the ocean; and this, and the deep mine of Kitspühl, form, therefore, intermediate links between those of Mexico and Cornwall.

Mr. Taylor stated, that, taking the diameter of the earth at eight thousand miles, and the greatest depth under the surface of the sea being twelve hundred and thirty feet, or about one fourth of a mile, it follows, that we have only penetrated to the extent of $\frac{1}{32000}$ part of the earth's diameter.

IV.—Canals in the United States.

The Americans have not rested satisfied with the natural inland navigation afforded by their rivers and lakes, nor made the bounty of Nature a plea for idleness, or want of energy; but, on the contrary, they have been zealously engaged in the work of internal improvement; and their country now numbers, among its many wonderful artificial lines of communication, a mountain rail-way, which, in boldness of design, and difficulty of execution, I can compare to no modern works I have ever seen, excepting, perhaps, the passes of the Simplon, and Mont Cenis, in Sardinia; but even these remarkable passes, viewed as engineering works, did not strike me as being more wonderful than the Alleghany rail-way, in the United States.

The objects, to which that enterprising people have chiefly directed their exertions for the advancement of their country in the scale of civilization, are, the removal of obstructions in navigable rivers; the junction of different tracts of natural navigation; the connection of large towns; and the formation of lines of communication from the Atlantic ocean to the great lakes, and the valleys of the Mississippi, Missouri, and Ohio. The number and extent of canals and rail-ways which they have executed, in effecting these important objects, sufficiently prove, that their exertions, during the short time they have been so engaged, have been neither small nor ill-directed. The aggregate length of the canals, at present in operation in the United States alone, amounts to upwards of two thousand seven hundred miles, and that of the rail-ways, already completed, to sixteen hundred miles. Nor are the labors of the people at an end; for, even now, there are no fewer than thirty-three rail-ways in an unfinished state, whose aggregate length, when completed, will amount to upwards of two thousand five hundred miles.

The zeal with which the Americans undertake, and the rapidity with which they carry on, every enterprise, which has the enlargement of their trade for its object, cannot fail to strike all, who visit the United States, as a characteristic of the nation. Forty years ago, that country was almost without a lighthouse, and now, no fewer than two hundred are nightly exhibited on its coast; thirty years ago, it had but one steamboat, and one short canal, and now, its rivers and lakes are navigated by between five and six hundred steamboats, and its canals are upwards of two thousand seven hundred miles in length; ten years ago, there were but three miles of rail-way in the country, and now, there are no less than sixteen hundred miles in operation. These facts appear much more wonderful, when it is considered, that many of these great lines of communication are carried for miles in a trough, as it were, cut through thick and almost impenetrable forests, where it is no uncommon occurrence to travel for a whole day, without encountering a village, or even a house, excepting, perhaps, a few log-huts, inhabited by persons connected with the works.

The routes of the principal canals and rail-roads in North America are not wholly confined to the seaward and more thickly-peopled States, but extend far into the interior. The stupendous canals, which have already been executed, enable vessels, suited to the inland navigation of the country, to pass from the Gulf of St. Lawrence to the Gulf of Mexico, and also from the city of New York to Quebec, on the St. Lawrence, or to New Orleans, on the Mississippi, without encountering the dangers of the Atlantic ocean. But, that the reader may be able fully to understand the nature of lines of inland navigation, so enormous, I shall give, in detail, the route from New York to New Orleans, which is constantly made by persons travelling between those places.

	Miles.
From New York to Albany, by the River Hudson, the distance is, ...	150
" Albany to Buffalo, by the Erie Canal, ...	363
" Buffalo to Cleveland, by Lake Erie, ...	210
" Cleveland to Portsmouth, by the Ohio Canal, . . .	309
" Portsmouth to New Orleans, by the Ohio and Mississippi Rivers, ...	1670
Total distance, . . .	2702

This extraordinary inland journey, of no less than two thousand seven hundred and two miles, is performed entirely by means of water-communication; six hundred and seventy-two miles of the journey are performed on canals, and the remaining two thousand and thirty miles of the route is river and lake navigation.

The internal improvements of the United States are placed under the management either of the Legislatures of the States, in which the works are situate, or of joint-stock companies. The works constructed by the Legislatures of the States, are called State Works, and are conducted by commissioners, chosen from the different

Legislatures, who publish annual reports on the works committed to their charge. The joint-stock companies, on the other hand, are composed of private individuals, who receive a charter from the Government, investing them with power to execute the work, and afterwards to conduct the affairs and transact the business of the company. The public works in the British dominions in North America have been executed, partly, at the expense, and under the direction, of the British Government, and partly, by companies of private individuals.

It is believed that canals, which were, until very lately, the only mode of conveyance employed in North America, were in use in Egypt, China, Ceylon, Italy, and Holland, before the Christian era; but the period, at which the first artificial water-communication was formed, and the country, in which the construction of a canal was first attempted, are equally unknown. The earliest canal constructed in France was the Languedoc, connecting the Bay of Biscay with the Mediterranean Sea, which was completed in the year 1681; and the first formed in Great Britain was that of Sankey Brook, in Lancashire, completed in 1760. Several short canals were made, for improving the river navigation, in the United States, about the end of the last century; but the first work of any importance, in that country, was the Santee canal, in the State of South Carolina, which was opened in the year 1802; and the first, in the British dominions in America, was the Lachine canal, in Lower Canada, opened in the year 1821. At the end of this chapter is a table of the principal canals in the United States. The table, which is compiled from the American almanacs, and the annual reports of the canal commissioners, contains the names of all the canals of any importance, now in operation in the country; together with such information, regarding their size and expense, as these documents contain.

The great length of many of the American canals is one remarkable feature in these astonishing works. In this respect, they far surpass any thing of the kind hitherto constructed in Europe. The longest canal in Europe is the Languedoc, which has a course of one hundred and forty-eight miles; and the most extensive in the United States is the Erie canal, which is no less than three hundred and sixty-three miles in length. But the cross-sectional area of the American canals is by no means so great as that of many in Europe. The North Holland Ship canal, for example, between the Zuyder Zee, at Amsterdam, and the Helder, which I lately visited, has a larger cross-sectional area, than any other European work of the same description. It measures one hundred and twenty-four feet six inches, at the water-line, and affords sufficient breadth to allow large vessels to pass each other with perfect ease. It is fifty-six feet in breadth, at the bottom, and has a depth of water of no less than twenty-one feet. This remarkable canal, which is nearly fifty miles in length, undoubtedly ranks as one of the greatest works of the kind that has ever been executed. It was constructed for the purpose of facilitating the passage of vessels to and from the port of Amsterdam; and, by means of the sheltered inland passage which it affords, the intricate and dangerous navigation of the Zuyder Zee is avoided. At the time when canals were introduced into America, however, the trade of the country was small, and did not warrant the expenditure of large sums of money in their construction, the chief object being to form a communication, with as little loss of time, or outlay of capital, as might be consistent with a due regard for the safety and stability of the work. It is not to be expected, therefore, that the American works, although on an extensive scale, should be constructed in the same spacious style as those of older and more opulent countries. The dimensions of many of the canals in the United States are now found to be inconveniently small, for the increased traffic which they have to support; and the great Erie canal, as well as some others, is at present undergoing extensive alterations, by which its breadth will be increased from forty to sixty feet, and its depth from four to seven feet. It is doubtful whether the increased depth will, on the whole, prove advantageous, especially for quick transport. According to Mr. Russell, the velocity of the wave due to a depth of four feet, making allowance for the sloping sides of the canal, is about seven miles an hour; and if the boat is dragged in the top of the wave, the horses must travel at somewhat more than this rate, in order to keep before it. If, on the other hand, the depth of the canal be seven feet, the velocity of the wave will be about nine miles an hour; a speed which it would be difficult for horses regularly to keep up. The boat would, consequently, travel at a less speed than the wave, which is shown by Mr. Russell, in his 'Researches in Hydrodynamics,' to be very disadvantageous.

English and American engineers are guided by the same principles in designing their works; but the different nature of the materials employed in their construction, and the climates and circumstances of the two countries, naturally produce a considerable dissimilarity in the practice of civil-engineers in England and America. At the first view, one is struck with the temporary and apparently unfinished state of many of the American works, and is very apt, before inquiring into the subject, to impute to want of ability what turns out, on investigation, to be a judicious and ingenious arrangement to suit the circumstances of a new country, of which the climate is severe,—a country, where stone is scarce, and wood is plentiful, and where manual labor is very expensive. It is vain to look to the American works for the finish, that characterizes those of France, or the stability, for which those of Britain are famed. Undressed slopes of cuttings and embankments, roughly-built rubble-arches, stone parapet-walls coped with timber, and canal-locks wholly constructed of that material, every where offend the eye accustomed to view European workmanship. But it must not be supposed that this arises from want of knowledge of the principles of engineering, or of skill to do them justice in the execution. The use of wood, for example, which may be considered, by many, as wholly inapplicable to the construction of canal-locks, where it must not only encounter the tear and wear occasioned by the lockage of vessels, but must be subject to the destructive consequences of alternate immersion in water and exposure to the atmosphere, is yet the result of deliberate judgement. The Americans have, in many cases, been induced to use the material of the country, ill adapted though it be, in some respects, to the purposes to which it is applied, in order to meet the wants of a rising community, by speedily, and perhaps superficially, completing a work of importance, which would otherwise be delayed, from a want of the means to execute it in a more substantial manner ; and, although the works are wanting in finish, and even in solidity, they do not fail for many years to serve the purposes for which they were constructed, as efficiently as works of a more lasting description.

When the wooden locks on any of the canals begin to show symptoms of decay, stone structures are generally substituted ; and materials, suitable for their erection, are with ease and expedition conveyed from the part of the country where they are most abundant, by means of the canal itself to which they are to be applied ; and thus the less substantial work ultimately becomes the means of facilitating its own improvement, by affording a more easy, cheap, and speedy transport of those durable and expensive materials, without the use of which, perfection is unattainable.

One of the most important advantages of constructing the locks of canals, in new countries, such as America, of wood, unquestionably is, that, in proportion as improvement advances, and greater dimensions, or other changes, are required, they can be introduced at little cost, and without the mortification of destroying expensive and substantial works of masonry. Some of the locks on the great Erie canal are formed of stone ; but, had they all been made of wood, it would, in all probability, have been converted into a ship-canal, long ago.

But the locks are not the only parts of the American canals in which wood is used. Aqueducts, over ravines or rivers, are generally formed of large wooden troughs, resting on stone pillars ; and even more temporary expedients have been chosen, the ingenuity of which can hardly fail to please those who view them as the means of carrying on improvements, which, but for such contrivances, might be stopped by the want of funds necessary to complete them.

Mr. M'Taggart, the resident engineer for the Rideau canal in Canada, gave a good example of the extraordinary expedients often resorted to, by suggesting a very novel scheme for carrying that work across a thickly wooded ravine, situate in a part of the country where materials for forming an embankment, or stone for building the piers of an aqueduct, could not be obtained but at a great expense. The plan consisted of cutting across the large trees in the line of the works, at the level of the bottom of the canal, so as to render them fit for supporting a platform on their trunks, and on this platform the trough containing the water of the canal was intended to rest. I am not aware whether this plan was carried into effect; but it is not more extraordinary than many of the schemes to which the Americans have resorted, in constructing their public works; and the great traffic sustained by many of them, notwithstanding the temporary and hurried manner in which they are finished, is truly wonderful. The number of boats navigating the Erie canal, in 1836, was no less than three thousand one hundred and sixty-seven, and the average number of lockages, one hundred and eighteen per day; facts which clearly prove the efficiency, as well as the utility, of the work.

With the exception of some few works, in the most southern States of the Union, the artificial navigation of North America, as well as that of the northern rivers and lakes, is completely suspended during a period of from three to five months, every year. During that time, the water is always withdrawn from the canals and feeders. This precaution is absolutely necessary, as the intense frost, with which the country is then visited, very soon proves destructive to the locks and aqueducts, by the expansion of the water, which, if permitted to remain in them, is speedily converted into a mass of ice.

The rate of travelling, which has been adopted on the American canals, the charges for the conveyance of passengers and goods, and the general laws for regulating canal transport, are fixed by the commissioners who have charge of the different works, and are not exactly the same in every State. The following observations, however, regarding the mode of travelling on the Pensylvania State canals, are generally applicable to all others in the country.

The tolls paid to the State, by the persons who have boats on these canals, are three halfpence per mile for each boat, and three farthings per mile for each passenger conveyed in them. The passenger-boats vary from twelve to fifteen feet in breadth, and are eighty feet in length; the large-sized boats weigh about twenty tons, and cost £250 each, and, when loaded with a full complement of passengers, draw twelve inches of water. They are dragged by three horses at once, which run ten-mile stages. The length of the tow-line, generally used, is about one hundred and fifty feet, and the rate of travelling is from four to four and a half miles per hour.

The works, which have been employed in forming the inland lines of water-communication in America, are of two kinds, called slackwater-navigation, and canals. The slackwater-navigation is the more simple of these operations, and can generally be executed at less expense. It consists in improving the navigation of a river by the erection of dams, or mounds, built in the stream, which have the effect of damming up the water, and increasing its depth. If there be not a great fall in the bed of the river, a single dam often produces a stagnation in the run of the water, extending for many miles up the river, and forming a spacious navigable canal. The tow-path is formed along the margin of the river, and is elevated above the reach of flood-water. The dams are passed by means of locks, such as are used in canals. This method of forming water-communication, has been extensively and successfully introduced in America, where limited means, and abundance of rivers, rendered it peculiarly applicable. One of the most extensive works, on this principle, in the country, was constructed by the Schuylkill Navigation Company, in the State of Pennsylvania, and consisted in damming up the water of the river Schuylkill. It extends from Philadelphia to Reading, and is situate in the heart of a country abounding in coal, from the transport of which, the Company derives its chief revenue. It is one hundred and eight miles in length, and its construction cost about £500,000. This line of navigation is formed by numerous dams thrown across the stream, with twenty-nine locks, which overcome a fall of six hundred and ten feet. It is navigated by boats of from fifty to sixty tons burden. These dams are constructed somewhat on the same principle as that erected on the Schuylkill, at Fairmount Water-works, near Philadelphia.

One great objection, to this mode of forming inland navigation, is the necessity of constructing works of great strength, sufficient to enable them to withstand the floods and ice, to which they are exposed, and by which they are very apt to be damaged, or even carried away. Accidents of this kind, however, may be in a great measure guarded against, by making a judicious selection of situations for the dams and locks, and placing them in such a manner in the bed of the river, that the current may act on them in the direction least detrimental to their stability, as has been done in the dam at Fairmount Water-works, just alluded to.

The number of boats, which passed through the locks of the Schuylkill navigation, in 1836, was twenty-four thousand four hundred and seventy, the tolls on which amounted to £14,043. The various articles taken up the river, during that year, weighed sixty-one thousand and seventy-nine tons, and those brought towards the sea, five hundred and seventy thousand and ninety-four tons, of which four hundred and thirty-two thousand and forty-five tons were anthracite coal, from the State of Pennsylvania.

Slackwater-navigation also occurs at intervals on many of the great lines of canal. About seventy-eight miles of the Rideau canal, in Canada, are formed in this way ; and in the United States, it is met with on the Erie, Oswego, Pennsylvania, Frankston, Lycoming, and Lehigh canals. The works which have been executed, in forming most of the water-communications, in America, however, are not generally of the slackwater kind, but resemble the canals in use in Europe, being, in fact, artificial trenches or troughs, with locks to enable vessels to pass from one evel to another. The locks are furnished with boom-gates, which are opened and shut by a long lever fixed to the tops of the quoin and mitre posts. The sluices, by which the water is admitted into the locks, are placed in the lower part of the gates. They are, in general, common hinge-sluices, opened by means of a rod extending to the top of the gates, and worked by a crank handle.

The canals of this construction, in the United States, are so very numerous, and resemble each other so much, that I do not consider it necessary to give a detailed description of the various works which have been executed on all of them, but shall content myself with giving a brief sketch of the Erie canal, which was the first in America, on which the conveyance of passengers was attempted, and is the longest canal in the world, regarding which we possess accurate information.

The Erie canal was commenced in 1817, and completed in 1825. The main line, leading from Albany, on the Hudson, to Buffalo, on Lake Erie, measures 363 miles in length, and cost about £1,400,000 sterling. The Champlain, Oswego, Chemung, Cayuga, and Crooked Lake, canals, and some others, join the main line, and, including these branch canals, it measures five hundred and forty-three miles in length, and cost upwards of £2,300,000. This canal is forty feet in breadth, at the water line, twenty-eight feet, at the bottom, and four feet in depth. Its dimensions have proved too small for the extensive trade which it has to support, and workmen are now employed in raising its banks, so as to increase the depth of water to seven feet, and the extreme breadth of the canal to sixty feet. The country through which it passes, is admirably suited for canal-navigation, and there are only eighty-four locks on the main line. These locks are each ninety feet in length, and fifteen in breadth, and have an average lift of eight feet two inches. The total rise and fall is six hundred and ninety-two feet. The tow-path is elevated four feet above the level of the water, and is ten feet in breadth. The Erie canal begins at Buffalo, on Lake Erie, and extends for a distance of about ten miles along the banks of Lake Erie and the river Niagara, as far as Tonawanda creek. By means of the slackwater-navigation, formerly described, the channel of the Tonawanda is rendered navigable for the distance of twelve miles, and the canal is then carried through a deep cutting, extending seven and a half miles, to Lockport. Here it descends sixty feet, by means of five locks excavated in solid rock, and afterwards proceeds, on a uniform level, for a distance of sixty-three miles, to Genesee river, over which it is carried on an aqueduct having nine arches, of fifty feet span, each. Eight and a half miles from this point, it passes over the Cayuga marsh, on an embankment two miles in length, and, in some places, seventy feet in height. It then passes through Lakeport and Syracuse, and, at this place, the "long level" commences, which extends for a distance of no less than sixty-nine and a half miles, to Frankfort, without an intervening lock. After leaving Frankfort, the canal crosses the river Mohawk, first by an aqueduct, of seven hundred and forty-eight feet in length, supported on sixteen piers, elevated twenty-five feet above the surface of the river, and afterwards, by another aqueduct, one thousand one hundred and eighty-eight feet in length, and at last reaches the city of Albany.

Albany is the capital of the State of New York, and contains a population of about thirty thousand. It is situate on the west, or right, bank of the Hudson, at the head of the natural navigation of the river; but some improvements have been made, which enable vessels of small burden to ascend as far as Waterford, thirteen miles above Albany. One of these improvements has been effected by the erection of a dam across the Hudson, eleven hundred feet in length, and nine feet in height, at a cost of upwards of £18,000. The lock, connected with this dam, measures one hundred and fourteen feet in length, and thirty feet in breadth. Albany, however, may be said to monopolize the trade of the river, and, in addition to the interest it possesses as a place of great commerce, it is important from its position at the outlet of the Erie canal, and as the seat of a large basin, or depôt, for the accommodation of the boats navigating it. This basin, which has an area of thirty-two acres, is formed by an enormous mound, placed lengthwise with the stream of the river Hudson, and enclosing a part of its surface. The mound is composed, chiefly, of earth, and is four thousand three hundred feet in length, and eighty feet in breadth, and, being completely covered with large warehouses, it now forms a part of the city of Albany, with which it is connected by means of numerous drawbridges. The place has, in consequence, very much the same appearance as many of the Dutch towns. The lower extremity of the mound is unconnected with the shore, a large passage being left for the ingress and egress of vessels; but its upper end is separated from the bank of the river, by a smaller opening, which is closed, when necessary, to prevent ice from injuring the craft lying in the basin. A stream of water is generally allowed to enter at the upper end, which, flowing through the basin, acts as a scour, and prevents it from silting up. The mound is surrounded by a wooden wharf, like those of New York and Boston, at which vessels discharge and load their cargoes. This admirable basin forms a part of the Erie canal works, and cost about £26,000.

According to the Report of the Canal Commissioners, dated March, 1837, the number of boats, registered in the Comptroller's office, as navigating the Erie canal and its branches, was,

In 1834,	.	2,585		
" 1835,	.	2,914	Increase,	329
" 1836,	.	3,167	"	253

The total number of clearances, or trips made during the same years, was,

In 1834,	.	64,794
" 1835,	.	69,767
" 1836,	.	67,270

The average number of lockages, per day, at each lock was,

In 1834,	.	95½
" 1835,	.	112
" 1836.	.	118

The whole tonnage, transported on the canal, during the year 1836, was 1,310,807 tons, the value of which amounted to $67,643,343, or £13,526,868. The proportion between the weight of freight, conveyed from the Hudson to the interior of the country, and that conveyed from the interior of the country to the Hudson, was in the ratio of one to five. The tolls, collected in 1836, for the conveyance of goods and passengers, amounted to £322,867. The rates of charge, according to which the tolls are collected, are annually changed, to suit the circumstances of the trade, and are not the same throughout the whole line of the canal, which renders it difficult to give a view of them. In 1836, the passage-money from Albany to Buffalo, in the packet-boat, was £3 3*s*., being at the rate of nearly 2*d*. per mile; and in a line-boat, which is an inferior conveyance, £1 18*s*., being at the rate of one penny and two tenths per mile. The expenditure for keeping the canal and its branches in repair, during 1836, was $410,236, or about £82,047; which, taking the whole length at five hundred and forty-three miles, gives an average of £151 per mile. The average cost of repairs, for the six preceding years, amounted to £136 per mile.

Before leaving the subject of canals, I must not omit to mention the Morris canal, in the State of New Jersey. This canal leads from Jersey, on the Hudson, to Easton, on the Delaware, and connects these two rivers. The breadth, at the water line, is thirty-two, and at the bottom, sixteen, feet, and the depth is four feet. It is one hundred and one miles in length, and is said to have cost about £600,000. It is peculiar, as being the only canal in America, in which the boats are moved from different levels by means of inclined planes, instead of locks, a construction, which was first introduced on the Duke of Bridgewater's canal, in England. The whole rise and fall, on the Morris canal, is one thousand five hundred and fifty-seven feet, of which two hundred and twenty-three feet are overcome by locks, and the remaining one thousand three hundred and thirty-four feet, by means of twenty-three inclined planes, having an average lift of fifty-eight feet each. The boats, which navigate this canal, are eight and one half feet in breadth of beam, from sixty to eighty feet in length, and from twenty-five to thirty tons burden. The greatest weight ever drawn up the planes is about fifty tons. The boat-car used on this canal, consists of a strongly made wooden crib, or cradle, on which the boat rests, supported on two iron wagons running on four wheels. When the car is wholly supported on the inclined plane, or is resting on a level, the four axles of the wagons are all in the same plane; but when one of the wagons rests on the inclined plane, and the other on the level surface, their axles no longer remain in the same plane, and their change of position produces a tendency to rack the cradle, and the boat which it supports; but this has been guarded against, in the construction of the boat-cars on the Morris canal, by introducing two axles, on which the whole weight of the crib and boat are supported, and on which the wagons turn, as a centre. The cars run on plate-rails, laid on the inclined planes, and are raised and lowered by means of machinery driven by water-wheels. The rail-way, on which the car runs, extends for a short distance from the lower extremity of the plane, along the bottom of the canal. When a boat is to be raised, the car is lowered into the water, and the boat being floated over it, is made fast to the part of the framework which projects above the gunwale. The machinery is then put in motion; and the car, bearing the boat, is drawn by a chain to the top of the inclined plane, at which there is a lock for its reception. The lock is furnished with gates, at both extremities; after the car has entered it, the gates next the top of the inclined plane are closed, and, those next the canal being opened, the water flows in and floats the boat off the car, when she proceeds on her way. Her place is supplied by a boat travelling in the opposite direction, which enters the lock, and the gates next the canal being closed, and the water run off, she grounds on the car. The gates next the plane are then opened, the car is gently lowered to the bottom, when it enters the water, and the boat is again floated. The principal objection, urged against the use of inclined planes, in canal navigation, for moving boats from different levels, is founded on the injury which the boats are apt to sustain in supporting great weights, while resting on the cradle, during its passage over the planes. It can hardly be supposed that a slimly-built canal-boat, measuring from sixty to eighty feet in length, and loaded with a weight of twenty or thirty tons, can be grounded, even on a smooth surface, without straining and injuring her timbers; a circumstance which is a decided objection to this mode of construction, and has operated powerfully in preventing its introduction in many situations, both in this country and in America. But, notwithstanding this objection, the twenty-three inclined planes on the Morris canal are in full operation, and act exceedingly well. No pains have been spared to render the machinery connected with them as perfect as possible, and the greatest credit is due to the engineer for the success which has hitherto attended the operation.—*Stevenson's 'Sketches of Civil Engineering in North America.'*

TABLE of the Principal Canals and Lines of Slack-water Navigation, constructed in the United States, up to the year 1840, inclusive. Compiled from the Reports of the Canal Companies, the American Almanac, and other sources.

The Canals marked thus * are State Canals; the others have been executed by Joint Stock Companies.

Names of the Canals.	Remarks.	Number of Locks.	Whole Height of Lockage in feet.	When opened.	Length in Miles.	Whole length in each State.	Reported Cost.
	MAINE.						
Cumberland and Oxford,	From Portland to Sebago Pond,	26	. .	1829	20½	50	£50,000 (both)
Saco River,	Slack-water navigation,	. .	. .	1829	29½		
	NEW HAMPSHIRE.						
Merrimack,	To obviate Falls on the Merrimack, four in number,	23	121	1812	11	11	28,400
	MASSACHUSETTS.						
Middlesex,	Boston Harbor to the River Merrimack; breadth at surface 30 feet, at bottom 20 feet, depth 3 feet,	20	136	1808	27		105,600
Blackstone,	Worcester to Providence,	. .	. .	1828	45		120,000
Hampshire and Hampden,	Farmington Canal to Northampton,	. .	. .	. .	22		
South Hadley,	To obviate Falls on the River Connecticut,	. .	. .	1792	2		
Montague,	Do. do. do.	. .	. .	. .	3	99	
	CONNECTICUT.						
Farmington,	New Haven to the Hampshire and Hampden Canal,	. .	. .	1831	54		600,000
Enfield,	To obviate Falls on the River Connecticut,	. .	. .	. .	5½	59½	
	Carry forward,	. .	. .	. .	. .	219½	

NAMES OF THE CANALS.	REMARKS.	Number of Locks.	Whole Height of Lockage in feet.	When opened.	Length in Miles.	Whole length in each State.	Reported Cost.
	Brought forward,	. .	. .	. .	. .	219½	
	NEW YORK.						
*Erie,	Albany to Buffalo,	84	. .	1825	363		£1,428,757
*Champlain,	Albany to Whitehall (with Feeder,)	34	. .	1824	76		235,994
*Oswego,	Syracuse and Oswego (one half Canal and one half Slackwater-navigation,)	14	. .	1828	38		113,087
*Cayuga and Seneca,	Geneva on Seneca Lake to Montezuma on the Erie Canal,	11	. .	1828	21		47,361
*Chemung,	Seneca Lake to Chemung River (with Feeder),	53	. .	1833	39		66,338
*Crooked Lake,	Connects Crooked Lake and Seneca Lake,	27	. .	1833	8		
*Chenango,	Erie Canal and Susquehanna River,	109	. .	. .	97		
Delaware and Hudson,	Connects the Hudson and Delaware, and extends up the Delaware and Lackawaxen Rivers,	110	1073	1828	109		392,091
Chittenango,	Chittenango to the Erie Canal,	4	. .	. .	1½	752½	446,364
	NEW JERSEY.						
Morris,	Jersey to Easton,	. .	1557	1836	101		600,000
Delaware and Raritan,	Bordentown to New Brunswick (with Feeder),	. .	. .	1834	67		500,000
Salem,	Salem Creek to Delaware,	. .	. .	. .	4	172	
	PENNSYLVANIA.						
*Delaware Division of the Pennsylvania Canal,	Bristol to Easton,	. .	164	1830	59¾		247,605
*Central ditto,	Columbia to Hollidaysburg,	111	585	1830	172		918,829
*Western ditto,	Johnstown to Pittsburg,	64	470	1830	105		560,000
*Susquehanna ditto,	Duncan's Island to Northumberland,	. .	86	1831	39		207,851
*North Branch,	Northumberland to Lackawannock,	. .	111	1830	73		279,682
*West Branch,	Northumberland to Dunnstown,	. .	131	1830	72		316,070
*Beaver,	Ohio River to Newcastle,	. .	132	. .	25		96,256
*Franklin Line,	Alleghany River to French Creek (17 miles Slackwater-navigation),	. .	128	. .	22		88,511
	Carry forward,	. .	. .	. .	567¾	1144	

NAMES OF THE CANALS.	REMARKS.	Number of Locks.	Whole Height of Lockage in feet.	When opened.	Length in Miles.	Whole length in each State.	Reported Cost.
	Brought forward,				567¾	1144	
	PENNSYLVANIA—*continued.*						
*French Creek Feeder,	Bemis Dam to Conneaut Lake,				23		£58,420
Union,	Connecting the rivers Susquehanna and Schuylkill,	91		1827	80		400,000
Schuylkill,	Philadelphia to Reading (Slackwater-navigation,)	129	610		108		500,035
Lehigh,	Delaware River to Stoddartsville (9½ miles Slackwater-navigation,)	53			46½		311,600
Conestoga,	River Susquehanna to Lancaster,	9			16		13,708
Codorus,		9			11½		
Conewaga,	To obviate Falls on the Susquehanna,	9			2½		
						855¼	
	DELAWARE.						
Chesapeake and Delaware,	Delaware River and Chesapeake Bay (66 feet broad at water-line, and 10 feet deep,)			1829	14		440,000
						14	
	MARYLAND.						
Chesapeake and Ohio,	Finished from Baltimore to Harper's Ferry,				81		
Port Deposit,	To obviate Rapids on the Susquehanna,				10		
Potomac,	To obviate the Falls of the Potomac,				2½		
						93½	
	VIRGINIA.						
Dismal Swamp,	Chesapeake Bay and Albemarle Sound,				23		175,973
James River,	To obviate Falls on James River,				9½		
						32½	
	NORTH CAROLINA.						
North West Canal,	North West River and Dismal Swamp,				6		
Weldon,	To obviate Falls of the Roanoke,				12		
Lake Drummond Canal,					5		
						23	
	Carry forward,					2162¼	

Names of the Canals.	Remarks.	Number of Locks.	Whole Height of Lockage in feet.	When opened.	Length in Miles.	Whole length in each State.	Reported Cost.
	Brought forward,	. .	. .	. .	. .	2162¼	
	South Carolina.						
Santee Canal,	Santee River and Charleston Harbor,	. .	. .	1802	22		£130,133
Wingaw,	Santee River and Wingaw Bay,	. .	. .	. .	10		
Dreln,	To obviate Fall on Saluda River,	. .	. .	. .	1¼		
Lockhart's,	Shoals on Broad River,	. .	. .	. .	2¾		
Saluda,	Saluda Shoals,	. .	. .	. .	6		
Lorricks,	On Broad River,	. .	. .	. .	1		
Catawba,	To obviate Falls on Catawba River,	. .	. .	. .	11¼	54¼	
	Georgia.						
Savannah and Ogeechee,	From Savannah to River Ogeechee,	. .	. .	1829	16	16	33,000
	Alabama.						
Huntsville Canal,	Triana on the Tennessee to Huntsville,	. .	. .		16	16	
	Louisiana.						
Carondelet,	Bayou St. John to New Orleans,	. .	. .	1805	6		
La Fourche,	Navigable only in times of high water,	. .	. .	. .	85		
Lake Veret,	La Fourche Canal to Lake Veret,	. .	. .	. .	8	99	
	Kentucky.						
Louisville and Portland,	To obviate Rapids of the Ohio,	4	24	1830	2	2	
	Ohio.						
Ohio Canal,	Lake Erie and Ohio,	152	1205	1832	309		
Miami,	Cincinnati to Dayton,	32	296	1830	65	374	149,000
	Total length,	. .	. .	. .	. .	2723½	

V.—Rail-ways in the United States.

Within a very few years, a wonderful change has been effected in land-communication throughout Great Britain and America, where rail-ways have been more extensively and successfully introduced than in any other parts of the world. As early as the sixteenth century, wooden tram-roads were used in the neighborhood of many of the collieries of Great Britain. In the year 1767, cast-iron rails were introduced at Colebrookdale, in Shropshire. In 1811, malleable iron rails were, for the first time, used in Cumberland, and the locomotive engine, on an improved construction, was successfully introduced on the Liverpool and Manchester line, in 1830. Little progress has hitherto been made in the formation of rail-ways on the Continent of Europe. A small one has been in existence, for some time, in the neighborhood of Lyons; but the only rail-road, constructed in France, for the conveyance of passengers by locomotive power, is that from Paris to St. Germains, which was opened only in 1837. In Bohemia, the Chevalier Gerstner, about eight years ago, constructed a rail-way of eighty miles in length, leading from the river Muldau to the Danube. In Belgium, the rail-way from Antwerp to Ghent has been in use for some time; and some lines are at present being constructed in Holland and Russia. But the purpose of the present article is to describe the state of this wonderful improvement in communication, in the United States.

The Quincy rail-road, in Massachusetts, was the first constructed in America. It was intended for the conveyance of stone from the Quincy granite-quarries to a shipping port, on the river Neponset, a distance of about four miles. At the end of this article is given a tabular list of the principal rail-roads which are already finished, and also of those that have been begun in the United States, which show the rapid increase of these works since 1827, the date at which the Quincy rail-road was completed. From these tables it appears that, in 1840, there were no fewer than seventy-one rail-ways completed, and in full operation, whose aggregate length amounts to about twenty-three hundred miles; and also, that twenty-three rail-ways were then in progress, which, when completed, will amount to about twenty-eight hundred miles. In addition to this, upwards of one hundred and fifty rail-way companies have been incorporated; and the works of many of them will, in all probability, be very soon commenced.

The Boston and Lowell rail-way, in Massachusetts, is twenty-six miles in length, and is laid with a double line of rails. The breadth between the rails, which is four feet eight and a half inches, is the same in all the American rail-roads, and the breadth between the tracks is six feet.

The supporters are granite blocks, six feet in length, and about eighteen inches square. These are placed transversely, at distances of three feet apart, from centre to centre, each block giving support to both of the rails. This construction was first introduced in the Dublin and Kingstown rail-way, in Ireland, but was found to produce so rigid a road, that great difficulty was experienced in securing the fixtures of the chairs. From the difficulty, also, of procuring a solid bed for stones of so great dimensions, most of them, after being subjected for a short time to the traffic of the rail-way, were found to be split.

Another construction has been tried on this line, consisting of longitudinal trenches, two feet six inches square, and four feet eight and a half inches apart, from centre to centre, formed in the ground, and filled with broken stone, hard punned down with a wooden beater, as a foundation for the stone blocks on which the rails rest. These blocks measure two feet square, and a foot in thickness, and a transverse sleeper of wood, two feet eight inches and a half in length, one foot in breadth, and eight inches in th'ckness, is placed between the blocks, to prevent them from moving.

The plan of resting the rail-way on a foundation of brok en stone was adopted, in the expectation that it might be sunk to a sufficient depth below the surface of the ground, to prevent the frost from affectıng it; but subsequent experience has shown that many of those rail-ways, whose construction was more superficial, have resisted the effects of frost much better.

The New York and Patterson rail-way is sixteen and a half miles in length, and extends along a marshy tract of ground. The foundation of the road consists of a line of pits under each rail, eighteen inches square, and three feet in depth. They are placed three feet apart, from centre to centre, and filled with broken stones. On this foundation, transverse wooden sleepers, measuring eight inches square, and seven feet in length, are firmly bedded, on which rest the longitudinal sleepers, measuring eight inches by six. To these, plate-rails of malleable iron, two and a half inches wide, and half an inch thick, weighing about thirteen pounds per lineal yard, are fixed by iron spikes.

In the Saratoga and Schenectady rail-way, the parallel trenches are eighteen inches square, and four feet eight and a half inches apart, from centre to centre. They extend throughout the whole line of the rail-way, and are firmly punned full of broken stones. Longitudinal sleepers of wood, measuring eight by five inches, are placed on these trenches, which support the transverse wooden sleepers, measuring six inches square, and placed three feet apart, from centre to centre. Longitudinal runners, measuring six inches square, are firmly spiked to the transverse sleepers, and the whole is surmounted by a plate-rail, half an inch thick, and two and a half inches wide, weighing about thirteen pounds per lineal yard.

The Newcastle and Frenchtown rail-way, which is sixteen miles in length, and forms part of the route from Philadelphia to Baltimore, is constructed in the same way as that between Schenectady and Saratoga, excepting that the plate-rail is two and a half inches broad, and five eighths of an inch thick, and weighs nearly sixteen pounds per lineal yard. The Baltimore and Washington railway is also constructed in the same manner, as regards the foundation and arrangement of the timbers ; but edge-rails are employed on that line, three and a half inches in breadth at the base, and two inches in height.

Several experiments have been made on the Columbia rail-road, in Pennsylvania, which is eighty-two miles in length, and is under the management of the State. Part of the road is constructed with trenches measuring two feet six inches in breadth, and two feet in depth, excavated in the ground, and filled with broken stone. In these, the stone blocks, two feet square, and a foot in thickness, are imbedded, at distances of three feet apart, to which the chairs and rails are spiked, in the ordinary manner. The rails on each side of the track are connected together by an iron bar. This attachment is rendered absolutely necessary, on many parts of the Columbia rail-road, by the sharpness of the curves, which, at the time when the work was laid out, were not considered so prejudicial on a rail-way, as experience has shown them to be.

Another plan tried on this road has a continuous line of stone curb, one foot square, resting on a stratum of broken stone, instead of the isolated stone blocks. A plate-rail, half an inch thick, and two and a half inches broad, is spiked down to treenails, of oak or locust wood, driven into jumper-holes bored in the stone curb.

The Boston and Providence rail-way is forty-one miles in length. Pits, measuring eighteen inches square, and one foot in depth, are excavated under each line of rail, at intervals of four feet apart. They are filled with broken stone, and form a foundation for the transverse wooden sleepers, measuring eight inches square, on which the chairs and rails are fixed in the usual manner.

One of the tracks, in very general use in America, is met with on the Philadelphia and Norristown, the New York and Haerlem and the Buffalo and Niagara rail-roads; and has been introduced on many others. It consists of two lines of longitudinal wooden runners, measuring one foot in breadth, and from three to four inches in thickness, bedded on broken stone, or gravel. On these runners, transverse sleepers are placed, formed of round timber, with the bark left on, measuring about six inches in diameter, and squared at the ends, to give them a proper rest. Longitudinal sleepers, for supporting the rails, are notched into the transverse sleepers. The rail is flat, made of wrought-iron, and varies in weight from ten to fifteen pounds per lineal yard. It is fixed down to the sleepers, at every fifteen or eighteen inches, by spikes four or five inches in length, the heads of which are countersunk in the rail.

The rails used on the Camden and Amboy rail-way, which is sixty-one miles in length, are parallel edge-rails, and are spiked to transverse sleepers of wood, and, in some places, to wood treenails driven into stone blocks. Their breadth is three and a half inches at the base, and two and a half at the top, and their height is four inches. They are formed in lengths of fifteen feet, and secured at the joints by an iron plate on each side, with two screw-bolts passing through the plates and rails. On the Philadelphia and Reading rail-road, rails of the same form have been adopted.

On several of the rail-roads, with a view to counteract the effects of frost, round piles of timber, about twelve inches in diameter, are driven into the ground as far as they will go, at the distance of three feet apart, from centre to centre. The tops are cross-cut, and the rails are spiked to them in the same way as in the Camden and Amboy Rail-way. The heads of the piles are furnished with an iron strap, to prevent them from splitting; and the rails are connected together, at every five feet, by an iron bar.

The Brooklyn and Jamaica rail-road is exceedingly smooth, and is said to resist the effects of frost very successfully. It consists of transverse sleepers, measuring eight by six inches, supported on slabs of pavement, two feet square, and six inches thick. The wooden runner is spiked on the inside of the chairs, to render them firm This rail rests on the *cheeks*, or sides, of the chair, and not on the bottom, as is generally the case.

The rail-road between Charleston and Augusta, and many others in the southern States, where there is a scarcity of materials for forming embankments, are carried over low-lying tracts of marshy ground, elevated on structures of wooden truss-work. The framing is used in situations where the level of the rails does not require to be raised more than ten or twelve feet above the surface of the ground. Piles, from ten to fifteen inches in diameter, are driven into the ground by a piling engine, and, in places where the soil is soft, their extremities are not pointed, but are left square, which makes them less liable to sink under the pressure of the carriages. The struts are attached to the tops of the piles, and are also fixed to dwarf piles driven into the ground. Their effect is to prevent lateral motion. It is evident, however, that these structures are by no means suitable or safe, for bearing the weight of locomotive engines or carriages; and, as may naturally be expected, very serious accidents have occasionally occurred on them. They are, besides, generally left quite exposed, and, in some situations, when they are even so much as twenty feet high, no room is left for pedestrians, who, if overtaken by the engine, can save themselves only by making a leap to the ground.

These varieties of construction were all in use in the United States in 1837; but the American engineers had not, at that time, come to any definite conclusion, as to which of them constituted the best rail-way. It seemed to be generally admitted, however, that the wooden structures were, in most situations, more economical than those formed of stone, and were also less liable to be affected by the frost. Structures of wood also possess a great advantage over those of stone, from the much greater ease with which the rails supported by them are kept in repair. Wooden rail-roads are more elastic, and bend under great weights, while the rigid and unyielding nature of the rail roads laid on stone blocks causes the impulses, produced by the rapid motion of locomotive carriages, or heavily loaded wagons, over the surface, to be much more severely felt, both by the machinery of the engine, and by the rails themselves. Experience, both in this country and in America, has shown the truth of these remarks. On the Liverpool and Manchester rail-way, for example, on which a large sum is annually expended in keeping the rails in order, the part of the road which requires least repair is that extending over Chat Moss, where the rails are laid on wooden sleepers, and the weight of passing trains of loaded wagons produces a sensible undulation in the surface of the rail-way, which at this place actually floats on the moss. These considerations are worthy of attention; and, since the introduction of Kyan's patent anti-dry-rot preparation, wood is beginning to be more generally employed for the construction of rail-ways in this country. The rails of the Dublin and Kingstown road are now laid on wood, and it has also been extensively employed on the Great Western rail-way, now in progress.

The rails used in the United States are of British manufacture. They are often taken to America as ballast; and the Government of the United States having removed the duty from iron imported for the purpose of forming rail-ways, the rails are laid down on the quays of New York nearly at the same cost, as in any of the ports of Great Britain. Those of the Brooklyn and Jamaica road, which are in lengths of fifteen feet, and weigh thirty-nine pounds per lineal yard, are of British manufacture, and cost at New York, when they were landed, in 1836, £8 per ton; the cast-iron chairs, which are also of British manufacture, weigh about fifteen pounds each, and cost £9 per ton. There is a great abundance of iron ore in America, and some of the veins in the neighborhood of Pittsburg are at present pretty extensively worked; but the Americans know that it would be bad economy to attempt to manufacture rails, so long as those made at Merthyr Tydvil Iron-works, in Wales, can be laid down at their sea-ports at the present small cost.

The stone blocks, in use on some of the rail-ways, are made of granite, which is found in many parts of the United States. Yellow pine is generally employed for the longitudinal sleepers, and cedar, locust, or white-oak, for the transverse sleepers on which the rails rest. Cedar, however, if it can be obtained, is generally preferred for the transverse sleepers, because it is not liable to be split by the heat of the sun, and is less affected than perhaps any other timber, by dampness and exposure to the atmosphere. The cedar sleepers used on the Brooklyn and Jamaica rail-way, measuring six inches by five, and seven feet in length, notched, and in readiness to receive the rails, cost 2*s.* 3½*d.* each, laid down at Brooklyn. It is a costly timber, and is not very plentiful in the United States. It has also risen greatly in value, since the introduction of rail-ways, for the construction of which it is peculiarly applicable. For all treenails, locust-wood is universally employed.

The American rail-roads are much more cheaply constructed than those in England, which is owing chiefly to three causes; *first*, they are exempted from the heavy expenses often incurred in the construction of English railways, by the purchase of land, and compensation for damages; *second*, the works are not executed in so substantial and costly a style; and, *third*, wood, which is the principal material used in their construction, is got at a very small cost. The first six miles of the Baltimore and Ohio rail-road, which is formed "in an expensive manner, on a very difficult route," has cost, on an average, about £12,000 per mile. The rail-roads in Pennsylvania cost about £5000 per mile; the Albany and Schenectady rail-road, upwards of £6000 per mile; the Schenectady and Saratoga rail-way, £1800 per mile; and the Charleston and Augusta rail-road, about the same.* Mr. Moncure Robinson, in a report relative to the Philipsburg and Juniata rail-road, states, that the first ten miles of the Danville and Pottsville rail-road, formed for a double track, but on which a single track only was laid, cost, on an average, £4400 per mile, and that the Honesdale and Carbondale rail-road, sixteen and one third miles in length, laid with a single track, and executed for a considerable portion of its length on truss-work, is understood, with machinery, to have averaged £3600 per mile. The average cost of these rail-ways, constructed in different parts of the United States, is £4942 per mile.

This contrasts, strongly, with the cost of the rail-ways constructed in Great Britian. The Liverpool and Manchester rail-way cost £30,000 per mile; the Dublin and

* Facts and suggestions relative to the New York and Albany rail way. New York, 1833.

Kingstown, £40,000; and the rail-way between Liverpool and London is expected to cost upwards of £25,000.

The following extract, embodying an estimate from Mr. Robinson's Report, will give some idea of the cheapness with which many of the American works are constructed:—

"The following plan," says Mr. Robinson, "is proposed for the superstructure of the Philipsburg and Juniata rail-road.

"Sills of white or post oak, seven feet ten inches long, and twelve inches in diameter, flattened to a width of nine inches, are to be laid across the road, at a distance of five feet apart, from centre to centre. In notches formed in these sills, rails of white-oak or heart-pine, five inches wide by nine inches in depth, are to be secured, four feet seven inches apart, measured within the rails. On the inner edges of these rails, plates of rolled iron, two inches wide by half an inch thick, resting at their points of junction on plates of sheet iron, one twelfth of an inch thick and four and a half inches long, are to be spiked, with five-inch wrought-iron spikes. The inner edges of the wooden rails to be trimmed slightly levelling, but flush at the point of contact with the iron rail, and to be adzed down, outside the iron, to pass off rain-water.

"Such a superstructure, as that above described, would be entirely adequate to the use of locomotive engines of from fifteen to twenty horses' power, constructed without surplus weight, or similar to those now in use on the little Schuylkill rail-road in this State, (Pennsylvania,) or the Petersburg rail-road in Virginia: and it will be observed that only the sills, which constitute but a very slight item in its cost, are much exposed to the action of those causes which induce decay in timber. It is particularly recommended for the Philipsburg and Juniata rail-road, by the great abundance of good materials, along the line of the improvement, for its construction, and the consequent economy with which it may be made.

"The following may be deemed an average estimate of the cost of a mile of superstructure, as above described.

	Dolls.
1056 trenches, 8 feet long, 12 inches wide, and 14 inches deep, filled with broken stone, at 25 cents each, .	264
Same number of sills, hewn, notched, and imbedded, at 50 cents each, ...	528
10,912 lineal feet of rails, (allowing $33\frac{1}{3}$ per cent. for waste,) at 4 cents per lineal foot, delivered, . .	436.48
2112 keys, at $2\frac{1}{2}$ cents each, ...	52.80
10,560 lineal feet of plate rails, 2 inches by $\frac{1}{2}$ inch, weight $3\frac{1}{3}$ lb. per foot, $15\frac{71}{100}$ tons, delivered at 50 dollars (£10) per ton, ...	785 50
1509 lbs. of 5-inch spikes, at 9 cents per pound, . .	135 81
Sheet iron under ends of rails, ...	30.21
Placing and dressing wood, and spiking down iron rails,	280
Filling between sills with stone, or horse-path, . .	180
2692 dollars, or about £540.	2692.80

It was found rather difficult to obtain much satisfactory information regarding the expense of upholding the American rail-ways. It is stated in a report made by the Directors of the Boston and Worcester rail-road, that Mr. Fessenden, their engineer, estimates the annual expenditure for repairing the road, carriages, and engines, and providing fuel and necessary attendance for forty-three and a half miles of rail-way, at £6829 per annum, which is at the rate of £157 per mile. The expense of the repairs on the Utica and Schenectady rail-road, which is about seventy-seven miles in length, amounts to £28,000 per annum, being at the rate of about £363 per mile. These sums for keeping rail-roads in repair are exceedingly small, compared with the amount expended in this country for the same purpose. On the Liverpool and Manchester rail-way, for example, the expense annually incurred, in keeping the engines in a working state, and the rail-way in repair. amounts to upwards of £30,000, or £1000 per mile This difference in the cost arises, in a great measure, from the comparatively slow speed at which the engines working on the American rail-ways are propelled, which, in the course of my own observation, never exceeded the average rate of fifteen miles per hour. On the State rail-ways, and also on many of those under the management of incorporated companies, fifteen miles an hour is the rate of travelling fixed by the administration of the rail-way, and this speed is seldom exceeded.

On some of the American rail-ways, where the line is short, or the traffic small, horse power is employed; but locomotive engines for transporting goods and passengers, are in much more general use. In New York, Brooklyn, Philadelphia, Baltimore, and other places, which have lines of rail-way leading from them, the depot, or station for the locomotive engines, is generally placed at the outskirts, but the rails are continued through the streets, to the heart of the town, and the carriages are dragged over this part of the line by horses, to avoid the inconvenience and danger, attending the passage of locomotive engines, through crowded thoroughfares.

The fuel used on most of the rail-ways is wood, but the sparks vomited out by the chimney are a source of constant annoyance to the passengers, and occasionally set fire to the wooden bridges on the line, and the houses in the neighborhood. Anthracite coal, as formerly noticed, has been tried, but the same difficulties which attend its use in steam-boat furnaces, are experienced, to an equal extent, in locomotive engines.

In situations where the summit-level of a rail-way cannot be attained, by an ascent sufficiently gentle for the employment of locomotive engines, or where the formation of such inclinations, though perfectly practicable, would be attended with an unreasonably large outlay, transit is generally effected by means of inclined planes, worked by stationary engines. This system has been introduced on the Portage rail-way, over the Alleghany Mountains, in America, on a more extensive scale, than in any other part of the world. The Portage or Alleghany rail-way forms one of the links of the great Pennsylvania canal and rail-road communication, from Philadelphia to Pittsburg,—a work of so difficult and vast a nature, and so peculiar, both as regards its situation and details, that it cannot fail to be interesting to every engineer, and I shall, therefore, state at some length the facts which I have been able to collect regarding it.

This communication consists of four great divisions, the Columbia rail-road, the Eastern Division of the Pennsylvania canal, the Portage or Alleghany railroad, and the Western Division of the Pennsylvania canal. These works form a continuous line of communication from Philadelphia, on the Schuylkill, to Pittsburg, on the Ohio, a distance of no less than three hundred and ninety-five miles.

Commencing at Philadelphia, the first Division of this stupendous work is the Philadelphia and Columbia rail-road, which was opened in the year 1834. It is eighty-two miles in length, and was executed at a cost of about £666,025, being at the rate of £8122 per mile. There are several viaducts of considerable extent on this rail-way, and two inclined planes worked by stationary engines. One of these inclined planes is at the Philadelphia end of the line. It rises at the rate of one in 14.6 for two thousand seven hundred and fourteen feet, overcoming an elevation of one hundred and eighty-five feet. The other plane, which is at Columbia, rises at the rate of one in 21.2 for a distance of one thousand nine hundred and fourteen feet, and overcomes an elevation of ninety feet. A very large sum is expended in upholding the inclined planes, and surveys have lately been made with a view to avoid them. The cost of maintaining the stationary power, and superintendence of the Philadelphia inclined plane, is said to be about £8000 per annum, and that of the Columbia plane, about £3498 per annum. Locomotive engines are used between the tops of the inclined planes. The steepest gradient on that part of the line is at the rate of one in one hundred and seventeen; but the curves are numerous, and many of them very sharp, the minimum radius being so small as three hundred and fifty feet. This line of rail-way was surveyed and laid out, before the application of locomotive power to rail-way conveyance had attained its present advanced state,—at a period when sharp curves and steep gradients were not considered so detrimental to the success of rail-ways, as experience has since shown them to be.

The passenger-carriages on the Columbia rail-road are extremely large and commodious. They are seated for sixty passengers, and are made so high in the roof, that the tallest person may stand upright in them, without inconvenience. There is a passage between the seats extending from end to end, with a door at both extremities and the coupling of the carriages is so arranged, that the passengers may walk from end to end of a whole train, without obstruction. In winter, they are heated by stoves. The body of each of these carriages measures from fifty to sixty feet in length, and is supported on two four-wheeled trucks, furnished with friction-rollers, and moving on a vertical pivot, in the manner formerly alluded to, in describing the construction of the locomotive engines. The flooring of the carriages is laid on longitudinal beams of wood, strengthened with suspension-rods of iron.

At the termination of the rail-way at Columbia, is the commencement of the Eastern Division of the Pennsylvania canal, which extends to Hollidaysburg, a town situate at the foot of the Alleghany Mountains. This canal is rather more than one hundred and seventy-two miles in length, and was executed at an expense of £918,829, being at the rate of £5342 per mile. There are thirty-three aqueducts, and one hundred and eleven locks, on the line, and the whole height of lockage is 585.8 feet. A considerable part of this canal is slack-water-navigation, formed by damming the streams of the Juniata and Susquehanna. The canal crosses the Susquehanna at its junction with the Juniata, at which point it attains a considerable breadth. A dam has been erected in the Susquehanna, at this place, and the boats are dragged across the river by horses, which walk on a tow-path attached to the outside of a wooden bridge, at a level of about thirty feet above the surface of the water.

Hollidaysburg is the western termination of the Eastern Division of the Pennsylvania canal. The town stands at the base of the Alleghany Mountains, which extend in a southwesterly direction, from New Brunswick, to the State of Alabama, a distance of upwards of eleven hundred miles, presenting a formidable barrier to communication between the eastern and western parts of the United States. The breadth of the Alleghany range varies from a hundred to a hundred and fifty miles, but the peaks of the mountains do not attain a greater height than four thousand feet above the medium level of the sea.

They rise with a gentle slope, and are thickly wooded to their summits. "The Alleghany Mountains present what must be considered their scarp, or steepest side, to the east, where granite, gneiss, and other primitive rocks, are seen. Upon these repose, first, a thin formation of transition rocks dipping to the westward, and next, a series of secondary rocks, including a very extensive coal formation."* The National road, which has already been noticed, was the first line of communication formed by the Americans over this range; and in the year 1831, an Act was passed for connecting the Eastern and Western Divisions of the Pennsylvania canal, by means of a rail-road. This important and arduous work, which cost about £526,871, was commenced within the same year in which the Act for its construction was granted, and the first train passed over it on the 26th of November, 1833; but it was not till 1835, that both the tracks were completed, and the rail-way came into full operation.

The rail-way crosses the mountains by a pass called "Blair's Gap," where it attains its summit-level, which is elevated two thousand three hundred and twenty-six feet above the mean level of the Atlantic ocean. Mr. Robinson surveyed a line of rail-way from Philipsburg to the river Juniata, which is intended to cross the Alleghany Mountains by the pass called "Emigh's Gap." The summit-level of this line is stated, in a report by the directors, to be two hundred and ninety-two feet lower than that of the Portage rail-way.

The preliminary operation of clearing a track for the passage of the rail-way, from a hundred to a hundred and fifty feet in breadth, through the thick pine forests with which the mountains are clad, was one in which no small difficulties were encountered. This operation, which is called *grubbing*, is little known in the practice of engineering in this country, and is estimated by the American engineers, in their various rail-way and canal reports, at from £40 to £80 per mile, according to the size and quantity of the timber to be removed; an estimate which, from the appearance of American forests, must, in many

* Encyclopædia Britannica, article *America*.

instances, be much too low. The timber removed from the line of the Alleghany rail-way is chiefly spruce and hemlock pine, of very large growth.

The line is laid with a double track, or four single lines of rails, and is twenty-five feet in breadth. For a considerable distance, the rail-way is formed by side-cutting along steep sloping ground, composed of clay-slate, bituminous coal, and clay, part of the breadth of the road being obtained by cutting into the hill, and part by raising embankments, protected by retaining walls of masonry. The rail-way is consequently liable to be deluged, or even entirely swept away, by mountain torrents, and the thorough drainage of its surface has been attended with great expense and difficulty. The retaining walls, by which the embankments are supported, are in some places not less than a hundred feet in height; they are built of dry-stone masonry, and have a batter of about one half to one, or six inches horizontal to twelve inches perpendicular. There are no parapet or fence walls on the railway, and on many parts of the line, especially at the tops of several of the inclined planes, the trains pass within three feet of precipitous rocky faces, several hundred feet high, from which the large trees, growing in the ravines below, almost resemble brushwood. One hundred and fifty-three drains and culverts, and four viaducts, have been built on the rail-way. One of the viaducts crosses the river Conemaugh, at an elevation of seventy feet above the surface of the water. There is also a tunnel on the line nine hundred feet in length, twenty feet in breadth, and nineteen feet in height.

The inclined planes are, however, the most remarkable works which occur on this line. The rail-way extends from Hollidaysburg on the eastern base, to Johnstown on the western base, of the Alleghany Mountains, a distance of thirty-six miles; and the total rise and fall, on the whole length of the line, is 2571.19 feet. Of this height, 2007.02 feet are overcome by means of tén inclined planes, and 564.17 feet by the slight inclinations given to the parts of the railway which extend between these planes. The distance from Hollidaysburg to the summit-level is about ten miles, and the height is 1398.31 feet. The distance from Johnstown to the same point is about twenty-six miles, and the height 1172.88 feet. The height of the summit-level of the rail-way, above the mean level of the Atlantic, is 2326 feet.

The machinery by which the inclined planes are worked consists of an endless rope passing round horizontal, grooved wheels, placed at the head and foot of the planes which are furnished with a powerful break, for retarding the descent of the trains. The ropes were originally made seven and a half inches in circumference, but they have lately been increased to eight inches, to prevent a tendency, which they formerly had, to slip in the grooved wheels, occasioned by their circumference being too small for the size of the groove, or hollow in the wheel. Two stationary engines, of twenty-five horses' power each, are placed at the head of the inclined planes, one of which is in constant use in giving motion to the horizontal wheels round which the rope moves, while the trains are passing the inclined planes. Two engines have been placed at each station, that the traffic of the rail-way may not be stopped, should any accident occur to the machinery of that which is in operation; and they are used alternately, for a week at a time. Water for supplying the boilers has been conveyed, at a great expense, to many of the stations, in wooden pipes upwards of a mile in length.

The planes are laid with a double track of rails, and an ascending and a descending train are always attached to the rope at the same time. Many experiments have been made, to procure an efficient safety-car, to prevent the trains from running to the foot of the inclined plane, in the event of the fixtures, by which they are attached to to the endless rope, giving way. Several of these safety-cars are in use, and are found to be a great security. The trains are attached to the endless rope simply by two ropes of smaller size made fast to the couplings of the first and last wagons of the train, and to the endless rope by a hitch or knot, formed so as to prevent it from slipping.

Locomotive engines are used on the parts of the road between the inclined planes.—*Stevenson's 'Sketch of Civil Engineering in North America.'*

Table of the Principal Rail-ways in operation in the United States, in 1840.

NAME.	COURSE.	When opened	Length in Miles.	Whole length in each State.
	MAINE.			
Bangor and Orono,	From Bangor to Orono,	1836	10	10
	NEW HAMPSHIRE.			
Nashua and Lowell,	Nashua to Lowell,	1838	15	15
	MASSACHUSETTS.			
Quincy,	Quincy Quarries to Neponset River,	1827	4	
Boston and Lowell,	Boston to Lowell,	1835	26	
Andover and Wilmington,	Andover to the Boston and Lowell Rail-road,	1836	7¾	
Andover and Haverhill,	Andover to Haverhill,	1838	10	
Boston and Providence,	Boston to Providence,	1835	41	
Dedham Branch,	Boston and Providence R. Road to Dedham,	1835	2	
Taunton Branch,	Boston and Providence Rail-road to Taunton,	1836	11	
Boston and Worcester,	Boston to Worcester,	1835	45	
Western Rail-way,	Worcester to Springfield,	1839	54	
Worcester and Norwich,	Worcester to Norwich,	1839	59	
Eastern Rail-road,	Boston to Newburyport,	1839	36	295¾
	RHODE ISLAND.			
Providence & Stonington,	Providence to Stonington,	1837	47	47
	CONNECTICUT.			
Hartford and New Haven,	Hartford to New Haven,	1839	40	
Housatonic,	Bridgeport to New Milford,	. .	40	80
	NEW YORK.			
Mohawk and Hudson,	Between the Rivers Mohawk and Hudson,	1832	16	
Saratoga & Schenectady,	Saratoga to Schenectady,	1832	22	
Rochester,	Rochester to Carthage,	1833	3	
Ithaca and Oswego,	Ithaca to Oswego,	1834	29	
Rensselaer and Saratoga,	Troy to Ballston,	1835	24½	
Utica and Schenectady,	Utica to Schenectady,	1836	77	
Buffalo and Niagara,	Buffalo to Niagara Falls,	1837	21	
Haerlem,	New York to Haerlem,	1837	7	
Lockport and Niagara,	Lockport to Niagara Falls,	1837	24	
Brooklyn and Jamaica,	Brooklyn to Jamaica,	1837	12	
Auburn and Syracuse,	Auburn to Syracuse,	. .	26	
Catskill and Canajoharie,	Catskill to Canajoharie,	. .	68	
Hudson and Berkshire,	Hudson to the Boundary of Massachusetts,	. .	30	
Tonawanda,	Rochester to Attica,	.	45	404½
	NEW JERSEY.			
Camden and Amboy,	Camden to Amboy,	1832	61	
Paterson,	Paterson to Jersey,	1834	16½	
New Jersey,	Jersey City to New Brunswick,	1836	31	
Morris and Essex,	Morristown to Newark,	. .	20	128½
	PENNSYLVANIA.			
Columbia,	Philadelphia to Columbia,	. .	82	
Alleghany,	Hollidaysburg to Johnstown, over the Alleghanies,	. .	36	
Mauch Chunk,	Mauch Chunk to the Coal-mines,	1828	5	
Room Run,	Mauch Chunk to the mines,	. .	5½	
	Carried forward,		128½	980¾

NAME.	COURSE.	When opened	Length in Miles.	Whole length in each State.
	Brought forward,	. .	128½	980¾
	PENNSYLVANIA, *continued.*			
Mount Carbon, . .	Mount Carbon to the mines,	1830	7½	
Schuylkill Valley, . .	Port Carbon to Tuscarora, with numerous branches,	. .	30	
Schuylkill, ...	. . . .	. .	13	
Mill Creek, ...	Port Carbon to Mill Creek,	. .	7	
Minehill and Schuylkill,	. . . .	. .	20	
Pine-grove, . .	Pine-grove to Coal-mines,	. .	4	
Little Schuylkill, . .	Port Clinton to Tamaqua,	1831	23	
Lackawaxen, . .	Lackawaxen Canal to the River Lackawaxen, .	. .	16½	
Westchester, . .	Westchester to Columbia Rail-road, . . .	1832	9	
Philadelphia and Trenton,	Philadelphia to Trenton,	1833	26½	
Philadelphia & Norristown	Philadelphia to Norristown	1837	19	
Central Rail-way, .	Pottsville to Danville,	. .	51½	
Philadelphia and Reading,	Philadelphia to Reading,	. .	40½	
Philadelphia & Baltimore,	Philadelphia to Baltimore,	. .	93	489
	DELAWARE.			
Newcastle & Frenchtown,	Newcastle to Frenchtown,	1832	16	16
	MARYLAND.			
Baltimore and Ohio, .	Completed to Harper's Ferry, with branches,	1835	86	
Winchester, . .	Harper's Ferry to Winchester, . . .	. .	30	
Baltimore & Port-Deposit,	Baltimore to Port-Deposit,	. .	34¼	
Baltimore & Washington,	Baltimore to Washington,	1835	40	
Baltimore & Susquehanna,	Baltimore to York, .	1837	59½	249¾
	VIRGINIA.			
Chesterfield, . .	Richmond to Chesterfield Coal-mines, . . .	. .	13	
Petersburg and Roanoke,	Petersburg to Blakely, on the Roanoke, . .	. .	59	
Winchester and Potomac,	Winchester to Harper's Ferry, ...	. .	30	
Portsmouth and Roanoke,	Portsmouth to Weldon,	. .	77½	
Richmond, Fredericksburg, and Potomac,	Richmond to Fredericksburg, ...	. .	58	
Manchester, . .	Richmond to Coal-mines,	. .	13	250½
	SOUTH CAROLINA.			
South Carolina Rail-road,	Charleston to Hamburg on the Savannah, . .	1833	136	136
	GEORGIA.			
Alatamaha & Brunswick,	Alatamaha to Brunswick,	. .	12	12
	ALABAMA.			
Tuscumbia and Decatur,	Mussel-Shoals, Tennessee River, . . .	. .	46	46
	LOUISIANA.			
Pontchartrain, . .	New Orleans to Lake Pontchartrain, . . .	1831	5	
Carrollton, . .	New Orleans to Carrollton,	. .	6	11
	KENTUCKY.			
Lexington and Ohio, .	Lexington to Frankfort,	.	29	
Frankfort and Louisville,	Frankfort to Louisville,		50	79
	Total length in miles,			2270

List of the other Rail-ways now in progress in the United States.

NAME.	COURSE.	Length in Miles.
	NEW HAMPSHIRE.	
Haverhill and Exeter,	Haverhill to Exeter, . .	18
Newburyport and Portsmouth, ...	Newburyport to Portsmouth, . .	24
	MASSACHUSETTS.	
Old Colony, . .	Taunton to New Bedford, ...	20
Western, . . .	Springfield to New York line, . .	63
	CONNECTICUT.	
Western, . . .	Hartford to Springfield, . . .	27
	NEW YORK.	
Long Island, . .	Jamaica to Greenport, ...	50
New York and Erie, .	New York to Lake Erie, ...	505
Saratoga and Washington,	Saratoga to Whitehall, . . .	41
	NEW JERSEY.	
Elizabethtown & Belvidere	Elizabethtown to Belvidere, . .	60
Burlington & Mount Holly,	Burlington to Mount Holly, . . .	7
	PENNSYLVANIA.	
Oxford, ...	Columbia Rail-road to Port Deposit,	38
Tioga, ...	Chemung Canal to Tioga Coal-mines,	40
	VIRGINIA.	
Greensville and Roanoke,	. . . .	18
	SOUTH CAROLINA.	
Charleston and Cincinnati,	Charleston to Cincinnati, . . .	500
	GEORGIA.	
Augusta and Athens, .	Augusta to Athens, ...	100
Macon and Forsyth, .	Macon to Forsyth, ...	25
Central Rail-road, .	Savannah to Macon, ...	200
	ALABAMA.	
Montgomery and Chattahoochee, . . .	. . . .	90
	MISSISSIPPI.	
Mississippi Rail-road. .	Natchez to Canton, ...	150
	KENTUCKY.	
Bowling Green and Barren River, . .	Bowling Green to Barren River, . .	1½
	OHIO.	
Mud River and Lake Erie,	Dayton to Sandusky, ...	153
Sandusky & Monroeville,	Sandusky to Monroeville, . . .	16
	MICHIGAN.	
Detroit and St. Joseph,	Detroit to the River St. Joseph, .	200
	Total length, .	2346½

VI.—Manufacture of Maple Sugar.

The following account of the manufacture of sugar, from the sap of the maple tree, is copied from the North American Sylva of Michaux.

The work is commonly taken in hand in the month of February, or in the beginning of March, while the cold continues intense, and the ground is still covered with snow. The sap begins to be in motion at this season, two months before the general revival of vegetation. In a central situation, lying convenient to the trees, from which the sap is drawn, a shed is constructed, called a sugar-camp, which is destined to shelter the boilers, and the persons who attend them, from the weather. An auger, three quarters of an inch in diameter, small troughs to receive the sap, tubes of elder or sumac, eight or ten inches long, corresponding in size to the auger, and laid open for a part of their length, buckets for emptying the troughs and conveying the sap to the camp, boilers of fifteen or eighteen gallons capacity, moulds to receive the sirup when reduced to a proper consistency for being formed into cakes, and, lastly, axes to cut and split the fuel, are the principal utensils employed in the operation.

The trees are perforated in an obliquely ascending direction, eighteen or twenty inches from the ground, with two holes, four or five inches apart. Care should be taken that the augers do not enter more than half an inch within the wood, as experience has shown the most abundant flow of sap to take place at this depth. It is also recommended to insert the tubes on the south side of the tree; but this useful hint is not always attended to.

The troughs, which contain two or three gallons, are made in the Northern States, of white pine, of white or black oak, or of maple; on the Ohio, the mulberry, which is very abundant, is preferred. The chestnut, the black walnut, and the butternut should be rejected, as they impart to the liquid the coloring matter and bitter principle, with which they are impregnated.

A trough is placed on the ground, at the foot of each tree, and the sap is, every day, collected and temporarily poured into casks, from which it is drawn out to fill the boilers. The evaporation is kept up by a brisk fire, and the scum is carefully taken off during this part of the process. Fresh sap is added, from time to time, and the heat is maintained, till the liquid is reduced to a sirup, after which it is left to cool, and then strained through a blanket, or other woollen stuff, to separate the remaining impurities.

Some persons recommend leaving the sirup, twelve hours, before boiling it for the last time ; others proceed with it immediately. In either case, the boilers are only half filled, and by an active, steady heat, the liquor is rapidly reduced to the proper consistency for being poured into the moulds. The evaporation is known to have proceeded far enough, when, upon rubbing a drop of the sirup between the fingers, it is perceived to be granular. If it is in danger of boiling over, a bit of lard or of butter is thrown into it, which instantly calms the ebullition. The molasses being drained off from the moulds, the sugar is no longer deliquescent, like the raw sugar of the West Indies. Maple sugar, manufactured in this way, is lighter colored, in proportion to the care with which it is made, and the judgement with which the evaporation is conducted. It is superior to the brown sugar of the Colonies, at least, to such as is generally used in the United States ; its taste is as pleasant, and it is as good for culinary purposes. When refined, it equals in beauty the finest sugar consumed in Europe.

The sap continues to flow for six weeks ; after which, it becomes less abundant, less rich in saccharine matter, and sometimes even incapable of crystallization. In this case, it is consumed in the state of molasses, which is superior to that of the West India Islands. After three or four days exposure to the sun, maple sap is converted into vinegar, by the acetous fermentation.

The amount of sugar manufactured in a year varies, from different causes. A cold and dry winter renders the trees more productive than a changeable and humid season. It is observed, that when a frosty night is followed by a dry and brilliant day, the sap flows abundantly :

and two or three gallons are sometimes yielded by a single tree, in twenty-four hours. Three persons are found sufficient to tend two hundred and fifty trees, which give one thousand pounds of sugar, or four pounds from each tree. But this product is not uniform, for many farmers on the Ohio do not commonly obtain more than two pounds from a tree.

Trees, which grow in low and moist places, afford a greater quantity of sap, than those, which occupy rising grounds, but it is less rich in the saccharine principle. That of insulated trees, left standing in the middle of fields, or by the side of fences, is the best. It is also remarked, that in districts which have been cleared of other trees, and even of the less vigorous sugar maples, the product of the remainder is proportionally more considerable.

VII.—Of the Manufacture of Beet Sugar.

The following account of this manufacture, in France, is extracted from a work compiled, in 1836, by Mr. Edward Church.

Cleansing of the Beet Roots.

The object of this operation is, to separate from the roots the green parts of the neck, which may not have been removed, the radicles, the defective parts, and the earth and the gravel which may adhere to these; when this is properly done, the washing, should it be required, (which is not the case in many places,) is easily and quickly performed. In all cases, the cleansing should be effectually done, otherwise the gravel and earth (should there any remain) will injure the rasps. Women and children perform this operation in France. For this purpose, each hand is provided with a sharp knife, from two to three inches broad, and ten long. With this tool, seated near a pile of beets, the laborer takes the beets one after another, scrapes them lengthwise, to detach the earth and stones, takes off the neck all round, and even a thin slice, when this has not been already done.

When a beet is too large to be applied conveniently to the rasp, the workmen should cut it in two, or in quarters, according to its dimensions. This must always be done longitudinally.

The cleaning of the beets should always take place in a room near the rasps and presses, in order that these different operations may follow conveniently and quickly. The place should be, when possible, a building sufficiently large to contain beets enough for the consumption of the works for at least four or five days, and leave room enough besides for the laborers to do their work easily. As fast as the roots are cleansed, they should be thrown into baskets about eighteen inches high, and a foot wide, of a conical shape, with handles. When several of these are filled they are carried to the rasp; there they leave the full baskets and take back the empty ones. Two women, in France, who understand their business, can clean easily from three to three and one half tons of roots in twelve hours' work, and carry them to the rasp. The wages of these women, in some parts of France, do not exceed twelve or fifteen cents each, per day; at this rate, the cleaning of a ton of beets would not cost over ten cents. It, of course, reduces the weight of the beet; the loss is estimated, usually, at from six to seven per cent.

The operation of washing the roots is, (as we before said,) by no means generally requisite; and a careful cleansing, as described above, is decidedly preferable, and it is not always, that water in sufficient quantity can be conveniently obtained. When a little stream is at hand, and they can be placed in baskets in the water, and remain till the earth is washed off by its motion, such a peculiar advantage should never be neglected; but this of rare occurrence.

This washing is the more difficult, too, as it must be executed in the winter, and the water frequently may be frozen. A general opinion once prevailed, that the cleansing with water was indispensable, and that the manufacture of sugar could not be undertaken without a locality which supplied an abundance of it; but this supposed necessity is groundless, for there are few spots where a sufficiency of water may not be found for the inconsiderable wants of a beet sugar manufactory.

Rasping the Beets.

The first idea of the famous Achard, when in search of the best mode of extracting the sugar from beets, was to *boil* them and reduce them to paste; but he soon found insuperable difficulties in the way of this process. The simple pressure without rasping has been repeatedly tried, and recently again by an improved press, and the rasp is as yet the only effectual mode employed, and too much care cannot be used in having this operation well done, as on it depends, in a great measure, the more or less sugar that is obtained. There is a great diversity in the construction of this machine, but the cylindrical rasp of Molard appears to have the preference. The cylinder is of cast-iron, into which one hundred and twenty saw plates are inserted. As a description of this would probably be unintelligible without a representation of it by an engraving, I will not attempt it. A man presses the beets enclosed in a box against the circumference of the cylinder, another workman, on the opposite side of the machine, removes the pulp, and, with the ladle with which he removes it, fills bags, as we shall more particularly explain hereafter. From eighty to one hundred pounds of beet are reduced to pulp, in one minute.

The rasping requires, as well as every other operation of this manufacture, great activity; and, as much as possible, the rasping more beets than are *immediately* wanted, must be avoided, as a prejudicial change takes place in the pulp, from a quarter to a half hour, at most, after it is produced. A blackish color, which gradually increases, is the indication of this change. It is therefore prudent that no more should be rasped than can be immediately pressed. The rasp must be kept perfectly clean by repeated washings. Onee a day, at least, every part of the machine, and all the tools appertaining to it, should be carefully cleansed, because every portion of juice, or pulp, which is suffered to remain on them, would soon serve as a leaven to excite fermentation.

It is immaterial what power is used to drive the rasps;

animal, water, and steam, power, and even wind, is sometimes used in France.

Extraction of the Beet Juice.

A variety of machines, and of power, has been used, for the pressing of the pulp, as well as for rasping the roots. Of late the Hydraulic press has superseded almost every other, for this last operation, at least, in large manufactories. The pulp, enclosed in bags, is submitted to the action of this machine; the bags are usually made of Russia duck. The cloth, though required to be strong, must not be so close that the *juice* cannot easily pass through it, or they will otherwise burst; on the other hand, it must be sufficiently so, to prevent the *pulp* passing through the tissue.

This last defect, however, is less to be feared than the first, so that the caution, most to be attended to, is, to avoid too close a texture; and it must be recollected that it will become closer when saturated with the juice. The size of the bags may be varied, but, generally speaking, half a yard wide and one yard long is a convenient dimension; they should not be more than three fourths filled. The bags must be kept perfectly clean, and they should be washed every day in *boiling water*, with a small addition of the sub-carbonate of soda. Wicker-work frames, on which the bags are to be piled, must be provided; they should be made strong, and proportioned to the size of the platform of the press, that is, of the same dimensions; they serve to support the piles of bags in their vertical position, on the hand-wagon, with which they are removed from the rasp to the press, and are themselves kept in place, when on the press, by stanchions, fixed to the platform of the press at the lower end, the other sliding through a groove fixed to the frame-work. These wicker-frames and bags are placed alternately under the press, usually to the number of thirty of each. As regards these frames, the caution of the cleanliness is renewed, and, in a word, must be applied to every branch of this manufactory.

A *Reservoir* is next to be provided, to receive the juice from the press, to be subsequently conveyed to the defecating boiler ; it must be supplied with pipes of communication with the press, and a pump to convey the juice it contains to the defecating boiler ; it should be placed on a lower level than the press, and receive the juice by an inclined plane. It must be made substantially of wood, and lined with copper, having a concavity in the centre, into which the bottom of the pump must be inserted, so as to empty it completely. The capacity must, of course, depend on the extent of the manufactory.

Mode of operating with the Press.

When the bags and wicker-frames have been piled as before described, alternately, to the number of thirty or more of each, on the platform, and the stanchions placed, the weight of the pulp alone causes a pretty plentiful flow of juice ; if the press used is a *screw* press, a *workman* takes hold of the lever, and turns it, then a second man assists, and then a third. When they have exerted their united strength on the lever, the job is done, and, after allowing the bags to drain, whilst they are filling others, the press is unscrewed, the bags removed, the pulp cakes disposed of, the bags cleansed, and the operation first described is continued, till the whole quantity of pulp prepared is disposed of.

Defecation of the Juice.

The juice of the beet, as it comes from the press, carries with it all the soluble parts of the root. It contains, in this state, not only *sugar* and *water*, but other component parts, which cannot be separated by evaporation alone ; they must be precipitated by chemical agents. Many and expensive experiments were made in search for these, which I shall not here attempt to explain. The present process is as follows : Suppose a boiler containing four hundred gallons of juice ; add, *before lighting the fire*, eight pounds sulphuric acid at sixty-six degrees, one part acid, three parts water, diluted, mix quickly and thoroughly with the juice, then take nine pounds of quicklime, weighed before it is slaked, then slake with warm water to the consistency of milk, throw this also into the juice, and stir the whole completely; the fire is now to be kindled under the boiler, and its contents raised to the temperature of one hundred and ninety degrees of Fahrenheit; then animal carbon, that has been employed in clarification, is added, and well mixed, and a portion of diluted ox blood stirred in carefully; the fire is withdrawn, the juice allowed to settle, and is drawn off clear, through a cock placed near the bottom of the boiler. It is important to observe that the juice, when the sulphuric acid is added, must *not be warm*. This process has failed in the hands of some imitators of M. Crespel, from a mistake on this point. M. Dubrunfaut acknowledges that he himself committed it.

Concentration of the Juice.

For this purpose, one or more boilers are necessary, with which the evaporation is begun and finished; in these the juice from the defecating boiler is received clear; then a slow fire is kept up in the beginning, and some albuginous matter, (white of eggs, or blood,) added, if it should seem to be required. After this, a man must attend closely to the boiler, and manage the fire. When froth appears, it will be his duty to throw a small piece of butter, or other grease, (which he should have near him,) into the vessel, which will immediately cause it to subside; he should also have a ladle to stir it when required. When the juice has reached the proper point, that is to say, twenty-six degrees of Baumes's areometer, when *boiling*, that is thirty degrees, when *cold*, it is time to proceed to the operation of clarifying.

Clarifying.

The object of this is, to separate the sirup concentrated to thirty degrees, or near it, from the extraneous matter which it holds in suspension, and moreover to deprive it, by clarifying agents, of all coloring matter, and other foreign substances which *were* in the juice, or have formed there whilst under the preceding operation, all which matter is injurious to the sugar. *Clarification* mav be divided into two distinct branches, the one *chemical*, having for its object, by clarifying agents, such as animal carbon, albumine, &c., to purify the sirup ; the other, *mechanical*, having for its object to separate from the same, the carbon and other solid bodies agglomerated by the albumine.

The first is managed with a boiler, only because the action of the chemical agents employed require to be aided by heat

Of all the means hitherto devised for clarification, none has been found so simple and so effective as that offered by the use of animal carbon, and albuginous or caseous matter.*

We will here suppose that the object in view is to clarify the portion of *sirup*, supplied by the defecation of one hundred gallons of *juice*, that is, sixteen and a half gallons of sirup concentrated to twenty-six degrees boiling and thirty degrees cold ; (it follows that for any other quantity it is only required to follow the same proportion ;) to do this, we must proceed to weigh eight pounds of animal carbon, and throw it into the boiler ; the sirup, when boiling, should be well stirred with the ladle, then with the skimmer ; the black agglomerated matter which rises to the surface should be broken up, and mixed again with the liquid ; when it is apparent that the carbon is sufficiently separated and mixed with the sirup, it may be left to boil for a few minutes. The sirup now assumes a turbid and murky appearance ; whilst this operation is proceeding, a quart of ox blood, or the white of four eggs, should be beat up, and diluted with water, or otherwise, two quarts of skimmed milk. This mixture must now be thrown into the boiler, taking care to mix the whole, well together. The ebullition will, of course, have been stopped by this addition ; and it is proper, till it begins again to boil, that it should be constantly stirred, to prevent the precipitation of the ingredients ; the ebullition must be kept up for a few minutes, and the sirup is then prepared for filtration.

* The process we are about to describe is varied by *different* manufacturers. By some, the acid is omitted altogether, and other agents substituted.

Filtration.

This is an exceedingly simple operation; a flannel cloth fixed to a frame is all that is required.

Sirup at the density of thirty degrees cold, as it comes from the filterer, is not sufficiently concentrated to crystallize; it is therefore necessary to submit it to another boiling, to evaporate the superabundant water it still contains, and so to produce the required crystallization.

This operation is only a continuation of the concentrating process, and also its completion; the same boiler, which is suitable for the first part of this process, is the one now again required, the fire must be carefully attended to, the sirup skimmed when required, and, if it rises in foam, must be stopped, as before, by a piece of grease; when the proof shows ninety and one half to ninety-one of Reaumer, two hundred and thirty-six degrees Fahrenheit, which point it may reach, if the sirup is *very good*, it is time to stop and empty the boiler. It would be more prudent to do so at eighty-nine and one half; the sugar would purify more easily, and, as the molasses must necessarily be reboiled, this supports the operation, all the better, for being a little richer in sugar.

The sixteen and one half gallons, with which we began our experiment, will now be reduced to ten and one half gallons. In this state it may be turned into a vessel, to cool gradually, where it may stay for ten or twelve hours, when it will fall to the temperature of one hundred and seventy degrees, or one hundred and eighty degrees, *Fahrenheit*, and then may be put into the pots for crystallization. These usually contain six to eight gallons. In turning it into these, masses of the crystals will be found, already, at the bottom and sides of the vessel. If the sirup is good, some attention is necessary in this operation, that the sirup should not be left to get too cold, before it is turned into the pots; as this would, in some degree, impede the crystallization. These should be kept in a close room, and at a steady temperature. The pots are of a conical form, with a hole in the bottom, which is stopped with a cork or clay. Thirty-six or forty hours after the sirup has remained in them, and when the temperature is reduced to seventy-seven degrees, Fahrenheit, or thereabout, the cork is removed, and the point of the cone placed over a vessel into which the molasses (which begins immediately to run) is received. In about fifteen days, in a temperature of from sixty to sixty-five degrees, Fahrenheit, they have furnished above two thirds of their molasses. In this degree of heat the *whole* of the molasses will not separate from the sugar; the pots are therefore removed to another room, where the temperature is kept at from one hundred and twenty to one hundred and forty degrees, Fahrenheit. There they are again placed over the recipients; but, before doing this, a rod is thrust through the hole in the point of the cone, to break the incrustation of sugar within, and facilitate the draining of the molasses. After remaining here fifteen days, the sugar must be completely freed from the molasses, and must now be taken out. For this purpose, the cone is placed on its base, shook against the platform on which it stands, and, in an hour or so, the sugar is detached in the form of the cone; the point of this is impregnated with molasses, and is to be removed. It makes an inferior sort of brown sugar. The rest of the product will be generally fine, light colored sugar, which is found to produce a larger proportion of refined sugar to the weight, than any made from the cane, and is, therefore, much preferred by refiners. The sugar made at the beginning of the season is easier made, and better than that made later.

The molasses collected in the process of crystallization, is reboiled, and subjected to the same process as the sirup, and a certain portion of sugar is the result; the residuum is used for many purposes, and is especially useful for cattle.

For further particulars, see the work cited; also, a manual translated from portions of the treatise of M. M. Blachette, Zoega, and J. De Fontenelle, and published by Marsh, Capen, Lyon, and Webb, and a more recent work, on the same subject, by David Lee Child.

VIII.—Voltaic Electrical Engraving.

The following account of the process of engraving in relief, upon copper-plates, by means of voltaic electricity, is from the London Atheneum, for October 27, 1839. A previous number of this paper contained a letter from M. Jacobi, detailing his experiments on the subject; and it appears that Mr. Thomas Spencer, of Liverpool, had also devoted much attention to the subject, and had not only succeeded in doing all that M. Jacobi had done, but had surmounted difficulties which M. Jacobi could not. Mr. Spencer proposes, by means of voltaic electricity, "to engrave in relief upon a plate of copper; deposit a voltaic copper-plate, having the lines in relief; obtain a facsimile of a medal, reverse or obverse, or of a bronze cast; to obtain voltaic impression from plaster, or clay, and to multiply the number of already-engraved copper-plates." The results which he has already obtained are said to be very beautiful.

Take a plate of copper, such as is used by an engraver; solder a piece of copper wire to the back part of it, and then give it a coat of wax; (this is best done by heating the plate, as well as the wax;) then write or draw the design on the wax, with a black lead pencil, or a point. The wax must now be cut through with a graver, or steel point, taking special care that the copper is thoroughly exposed, in every line. The shape of the tool or graver employed must be such, that the lines made are not V-shape, but, as nearly as possible, with parallel sides. The plate should next be immersed in dilute nitric acid; say three parts water to one of acid. It will at once be seen whether it is strong enough, by the green color of the solution, and the bubbles of nitrous gas evolved from the copper. Let the plate remain in it long enough for the exposed lines to get slightly corroded, so that any minute portions of wax, which might remain, may be removed. The plate, thus prepared, is placed in a trough, separated into two divisions by a porous partition of plaster of Paris, or earthenware; the one division being filled with a saturated solution of sulphate of copper, and the other with a saline, or acid, solution. The plate to be engraved is placed in the division containing the solution of the sulphate of copper, and a plate of zinc, of equal size, is placed in the other division. A metallic connection is then made between the copper and zinc plates, by means of the copper wire soldered to the former ; and the voltaic circle is thus completed. The apparatus is then left for some days. As the zinc dissolves, metallic copper is precipitated, from the solution of the sulphate on the copper-plate, wherever the wax has been removed by the engraving tool. After the voltaic copper has been deposited in the lines engraved in the wax, the surface of it will be found to be more or less rough, according to the quickness of the action. To remedy this, rub the surface with a piece of smooth flag, or pumice-stone, with water. Then heat the plate, and wash off the wax ground, with spirits of turpentine and a brush. The plate is now ready to be printed from, at an ordinary press.

In this process, care must be taken that the surface of the copper in the lines be perfectly clean, as otherwise, the deposited copper will not adhere with any force, but is easily detached when the wax is removed. It is in order to insure this perfect cleanness of the copper, that it is immersed in dilute nitric acid. Another cause of imperfect adhesion of the deposited copper, which Mr. Spencer has pointed out, is the presence of a minute portion of some other metal, such as lead, which, by being precipitated before the copper, forms a thin film, which prevents the adhesion of the subsequently deposited copper. This circumstance may, however, be turned to advantage, in some of the other applications of Mr. Spencer's process, where it is desirable to prevent the adhesion of the deposited copper.

In copying a coin, or medal, Mr. Spencer describes two methods. The one is by depositing voltaic copper on the surface of the medal, and thus forming a mould, from which, facsimiles of the original medal may readily be obtained, by precipitating copper into it. The other is even more expeditious. Two pieces of clean milled sheet lead are taken, and the medal being placed between them, the whole is subjected to pressure in a screw-press, and a complete mould, of both sides, is thus formed in the lead, showing the most delicate lines, (in reverse.) Twenty, or even a hundred, of these, may be so formed on a sheet of lead, and the copper deposited by the voltaic process, with the greatest facility. Those portions of the surface of the lead, which are between the moulds, may be varnished, to prevent the deposition of the lead, or, a whole sheet of voltaic copper having been deposited, the medals may afterwards be cut out. When copper is to be deposited on a copper mould, or medal, care must be taken to prevent the metal deposited adhering. This Mr. Spencer effects by heating the medal, and rubbing a small portion of wax over it. This wax is then wiped off, a sufficient portion always remaining to prevent adhesion.

Enough has been said, to enable any one to repeat, and follow up, Mr. Spencer's interesting experiments. The variations, modifications, and adaptations, of them, are endless ; and many new ones will naturally suggest themselves to every scientific reader.

IX.—Photogenic Drawing.

Some account of Photography, or Photogenic drawing has been introduced in the previous pages of this work. The following article, containing a description of the process, is from a work on this subject, published by M. Daguerre, and translated by Mr. Memes, in 1839.

The designs are executed upon thin plates of silver, plated on copper. Although the copper serves principally to support the silver foil, the combination of the two metals tends to the perfection of the effect. The silver must be the purest that can be procured. As to the copper, its thickness ought to be sufficient to maintain the perfect smoothness and flatness of the plate, so that the images may not be distorted by the warping of the tablet; but unnecessary thickness, beyond this, is to be avoided, on account of the weight. The thickness of the two metals united ought not to exceed that of a stout card

The process is divided into five operations.

1. The first consists in polishing and cleaning the plate, in order to prepare it for receiving the sensitive coating, upon which the light traces the design.

2. The second is to apply this coating.

3. The third is the placing the prepared plate, properly, in the camera obscura, to the action of light, for the purpose of receiving the image of Nature.

4. The fourth brings out this image, which, at first, is not visible, on the plate being withdrawn from the camera obscura.

5. The fifth, and last, operation has, for its object, to remove the sensitive coating on which the design is first impressed, because this coating would continue to be affected by the rays of light, a property which would necessarily and quickly destroy the picture.

First Operation.—Preparing the Plate.

The requisites, for this operation, are,

A small phial containing olive oil.

Some very finely-carded cotton.

A small quantity of very fine pumice powder, ground with the utmost care, tied up in a bag of muslin, sufficiently thin to allow the powder to pass through, when the bag is shaken.

A phial of nitric acid, diluted with water, in the proportion of one pint of acid, to sixteen pints of distilled water. These proportions express volume, not weight.

A frame of iron wire, upon which to place the plate, in order that it may be heated by means of a spirit-lamp.

Lastly, a small spirit-lamp.

As already stated, these photographic delineations are executed upon silver, plated on copper. The size of the plate will depend, of course, on the dimensions of the camera. We must begin, by polishing it carefully. To accomplish this, the surface of the silver is powdered all over with the pumice, by shaking the bag, without touching the plate.

Next, with some cotton dipped in a little olive oil, the operator rubs the plate gently, rounding his strokes. During this operation, the plate must be laid flat upon several folds of paper, care being taken to renew these, from time to time, that the tablet be not twisted from any inequality in the support.

The pumice must be renewed, and the cotton changed, several times. The mortar, employed for preparing the pumice, must be of porphyry. The powder is afterwards finished, by grinding upon polished glass with a glass muller, and very pure water. And lastly, it must be perfectly dried. It will be readily apprehended, of what importance it is to attend to these directions, since upon the high polish of the silver, depends, in a great measure, the beauty of the future design. When the plate is well polished, it must next be cleaned, by powdering it all over, once more, with pumice, and rubbing with dry cotton, always rounding and crossing the strokes, for it is impossible to obtain a true surface by any other motion of the hand. A little pledget of cotton is now rolled up, and moistened with the diluted acid already mentioned, by applying the cotton to the mouth of the phial, and inverting it, pressing gently, so that the centre only of the cotton may be wetted, and but slightly, care being taken, not to allow any acid to touch the fingers. The surface of the plate is now rubbed *equally*, all over, with the acid, applied by the pledget of cotton. Change the cotton, and keep rubbing, rounding as before, that the acid may be equally spread, yet in so small a quantity, as just to skim the surface, so to speak. If, as frequently happens, the acid run into small drops, from the high polish, change the cotton repeatedly, and break down the globules as quickly as possible, but always by gently rubbing, for if allowed to rest, or to run upon the plate, they will leave stains. It will be seen when the acid has been properly diffused, from the appearance of a thin veil, spread regularly over the whole surface of the plate. Once more powder over pumice, and clean it with fresh cotton, rubbing as before, but very slightly.

The plate is now to be subjected to a strong heat. It is placed upon the wire frame, the silver upwards. The spirit-lamp is applied below the hand, moving it round, the flame touching and playing upon the copper. This operation being continued at least five minutes, a white strong coating is formed all over the surface of the silver, if the lamp has been made to traverse with proper regularity. The lamp is now withdrawn. A fire of charcoal may be used instead of the lamp, and is, perhaps, preferable, the operation being sooner completed. In this latter case, the wire frame is unnecessary, because the plate may be held by one corner with pincers, and so held over the fire, moving it at the same time, till all is equally heated, and the veil appear, as before described.

The plate is now to be cooled, *suddenly*, by placing it on a cold substance, such as a mass of metal, or stone, or, best of all, a marble table. When perfectly cold, it is to be again polished, an operation speedily performed, since the gummy appearance merely has to be removed, which is done by the dry pumice and cotton, repeated several times, changing the cotton frequently. The polishing being thus completed, the operation of the acid is to be repeated three different times, dry pumice being powdered over the plate, each time, and polished off very gently with the cotton, which must be very clean, care being taken not to breathe upon the plate, or to touch it with the fingers, or even with the cotton upon which the fingers have rested; for the slightest stain upon the surface will be a defect in the drawing.

When the plate is not intended for immediate use, the last operation of the acid is not performed. This allows any number of plates to be kept prepared, up to the last slight operation; and they may be purchased in this state, if required. It is, however, indispensable, that a last operation by acid, as described, be performed on every plate, immediately before it be placed in the camera. Lastly, every particle of dust is removed, by gently cleaning the whole edges, and back, also, with cotton.

Second Operation.—Coating the Plate.

For this operation, we require,

A box.

A small board.

Four small metallic bands, the same substance as the plates.

A small handle, and a box of small tacks.

A phial of iodine.

The plate is first to be fixed on the board, by means of the metallic bands, with their small catches and tacks. The iodine is now put into a little dish at the bottom of the box. It is necessary to divide the iodine into pieces, in order to render the exhalation the more extensively and more equally diffused; otherwise, it would form circles in the centre of the plate, which would destroy this essential requisite. The board is now fitted into its position, the plate face downwards, the whole being supported by small brackets projecting from the four corners of the box, the lid of which is then closed. In this position, the apparatus remains till the vaporization of the iodine, which is condensed upon the plate, has covered its surface with a fine coating of a yellow gold color. If this operation be protracted, the gold color passes into violet, which must be avoided; because in this state the coating is not so sensitive to the impressions of light. On the contrary, if the coating be too pale, the image of Nature in the camera will be too faint to produce a good picture. A decided gold color,—nothing more, nothing less,—is the only assurance that the ground of the future picture is duly prepared. The time for this cannot be determined, because it depends on several circumstances. Of these, the two principal are the temperature of the apartment, and the state of the apparatus. The operation should be left entirely to spontaneous evaporation of the iodine; or, at all events, no other heat should be used, than what can be applied through the temperature of the room, in which the operation takes place. It is also very important, that the temperature of the inside of the box be equal to that of the air outside; for, otherwise, a deposition of moisture takes place upon the plate, a circumstance most injurious to the final result. Secondly, as respects the state of the apparatus; the oftener it has been used, the less time is required, because, in this case, the interior of the box being penetrated with the vapors of iodine, these arise from all sides, condensing thus more equally and more rapidly upon the surface of the plate ; a very important advantage. Hence, it is of consequence to leave always a small quantity of iodine in the cup, and to protect this latter from damp. Hence, likewise, it is obvious, that an apparatus of this kind, which has been some time in use, is preferable to a new box ; for, in the former, the operation is always more expeditiously performed.

Since, from these causes, the time cannot be fixed, *a priori*, and may vary from five minutes to half an hour, rarely more, unless the weather be too cold, means must be adopted for examining the plate, from time to time. In these examinations, it is important not to allow the light to fall directly upon the plate. Also, if it appear that the color is deeper on one side of the plate than the other, to equalize the coating, the board must be replaced, not exactly in its former position, but turned one quarter round, at each inspection. In order to accomplish these repeated examinations, without injuring the sensibility of the ground, or coating, the process must be conducted in a darkened apartment, into which the light is admitted sideways, never from the roof ; the door left a little ajar answers best. When the operator would inspect the plate, he raises the lid of the box, and, lifting the board with both hands, turns up the plate quickly, and very little light suffices to show him the true color of the coating. If too pale, the plate must be instantly replaced, till it attain the proper gold tone ; but if this tint be passed, the coating is useless, and the operations must be repeated from the commencement of the first.

From description, this operation may, perhaps, seem difficult ; but with a little practice, one comes to know, pretty nearly, the precise interval necessary to produce the true tone of color, and also to inspect the plate with great rapidity, so as not to allow time for the light to act.

When the coating has reached the proper tone of yellow, the plate, with the board to which it is fixed, is slipped into the frame, and thus adjusted, at once, in the camera. In this transference, care must be taken to protect the plate from the light. A taper should be used ; and even with this precaution, the operation ought to be performed as quickly as possible, for a taper will leave traces of its action, if continued for any length of time.

We pass now to the third operation, that of the camera. If possible, the one should *immediately* succeed the other ; the longest interval between the second and third ought not to exceed an hour. Beyond this space, the action of the iodine and silver no longer possesses the requisite photogenic properties.

Observanda.—Before making use of the box, the operator should clean it thoroughly, turning it bottom upwards, in order to empty it of all the particles of iodine which may have escaped from the cup, avoiding, at the same time, touching the iodine with the fingers. During the operation of coating, the cup ought to be covered with a piece of gauze stretched on a ring. The gauze regulates the evaporation of the iodine, and also prevents the compression of the air, on the lid being shut, from scattering the particles of iodine, some of which, reaching the plate, would leave large stains on the coating. For the same reason, the top should always be let down with the greatest gentleness, not to raise the dust in the inside, the particles of which, being charged with the vapor of the iodine, would certainly reach and damage the plate.

Third Operation.—The Camera.

The apparatus, required in this operation, is limited to the camera obscura.

This third operation is that, in which, by means of light, acting through the camera, Nature impresses an image of herself on the photographic plate, enlightened by the sun, for then the operation is more speedy. It is easy to conceive that this operation, being accomplished only through the agency of light, will be the more rapid in proportion as the objects, whose photographic images are to be delineated, stand exposed to a strong illumination, or in their own nature present bright lines, and surfaces.

After having placed the camera in front of the land scape, or facing any other object of which it may be desirable to obtain a representation, the first essential is a perfect adjustment of the focus, that is to say, making your arrangements, so as to obtain the outlines of the subject with great neatness. This is accomplished, by advancing or withdrawing the frame of the obscured glass, which receives the images of natural objects. The adjustment being made with satisfactory precision, the movable part of the camera is fixed by the proper means, and the obscured glass being withdrawn, its place is supplied by the apparatus, with the plate attached, as already described, and the whole secured by small brass screws. The light is, of course, all this time excluded by the inner doors. These are now opened, by means of two semicircles, and the plate is disposed, ready to receive its proper impressions. It remains only to open the aperture of the camera, and to consult a watch.

This latter is a task of some nicety, inasmuch as nothing is visible, and it is quite impossible to determine the time necessary for producing a design, this depending entirely on the intensity of the light on the objects, the imagery of which is to be reproduced. At Paris, for example, this varies from three to thirty minutes.

It is likewise to be remarked, that the seasons, as well as the hour of the day, exert considerable influence on the celerity of the operation. The most favorable time is from seven to three o'clock; and a drawing which, in the months of June and July, at Paris, may be taken in three or four minutes, will require five or six, in May or August; seven or eight, in April and September; and so on, in proportion to the progress of the season. These are only general data for very bright, or strongly illuminated, objects; for it often happens, that twenty minutes are necessary, in the most favorable months, when the objects are entirely in shadow.

After what has just been said, it will readily occur to the reader, that it is impossible to specify, with precision, the exact length of time necessary to obtain photographic designs. Practice is the only sure guide; and, with this advantage, one soon comes to appreciate the required time, very correctly. The latitude is, of course, a fixed element in this calculation. In the south of France, for example, and generally in all those countries, in which light has great intensity, as Spain, Italy, &c., we can easily understand that these designs must be obtained with greater promptitude, than in more northern regions. It is, however, very important, not to exceed the time necessary, in different circumstances, for producing a design; because, in that case, the lights in the drawing will not be clear, but will be blackened by a too-prolonged solarization. If, on the contrary, the time has been too short, the sketch will be very vague, and without the proper details.

Supposing that he has failed in a first trial, by withdrawing the tablet too soon, or by leaving it too long exposed, the operator, in either case, should commence with another plate immediately; the second trial, being corrected by the first, almost insures success. It is even useful, in order to acquire experience, to make some essays of this kind.

In this stage of the process, it is the same as for the coating; we must hasten to the next operation. When the plate is withdrawn from the camera, it should immediately be subjected to the subsequent process; there ought, at most, not to be a longer interval than an hour, between the third and fourth operations; but one is always surest of disengaging the images, when no space has been allowed to intervene.

Fourth Operation.—Mercurial, or Disengaging, Process.

Here are required, a phial of mercury, containing at least three ounces.

A lamp, with spirit of wine.

An iron vessel, prepared with apparatus for receiving the plate, and submitting it to the vapor of mercury.

A glass funnel with a long neck.

By means of the funnel, the mercury is poured into the cup, at the bottom of the larger vessel. The quantity must be sufficient to cover the bulb of a thermometer. Afterwards, and throughout the remaining operations, no light, save a taper, can be used.

The board, with the plate affixed, is now to be withdrawn from the frame already described, as adapted to the camera. The board and plate are placed within the ledges of the black iron vessel, at an angle of forty-five degrees, the tablet with sketch downwards, so that it can be seen through the glass. The top is then gently put down, so as not to raise up particles of the mercury.

When all things are thus disposed, the spirit lamp is lighted, and placed under the cup containing mercury. The operation of the lamp is allowed to continue till the thermometer, the bulb of which is covered by the mercury, indicates a temperature of sixty degrees centigrade, [140°, Fahrenheit.] The lamp is then immediately withdrawn. If the thermometer has risen rapidly, it will continue to rise without the aid of the lamp; but this elevation ought not to exceed seventy-five degrees centigrade, [167° Fahrenheit.]

The impress of the image of Nature exists upon the plate, but it is invisible. It is not till after the lapse of several minutes, that the faint tracery of objects begins to appear, of which the operator assures himself, by looking through the glass, by the light of a taper, using it cautiously, that its rays may not fall upon, and injure, the nascent images of the sketch. The operation is continued till the thermometer sink to forty-five degrees centigrade, [113°, Fahrenheit;] the plate is then withdrawn, and this operation completed.

When the objects have been strongly illuminated, or when the action in the camera has been continued rather too long, it happens that this fourth operation is completed before the thermometer has fallen even to fifty-five degrees centigrade. One may always know this, however, by observing the sketch through the glass.

It is necessary, after each operation, to clean the inside of the apparatus carefully, to remove the slight coating of mercury adhering to it. When the apparatus has to be packed, for the purpose of removal, the mercury is withdrawn by a small cock, inclining the vessel to that side.

One may now examine the sketch, by a feeble light, in order to be certain that the processes hitherto have succeeded. The plate is now detached from the board, and the little bands of metal, which held it there, are carefully cleaned with pumice and water, after each experiment; a precaution rendered necessary from the coating both of iodine and mercury, which they have acquired. The plate is now deposited in the grooved box, until it undergoes the fifth and last operation. This may be deferred, if not convenient; for the sketch may now be kept for months, in its present state, without alteration, provided it be not too frequently inspected by the full daylight.

Fifth Operation.—Fixing the Impression.

The object of this final process, is to remove from the tablet the coating of iodine, which, continuing to decompose by light, would otherwise speedily destroy the design, when too long exposed. For this operation, the requisites are,

A saturated solution of common salt, or a weak solution of hyposulphite of pure soda.

An apparatus of japanned white iron, for washing the designs.

Two square troughs, of sheet copper.

A vessel for distilled water.

In order to remove the coating of iodine, common salt is put into a bottle, with a wide mouth, which is filled one fourth with salt and three fourths with pure water. To dissolve the salt, shake the bottle, and, when the whole forms a saturated solution, filter through paper. This solution is prepared in large quantities, beforehand, and kept in corked bottles.

Into one of the square troughs, pour the solution, filling it to the height of an inch; into the other, pour, in like manner, your water. The solution of salt may be replaced by one of hyposulphite of soda, which is even preferable, because it removes the iodine entirely, which the saline solution does not always accomplish, especially when the sketches have been laid aside for some time, between the fourth and fifth operations. It does not require to be warmed, and a less quantity is required.

First, the plate is placed in common water, poured into a trough, plunging and withdrawing it immediately, the surface merely requiring to be moistened; then plunge it into the saline solution, which latter would act upon the drawing, if not previously hardened by the washing in pure water. To assist the effect of the saline solutions, the plate is moved about in them, by means of a little hoop of copper wire. When the yellow color has quite disappeared, the plate is lifted up with both hands, care being taken not to touch the drawing, and plunged again into the first trough of pure water.

Next, the apparatus and the bottle having been previously prepared, made very clean, and the bottle filled with distilled water, the plate is withdrawn from the trough, and being instantly placed upon the inclined plane, distilled water, hot, but not boiling, is made to flow in a stream over its whole surface, carrying away every remaining portion of the saline wash.

If hyposulphite has been used, the distilled water need not be so hot, as when common salt has been employed.

Not less than a quart of distilled water is required, when the design is, in its dimensions, eight and a half by six and a half inches. The drops of water, remaining on the plate, must be removed by forcibly blowing upon it, for otherwise, in drying, they would leave stains on the drawing. Hence, also, will appear the necessity of using very pure water; for if, in this last washing, the liquid contain any admixture of foreign substances, they will be deposited on the plate, leaving behind numerous and permanent stains. To be assured of the purity of the water, let a drop fall upon a piece of polished metal; evaporate by heat, and if no stain be left, the water is pure. Distilled water is always sufficiently pure, without this trial.

After this washing, the drawing is finished; it remains only to preserve it from the dust, and from the vapors that might tarnish the silver. The mercury, by the action of which the images are rendered visible, is partially decomposed; it resists washing, by adhesion to the silver, but cannot endure the slightest rubbing.

To preserve these sketches, then, place them in squares of strong pasteboard, with a glass over them, and frame the whole in wood. They are thenceforth unalterable, even by the sun's light.

In travelling, the collector may preserve his sketches in a box; and, for greater security, may close the joints of the lid with a collar of paper.

It is necessary to state, that the same plate may be employed for several successive trials, provided the silver be not polished through to the copper. But it is very important, after each trial, to remove the mercury immediately, by using the pumice powder with oil, and changing the cotton frequently during the operation. If this be neglected, the mercury finally adheres to the silver; and fine drawings cannot be obtained, if this amalgam be present. They always, in this case, want firmness, neatness, and vigor of outline, and general effect.

A number of experiments, with prepared paper, have been made by different individuals, with various degrees of success, in Great Britain. From among the notices of these experiments, as they have appeared in different journals, the following selections have been made.

In the spring of 1834, Mr. Talbot began a series of experiments, with the hope of turning to useful account the singular susceptibility evinced by the nitrate of silver, when exposed to the rays of a powerful light. He says, "In the course of my experiments directed to that end, I have been astonished at the variety of effects, which I have found produced, by a very limited number of different processes, when combined in various ways; and also, at the length of time, which sometimes elapses, before the full effect of these manifests itself with certainty. For I have found, that images formed in this manner, which have appeared in good preservation, at the end of twelve months from their formation, have nevertheless somewhat altered, during the second year." He was induced, from this circumstance, to watch more closely the progress of this change, fearing that, in process of time, all his pictures might be found to deteriorate. This, how ever, was not the case, and several have withstood the action of the light, for more than five years.

The images, obtained by this process, are themselves white, but the ground is differently and agreeably colored; and, by slightly varying the proportions, and some trifling details of manipulation, any of the following colors were readily obtained; light blue, yellow, pink, brown, black, and a dark green, nearly approaching to black.

The first objects, to which this process was applied, were leaves and flowers, which it rendered with extraordinary fidelity, representing even the veins and minute hairs with which they were covered, and which were frequently imperceptible, without the aid of a microscope. Mr. Talbot goes on to mention, that the following considerations led him to conceive the possibility of discovering a preservative process. Nitrate of silver, which has become darkened by exposure to the light, is no longer the same chemical substance as before; therefore, if chemical re-agents be applied to a picture, obtained in the manner already mentioned, the darkened parts will be acted upon in a different manner from those which retain their original color, and, after such action, they will probably be no longer affected by the rays of the sun, or, at all events, will have no tendency to assimilate by such exposure; and, if they remain dissimilar, the picture will continue distinct, and the great difficulty be over come.

The first trials of the inventor, to destroy the susceptibility of the metallic oxide, were entirely abortive; but he has at length succeeded, to an extent equal to his most sanguine expectations. The paper, employed by Mr. Talbot, is superfine writing-paper; this is dipped into a weak solution of common salt, and dried with a towel, till the salt is evenly distributed over the surface; a solution of nitrate of silver is then laid over one side of the paper, and the whole is dried by the heat of the fire. It is, however, necessary to ascertain, by experiment, the exact degree of strength requisite in both the ingredients; for, if the salt predominates, the sensibility of the paper gradually diminishes, in proportion to this excess, till the effect almost entirely disappears.

In endeavoring to remedy this evil, Mr. Talbot discovered, that a renewed application of the nitrate not only obviated the difficulty, but rendered the preparation more sensitive than ever ; and, by a repetition of the same process, the mutability of the paper will increase to such a degree, as to darken of itself, without exposure to the light. This shows, that the attempt has been carried too far, and the object of the experimentalist must be to approach, without attaining this condition. Having prepared the paper, and taken the sketch, the next object is, to render it permanent, by destroying the susceptibility of the ingredients for this purpose. Mr. Talbot tried ammonia, and several other re-agents, with little success, till the iodine of potassium, greatly diluted, gave the desired result: this liquid, when applied to the drawing, produced an iodine of silver, a substance insensible to the action of light. This is the only method of preserving the picture in its original tints; but it requires considerable nicety, and an easier mode is sufficient for ordinary purposes. It consists in immersing the picture in a strong solution of salt, wiping off the superfluous moisture, and drying it by the heat of the fire ; on exposure to the sun, the white parts become of a pale lilac, which is permanent and immovable. Numerous experiments have shown the inventor, that the depth of these tints depends on the strength of the solution of salt. He also mentions, that those prepared by iodine become a bright yellow, under the influence of heat, and regain their original color, on cooling. Without the application of one of these preservatives, the image will disappear, by the action of the sun ; but, if enclosed in a portfolio, will be in no danger of alteration : this, Mr. Talbot remarks, will render it extremely convenient to the traveller, who may take a copy of any object he desires, and apply the preservative at his leisure. In this respect, Mr. Talbot's system is superior to that of M. Daguerre, since it would be scarcely possible for a traveller to burden himself with a number of metallic plates, which, in the latter process, are indispensable.

An advantage of equal importance exists in the rapidity with which Mr. Talbot's pictures are executed; for which half a second is considered sufficient; a circumstance that gives him a better chance of success in delineating animals, or foliage.—*Foreign Quarterly Review.*

Notice of a cheap and simple method of preparing paper for Photograpic Drawing, in which the use of any salt of silver is dispensed with: by MUNGO PONTON, Esq., F. R. S. E., Foreign Secretary Society of Arts for Scotland. Communicated by the Society of Arts.*

While attempting to prepare paper with the chromate of silver, for which purpose I used first the chromate of potash, and then the bichromate of that alkali, I discovered, that, when paper was immersed in the bichromate of potash alone, it was powerfully and rapidly acted on by the sun's rays. It accordingly occurred to me, to try paper so prepared, to obtain drawings, though I did not at first see how they were to be fixed. The result exceeded my expectations. When an object is laid in the usual way on this paper, the portion exposed to the light speedily becomes tawny, passing more or less into a deep orange, according to the strength of the solution, and the intensity of the light. The portion covered by the object retains the original bright yellow tint, which it had before exposure, and the object is thus represented yellow upon an orange ground, there being several gradations of shade, or tint, according to the greater or less degree of transparency in the different parts of the object.

In this state, of course, the drawing, though very beautiful, is evanescent. To fix it, all that is required is careful immersion in water, when it will be found that those portions of the salt, which have not been acted on by the light, are readily dissolved out, while those which have been exposed to the light are completely fixed in the paper. By this second process, the object is obtained white, upon an orange ground, and quite permanent. If exposed, for many hours together, to strong sunshine, the

* Read before the Society of Arts for Scotland, 29th May, 1839.

color of the ground is apt to lose in depth, but not more so than most other coloring matters.

The action of light, on the bichromate of potash, differs from that upon the salts of silver. Those of the latter, which are blackened by light, are of themselves insoluble in water; and it is difficult to impregnate paper with them, in an equable manner. The blackening seems to be caused by the formation of oxide of silver. In the case of the bichromate of potash, again, that salt is exceedingly soluble, and paper can be easily saturated with it. The agency of light not only changes its color, but deprives it of solubility, thus rendering it fixed in the paper. This action appears to me to consist in the disengagement of free chromic acid, which is of a deep red color, and which seems to combine with the paper. This is rendered more probable, from the circumstance, that the neutral chromate exhibits no similar change.

The active power of the light, in this instance, resides principally in the violet rays, as is the case with the blackening of the salts of silver. To demonstrate this, three similar flat bottles were filled, one with ammoniuret of copper, which transmits the violet rays, one with bichromate of potassa, transmitting the yellow rays, the third, with tincture of iodine, transmitting the red rays. The paper was readily acted on through the first, but scarcely, if at all, through the second and third; although much more light passed through the bottle filled with bichromate of potassa, than through the one filled with ammoniuret of copper.

The best mode of preparing paper with bichromate of potash is, to use a saturated solution of that salt; soak the paper well in it, and then dry it rapidly, at a brisk fire, excluding it from daylight. Paper, thus prepared, acquires a deep orange tint, on exposure to the sun. If the solution be less strong, or the drying less rapid, the color will not be so deep.

A pleasing variety may be made, by using sulphate of indigo along with the bichromate of potash, the color of the object, and of the paper, being then of different shades of green. In this way, also, the object may be represented of a darker shade than the ground.

Paper, prepared with bichromate of potash, is equally sensitive with most of the papers, prepared with salts of silver, though inferior to some of them. It is not sufficiently sensitive for the camera obscura, but answers quite well for taking drawings from dried plants, or for copying prints, &c. Its great recommendation is, its cheapness, and the facility with which it can be prepared. The price of the bichromate of potash is 2*s.* 6*d.* per lb., whereas, of the nitrate of silver, only half an ounce can be obtained for that sum. The preparing of paper, with the salts of silver, is a work of extreme nicety, whereas, both the preparing of the paper with the bichromate of potash, and the subsequent fixing of the images, are matters of great simplicity; and I am therefore hopeful, that this method may be found of considerable practical utility, in aiding the operations of the lithographer.—***Jameson's Journal, April to July***, 1839

GLOSSARY.

MANY words, not contained in this GLOSSARY, will be found defined or described, in the body of the Work, in their proper places. For these, see *Index*.

Acescent, becoming sour.
Acetate, a salt, containing acetic acid.
Acetic acid, a vegetable acid which exists in vinegar.
Acetous, having the character of vinegar.
Acetous fermentation, the fermentation which produces vinegar.
Acicular, shaped like needles.
Acid, a substance, or fluid, which turns vegetable blues to a red, and forms saline compounds with alkalies, &c. Most of the acids contain oxygen.
Albumen, a fluid found in living bodies, which coagulates by heat. White of egg is an example.
Alkali, a substance in chemistry, which turns vegetable blues to a green, and combines with acids, forming salts.
Alloy, a compound of different metals.
Alumine, an earth, which exists in clay, alum, &c.
Aluminium, a metal, which is the basis of alumine.
Amalgam, a compound of mercury with another metal.
Ammonia, volatile alkali.
Amorphous, not having a determinate or certain form.
Argillaceous, containing clay, or resembling it.
Argillaceous schist, common slate.
Arseniuret, a compound with arsenic.
Barilla, the ashes of certain maritime plants.
Barometer, an instrument for measuring the weight of the atmosphere.
Base, an ingredient in a chemical compound. Thus, sulphuric acid is found combined with various bases, such as soda, magnesia, &c.
Bichloride, a double chloride. A compound, having two proportionals of chlorine.
Boracic acid, a compound of oxygen and boron, which last is a simple combustible substance.
Borates, compounds of boracic acid with a base.
Brake, or *Break*, a lever, which is occasionally pressed down upon the wheel of a carriage, to retard its velocity.
Bromide, a compound of bromine and some other substance.
Bromine, an elementary substance, related to iodine and chlorine, and found in sea water.

Camera lucida, } optical instruments, by which the images of ob-
Camera obscura, } jects, as, for example, buildings or trees, are thrown upon a paper, or other plane surface.

Carbonaceous, containing carbon or coal.

Carbon, a simple inflammable body, forming the principal part of wood and coal, and the whole of the diamond.

Carbonate, a compound or a salt, containing carbonic acid.

Carbonic acid, a compound gas, consisting of carbon and oxygen. It has lately been obtained in a solid form.

Carbonic oxide, a gas composed of carbon combined with the smallest quantity of oxygen.

Carbonization, conversion into coal.

Carburetted hydrogen, a gas, composed of carbon and hydrogen ; as coal gas.

Carburet, a name given to certain compound substances, of which carbon forms a part.

Caseous, having the consistence of cheese.

Centre of gravity, that point in a body, about which all the parts are equally balanced.

Centrifugal, tending to fly off from the centre.

Chloride, a compound of chlorine and some other substance.

Chlorine, a simple substance, formerly called oxymuriatic acid. In its pure state, it is a gas, and, like oxygen, supports the combustion of some inflammable substances.

Chromate, a combination of chromic acid.

Chromium, a brittle metal, of a yellowish white color.

Chromic acid, an acid of which chromium is the basis.

Chromate, a compound of chromic acid with some other substance, or base.

Clay schist, common slate.

Cohesive attraction, the force by which the particles of a body cohere together.

Coluber, a snake, having plates on the belly and scales on the tail.

Comparative anatomy, the science which treats of the structure of other animals, compared with that of man.

Concentric, having the same centre.

Conic sections, the curves produced by cutting across a cone, in different directions.

Cupreous, containing copper.

Cycloid, the curve described by a point in the circumference of a circle, while the circle rolls along a straight line.

Cylinder, a figure with circular ends and straight, parallel sides. A round ruler and a wafer box are rough examples of the cylindrical shape.

Debris, fragments, or remains, of disintegrated rocks.

Deliquescent, dissolving by fluid absorbed from the atmosphere.

Disintegrated, broken up or crumbling, for the most part, by the action of air and moisture.

Eccentric, or *excentric*. This term is applied to a wheel, the axis of which is not in its centre.

Effervescence, a motion resembling boiling.

Efflorescence, the conversion of crystals into powder by the loss of their water of crystallization.
Electro-magnetism, a science which shows the connexion of electricity and magnetism.
Epicycloid, the curve described by a point in the circumference of one circle, while rolling upon the circumference of another.
Flange, or *Flanch*, a rim, or part projecting from the whole circumference. Flanges are used in the wheels of rail-road cars, to prevent them from slipping off the track ; also, at the ends of iron pipes, to enable them to be screwed together.
Flocculent, resembling locks of down, or cotton.
Fluate of lime, or *Fluor spar*, lime combined with fluoric acid. At Derbyshire, in England, it is found in crystalline masses, beautifully variegated with purple.
Flush, even, or in the same surface.
Friction, the rubbing of surfaces together.
Friction rollers, little wheels, or cylinders, used to diminish friction.
Fulcrum, the point of support on which a lever rests.
Gallate, a salt, formed of gallic acid and a base.
Gallic acid, an acid obtained from nutgalls.
Gear, the teeth of wheels, by which one moves another.
Gelatin, an animal substance which is dissolved by hot water, and which forms common glue.
Geognostic, appertaining to a knowledge of the earth's structure.
Geological strata, the natural layers which are met with in penetrating the earth.
Gneiss, stratified granite.
Gobelins, the name of a celebrated manufactory of tapestry in Paris, so called, after two brothers of that name, who founded the manufactory in the reign of Francis I.
Gravity, the general property by which bodies are attracted towards each other, as seen in a stone falling towards the earth.
Graywacke, a kind of rock, of a gray or brown color, composed of grains and fragments of different materials.
Hæmatite, an ore of iron.
Hydrate, a solid compound with water.
Hydrate of lime, a solid compound of lime with water.
Hydraulics, the science which treats of the motion of fluids.
Hydraulic cement, mortar, which hardens under water.
Hydrochlorate, a salt containing hydrochloric, or muriatic, acid.
Hydrochloric acid, see *Muriatic acid*.
Hydrodynamics, the science which treats of the power or force of water.
Hydrogen, a very light, inflammable gas, of which water is, in part, composed. It is used to inflate balloons.
Hydrostatic pressure, the property of fluids by which they press equally in all directions.
Hydrostatics, the science which treats of the pressure of fluids.
Hydrosulphuret, a compound of hydrogen and sulphur with another body.
Hyperbola, one of the conic sections.

Hyposulphite, a combination of hyposulphurous acid with a base, as, for example, with soda.
Inclination, slant, slope, or obliquity.
Inertia, the tendency which a body has to continue at rest, or to move in a straight line, if it moves at all.
Infiltration, the penetration of a fluid into the pores of a solid, as in soaking.
Infusion, a solution of a vegetable substance, made without boiling.
Initial, that which exists at the first moment. Primary, incipient.
Inspissated, thickened, as when the juice of a plant is partly dried.
Iodine, a simple substance, of a grayish black color, and metallic lustre, having a violet-colored vapor. It is obtained from marine plants.
Iridium, a metal, found in minute quantities in the ores of platinum.
Kelp, the ashes of seaweed.
Larvæ, the name given to certain insects in their primary state, before they acquire wings; as the caterpillar.
Litharge, an oxide of lead partly vitrified, or converted into glass.
Magnesia, a kind of earth, light and white, with alkaline properties.
Malachite, an ore of copper.
Malic acid, a vegetable acid which exists in cider.
Minimum, the smallest quantity.
Momentum, the force possessed by a body in motion, made up of its weight and velocity.
Muffle, a vessel resembling a little oven, placed in furnaces to contain crucibles and other objects, which require to be protected from smoke and ashes.
Muriate, a salt, containing muriatic or hydrochloric acid.
Muriatic acid, an acid, composed of chlorine and hydrogen; called, also, hydrochloric acid, and spirit of salt.
Nitrate, a salt, containing nitric acid.
Nitric acid, an acid composed of oxygen and nitrogen.
Nitrogen, or *azote*, a simple substance, which exists, in the form of gas, in the atmosphere. It does not support respiration nor flame.
Ochre, an earth colored yellow or red by oxide of iron.
Ochreous, containing ochre.
Orrery, a machine, constructed to show the motions of the heavenly bodies.
Osmium, a metal, found in minute quantities in the ores of platinum.
Oxalic acid, a vegetable acid which exists in sorrel.
Oxidable, capable of being oxidized.
Oxidation, combination with oxygen; as in the rusting and tarnishing of metals.
Oxide, a compound (which is not acid) of a substance with oxygen:—Example, oxide of iron.
Oxygen, a simple and very important substance, which exists in the atmosphere, and supports the breathing of animals and the burning of combustibles.
Oxymuriatic acid, see *Chlorine*.
Parallelogram, an oblong square.
Parallelopiped, a solid body, of which the four sides are parallelograms, and the two ends square.

Piles, large wooden posts or timbers, driven into the mud, to suppor bridges and other structures.
Piling engines, engines for driving piles.
Plasticity, the property or capacity of being moulded.
Pontoon, a kind of flat-bottomed boat, used to support bridges, floating machinery, &c.
Potass, an alkali, composed of potassium and oxygen.
Potassium, a light and very inflammable metal, discovered in potass, by Sir H. Davy.
Power of a number, the product obtained by multiplying a number by itself. The product obtained by the first multiplication is called the square. If this be again multiplied by the same number, it gives the cube ; and so on, for the higher powers.
Precipitation. When a substance, dissolved in a liquid, is afterwards separated, in a solid state, by the addition of another substance, it is said to be precipitated.
Purple of Cassius, a purple powder, precipitated from a solution of gold.
Pyrites, a compound of a metal with sulphur, having a metallic lustre, and often crystallized.
Pyritous, having the charactes of pyrites.
Pyrometer, an instrument for measuring high degrees of heat, as in furnaces, &c.
Radicles, small roots.
Radius, a line drawn from the centre of a circle to its circumference.
Reticulated, resembling the appearance of a net.
Rhodium, a metal found in minute quantities in the ores of platinum.
Salt, a compound, produced by the union of an acid with a base.
Saturated solution, a liquid, holding so much of a substance dissolved, that it can dissolve no more.
Scalpel, a dissecting knife.
Schist, or *Schistus*, slate.
Sector of a circle, a part contained between two radii and an arc. The sector of a cylinder is a longitudinal part which bears the same relation to the whole, as a sector does to a circle.
Silica, or *silex*, an earth which exists in flint, sand, &c.
Silicium, a metal, or simple substance, which is the basis of silica
Sinuosities, windings.
Soda, an alkali, obtained from the ashes of marine plants.
Spar, a general name given to crystallized minerals.
Stanniferous, containing tin.
Stratification, disposal in layers.
Stratum, plural *strata*, a layer of earth, rock, or other mineral substance.
Striated, marked with fine parallel lines.
Sulphate, a salt, containing sulphuric acid.
Sulphur, or *brimstone*, a simple, inflammable substance, well known.
Sulphuret, a compound of sulphur with another body.
Sulphuretted hydrogen, a gas, composed of sulphur and hydrogen.
Sulphuret of carbon, a compound of sulphur and carbon.
Sulphuric acid, an acid composed of oxygen and sulphur.

Summit level, the highest part of a canal, or rail-road.
Tangent, an external straight line, which touches, but does not cross, a circle.
Tartaric acid, a vegetable acid which exists in wine.
Thermæ, baths of the Romans, which were large and magnificent buildings.
Thermal waters, warm or hot springs.
Thermometer, an instrument, for measuring heat.
Traction, the act of drawing a load. Draught.
Treenails, (pronounced *trunnels*,) the wooden pins which confine the planking to the sides of vessels. Also, similar pins, employed for other purposes.
Vacuum, empty space. A perfect vacuum is rarely, if ever, produced. The vacuum of the air pump, and that of the barometer, are approximations only, in which some gas or vapor is present.
Vaporization, conversion into vapor, commonly at a boiling temperature.
Velocipede, a carriage with two wheels, one before the other, on which a person rides, pushing himself forward with his feet.
Viaduct, a piece of masonry built across a stream or valley, to support a road, or a rail-way.
Vice versa, the side being changed, or the question reversed.
Vitreous, glassy.
Water-joint, a movable joint, made so tight as to exclude water

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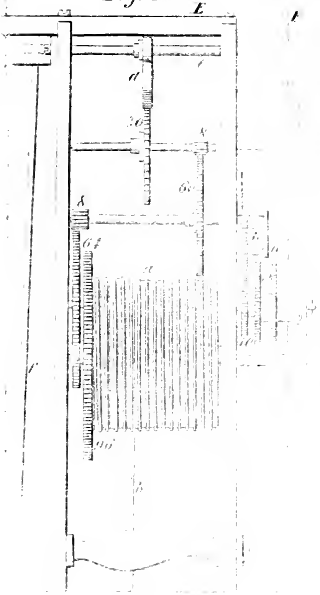

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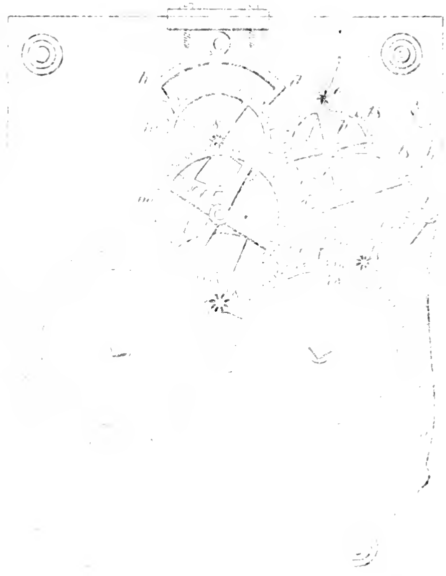

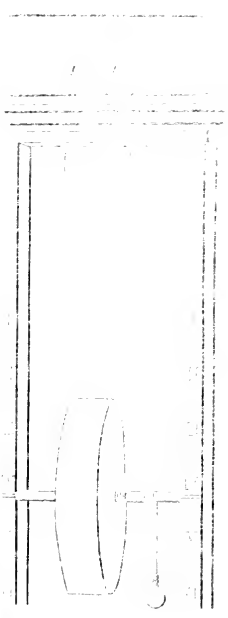

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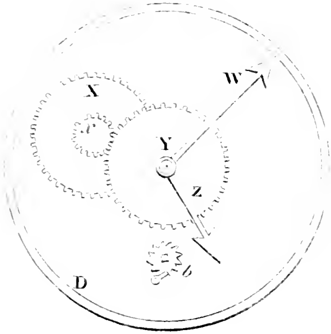

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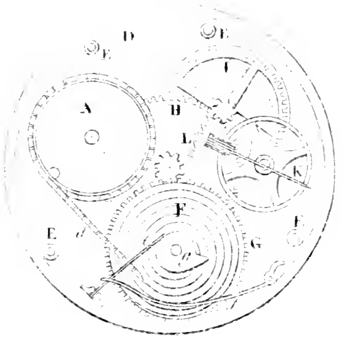

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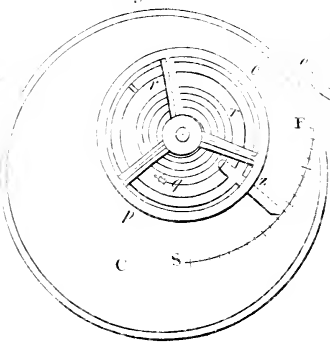

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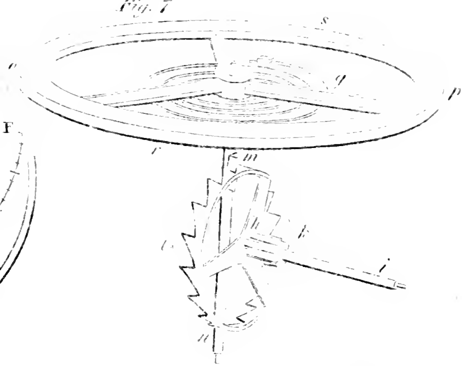

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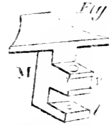

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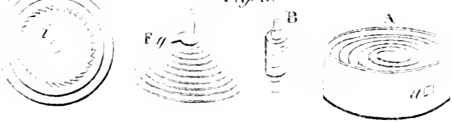

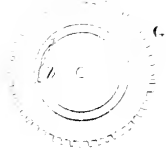

Fig. 6.