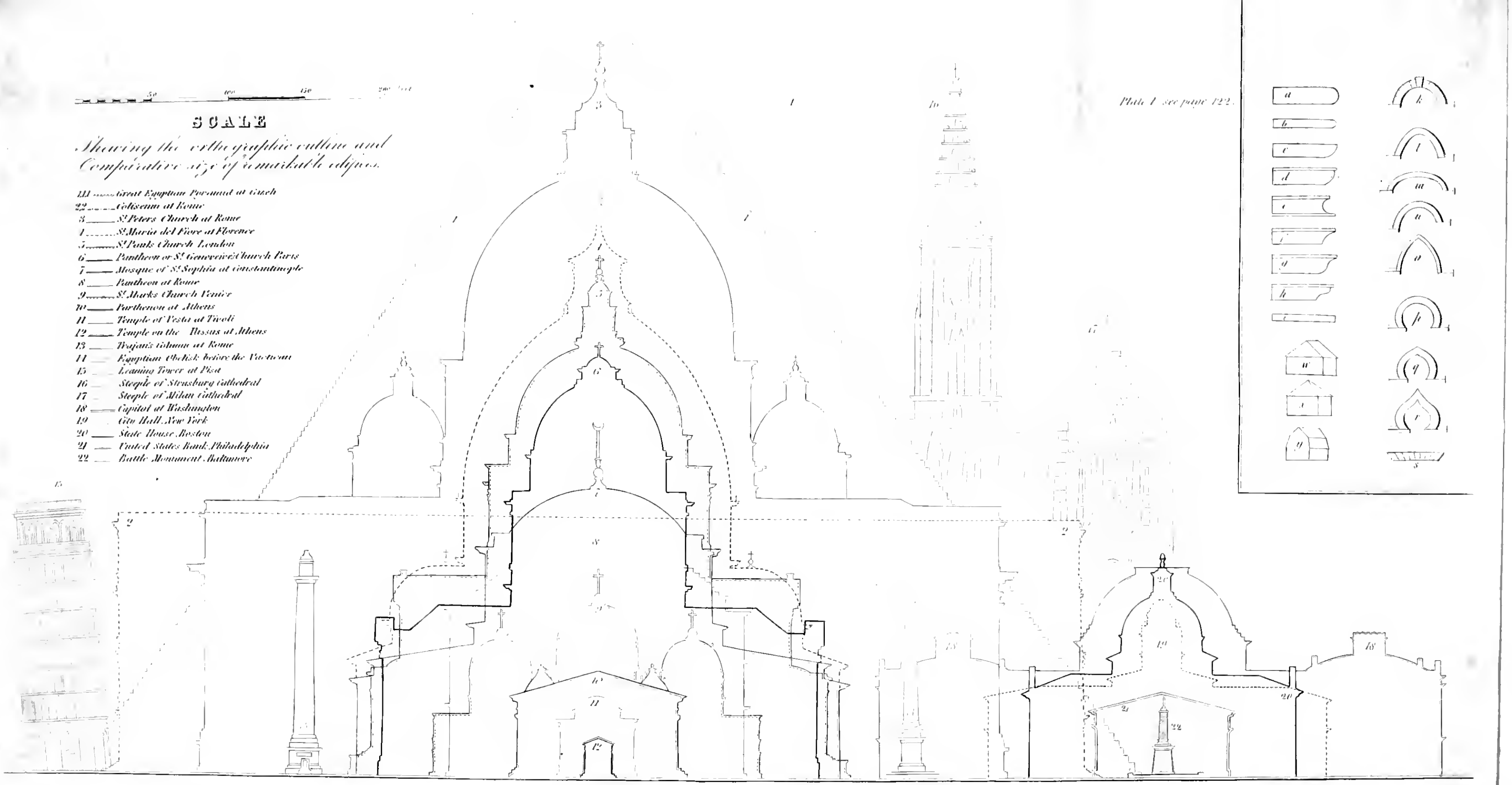
Plate 1 see page 122.
50
100
150
200 feet
SCALE
Shewing the orthographic outline and Comparative size of remarkable edifices.
1.1 Great Egyptian Pyramid at Gizeh
2.2 Coliseum at Rome
3 St Peters Church at Rome
4 St Maria del Fiore at Florence
5 St Pauls Church London
6 Pantheon or St Genevieve's Church Paris
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15 Leaning Tower at Pisa
16 Steeple of Strasburg Cathedral
17 Steeple of Milan Cathedral
18 Capitol at Washington
19 City Hall New York
20 State House Boston
21 United States Bank Philadelphia
22 Battle Monument Baltimore

ELEMENTS

OF

TECHNOLOGY,

TAKEN CHIEFLY FROM

A COURSE OF LECTURES

DELIVERED

AT CAMBRIDGE,

ON THE

APPLICATION OF THE SCIENCES

TO THE

USEFUL ARTS.

NOW PUBLISHED

FOR THE USE OF SEMINARIES AND STUDENTS.

BY JACOB BIGELOW, M. D.

Professor of Materia Medica, and late Rumford Professor in Harvard University; Member of the American Academy of Arts and Sciences; of the American Philosophical Society; of the Linnæan Societies of London and Paris, &c.

SECOND EDITION,

WITH ADDITIONS.

BOSTON:
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1831.

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ADVERTISEMENT

TO THE FIRST EDITION.

A COURSE of Lectures on most of the subjects which occupy this volume, has been delivered at Cambridge, during ten years past, in pursuance of the will of the late Count Rumford, by whose bequest a professorship is founded in Harvard University, on the Application of the Sciences to the Useful Arts. Parts of the same course have been repeated in Boston, to large audiences.

The degree of interest which has been taken in these Lectures, has led me to believe that the subject is, in itself, peculiarly capable of exciting the attention and curiosity of students. There can be no doubt that the knowledge, which this study is intended to furnish, is of great use in the common affairs of life; and probably its advancement has contributed, more than that of any other science, to the improved condition of the present age.

A certain degree of acquaintance with the theory and scientific principles of the common arts, is found so generally important, that most educated men, in the course of an ordinary practical life, are obliged to obtain it from some source, or to suffer inconvenience for the want of it. He who builds a house, or buys an estate, if he would avoid disappointment and loss, must know something of the arts, which render them appropriate, and tenantable. He who travels abroad to instruct himself, or enlighten his countrymen, finds in the works of art, the most commanding objects of his attention and interest. He who remains at home, and limits his ambition to the more humble object of keeping his apartment warm, and himself comfortable, can only succeed through the instrumentality of the arts.

There has probably never been an age in which the practical applications of science have employed so large a portion of the talent and enterprise of the community, as in the present ; nor one in which their cultivation has yielded such abundant rewards. And it is not the least of the distinctions of our own country, to have contributed to the advancement of this branch of improvement, by many splendid instances of inventive genius and successful perseverance.

The importance of the subject, and the prevailing interest, which exists in regard to the arts and their practical influences, appear to me to have created a want, not yet provided for, in our courses of elementary education. Information on these subjects is scattered through the larger works on mechanics, on chemistry, mineralogy, engineering, architecture, domestic economy, the fine arts, &c., so that it rarely happens that a student in any of our colleges gathers information enough to understand the common technical terms which he meets with in a modern book of travels, or periodical work. It is only by making the elements of the arts themselves, subjects of direct attention, that this deficiency is likely to be supplied.

To embody, as far as possible, the various topics which belong to such an undertaking, I have adopted the general name of Technology, a word sufficiently expressive, which is found in some of the older dictionaries, and is beginning to be revived in the literature of practical men at the present day. Under this title it is attempted to include such an account as the limits of the volume permit, of the principles, processes, and nomenclatures of the more conspicuous arts, particularly those which involve applications of science, and which may be considered useful, by promoting the benefit of society, together with the emolument of those who pursue them.

In preparing for the press the lectures on which this work is founded, some variations from the original form have been made, together with such additions as my leisure from professional engagements has permitted. In doing this, occasional use has been made of the works of Robison, Young, Tredgold, and several of the late chemical writers. But as the present elementary volume is composed for the instruction of the uninitiated, rather than for the perfection of adepts, it has been found necessary to condense and to endeavor to render intelligible the subjects of consideration, rather than to dilate them by minute expositions and details. For the use of those students, who may wish to extend their inquiries in reference to any of the particular subjects, a list of some of the more prominent authors, and works of value, that treat upon the several subjects, is subjoined at the end of each chapter. Among some of these works, the authorities for the facts stated in the preceding chapters, will in most instances be found.

For the convenience of seminaries which may make use of this work, the wood cuts and diagrams which are interspersed with the text, are reprinted at the end of the volume.

J. B.

ADVERTISEMENT

TO THE SECOND EDITION.

In the present edition, it has not been thought necessary to make any important deviations from the plan of the first. No material part of the work has been omitted. Such additions as it has been thought proper to make, will be found incorporated with the text under their respective heads.

Boston, June, 1831.

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INTRODUCTION.

Whenever we attempt to draw a dividing line between the *sciences*, usually so called and the *arts*, it results in distinctions, which are comparative, rather than absolute. In many branches of human knowledge, the two are so blended together, that it is impossible to make their separation complete. In common language, we apply the name of *sciences* to those departments of knowledge which are more speculative, or abstract, in their nature, and which are conversant with truths or with phenomena, that are in existence at the time we contemplate them. The *arts*, on the contrary, are considered as departments of knowledge, which have their origin in human ingenuity, which depend on the active, or formative processes of the human mind, and which, without these, would not have existed. Our knowledge may be said to have been found out originally by discovery and invention. Discovery is the process of science; invention is the work of art. So common, however, is the connexion of the two with each other, that we find both a science and an art involved in the same branch of study. For example, chemistry is a science depending on the immutable relations of matter, which relations must have existed, had there never been minds to study them. Yet these laws of matter would not have become the subjects of science, had not mankind invented the *art* of separating their agents, and making them cognizable to the senses. To build a ship, to construct a watch, or to paint a picture, are all operations of art; yet they all have their foundation in a certain acquaintance with mathematical rules, and principles of natural philosophy. Those artists, who work with a thorough knowledge of principles, we are accustomed to denominate scientific; while those who experiment at random, or who blindly copy the results of others, we consider empirical. Thus it appears that an intimate connexion and dependence exists between sciences and arts, and it follows that the claim which they offer to our attention is in a great measure of the same kind. Of the latter, as well as the former, we already require some, as branches of a common education; while of the rest there are few which may not be advantageously studied, either as affording exercise for talents, discipline for taste, or practical advantage in the common concerns of life.

The connexion of the arts with the sciences is more common and obvious in modern times, than it was in the days of antiquity. During the process of civilization, or the whole period which elapses between barbarism and complete refinement, the arts have uniformly taken precedence both of science and literature. Rude nations commence the improvement of their state, by an attention to agriculture, to building, to navigation, and to sculpture. The want of an acquaintance with the real or scientific principles of these arts, obliges them to substitute the effects of manual labor and dexterity, for scientific method; and hence the paths in which they excel, have been usually of a different character from those of people whose knowledge and resources are greater. The ancients, who were but recently descended from barbarians, were obliged to make the most of small means, because the stock of previous or common information, from which they could draw, was extremely limited. The moderns have the accumulated learning of ages before them, and have only to select and apply their agents from among a multitude of means already discovered. The qualities, by which the former arrived at excellence, were more or less concentrated in individuals;

while with us the means of excellence are recorded in books, and are at the disposal of communities. They possessed the quick eye, the expert hand, acute taste and unwearied industry. For these we substitute preparatory science, economical computation, and mechanical power. Their processes differed from ours, as the process of the savage who fashions and polishes his war-club, by the truth of his eye, and the patience and dexterity of his hand; differs from that of the civilized mechanic, who turns the same kind of thing, in a lathe, which another man has invented for him, in a hundredth part of the time. The ancients were prodigal of means, and lavished men and treasures when any great work was to be accomplished. The moderns save expense, and labor, and time in everything. The economy of the ancients consisted in diminishing their personal wants; ours, in devising cheap means to gratify them. They prepared their soldiers for war by inuring them to hunger and fatigue; we, by keeping them well fed and clothed. Their stateliest edifices were destitute of chimnies and glass windows, yet when left to themselves, they have stood for thousands of years. Ours abound in the means of making their present tenants comfortable, but are often built too cheaply to be durable. They conveyed water to their cities in immense horizontal channels supported on arcades of prodigious elevation. We convey it over mountains and under vallies in hydraulic pipes of the most trivial size. Wherever art could precede philosophy, the ancients have exhibited the grandest productions of genius and strength; but, in the application of philosophy to the arts, the moderns have achieved what neither genius nor strength, unassisted, could have performed. The imitative arts, and those which required only boldness and beauty of design, or perseverance in execution, were carried in antiquity to the most signal perfection. Their sculpture has been the admiration of subsequent ages, and their architecture has furnished models which we now strive to imitate, but do not pretend to excel. We might, if this were the place, add their poetry, and their oratory, to the list of arts which flourished in perfection during the youthfulness of intellectual cultivation. But in modern times there is a maturity, a cautiousness, a habit of induction, which is founded on the advanced state of philosophic knowledge. Our arts have been the arts of science, built up from an acquaintance with principles, and with the relations of cause and effect. With less bodily strength, and probably with not more vigorous intellects, we have acquired a dominion over the physical and moral world, which nothing but the aid of philosophy could have enabled us to establish. We convert natural agents into ministers of our pleasure and power, and supply our deficiencies of personal force by the application of acquired knowledge. Among us, to be secure, it is not necessary that a man should be powerful and alert; for even where laws fail, the weak take rank with the strong, because the weakest man may arm himself with the most formidable means of defence. The labor of a hundred artificers is now performed by the operations of a single machine. We traverse the ocean in security, because the arts have furnished us a more unfailing guide than the stars. We accomplish what the ancients only dreamt of in their fables; we ascend above the clouds, and penetrate into the abysses of the ocean.

The application of philosophy to the arts is a more fruitful theme, than can well be condensed into a limited work, or course of instruction. While it comprises some of the sources even of ancient refinement, it includes a great part of the grounds of modern superiority. The application of philosophy to the arts may be said to have made the world what it is at the present day. It has not only affected the physical, but has changed the moral and political condition of society. The invention of the printing press, dispersed the darkness of the middle ages, and carried truth and knowledge to every portion of the world. The artificial combination of sulphur, nitre, and charcoal, has revolutionized the customs and the arts of war, and even in military life, has given the mind the advantage over the body. The moderns have imparted magnetism to a piece of steel, and suspended it on a pivot; and what has been the consequence? It has opened to them a path across unknown seas, and has disclosed a new continent to the inhabitants of the old, a successor to their arts and their power. It has developed the wealth of unknown islands, has brought the remotest countries together, and has made the ocean the resort and support of multitudes. Let any one, who would know what modern arts have accomplished, compare the repeating watch, and the unerring chronometer of the present day, with the rude sun-dial and clepsydra of the ancients. Let him consider the multiplied advantages which attend the invention of glass, which has enabled us to combine light with warmth in our houses; which has given sight to the aged, which has opened the heavens to the astronomer, and the wonders of microscopic life to the naturalist. Let him attend to the complicated engines and machinery, which are now introduced into almost every manufacturing process, and which render the physical laws of inert matter a substitute for human strength.

But it is not the contrast with antiquity alone, that enables us to appreciate the benefits which modern arts confer. In the present inventive age, even short periods of time bring with them momentous changes. Every generation takes up the march of improvement where its predecessors had stopped, and every generation leaves to its successors an increased circle of advantages and acquisitions. Within the memory of many who are now upon the stage, new arts have sprung up, and practical inventions, with dependent sciences; bringing with them consequences which have diverted the industry, and changed the aspect of civilized countries. The augmented means of public comfort and of individual luxury, the expense abridged and the labor superseded, have been such, that we could not return to the state of knowledge which existed even fifty or sixty years ago, without suffering both intellectual and physical degradation. At that time, philosophy was far distant from its present mature state, and the arts which minister to national wealth were in comparative infancy. No man then knew the composition of the atmosphere, or of the ocean. The beautiful and intricate machinery, which weaves the fabric of our clothing, was not even in existence. When George III. visited the works of Messrs Boulton and Watt, at Birmingham, and was told that they were manufacturing an article of which kings were fond, and that that article was power; he was struck with the force and disadvantageousness of the comparison. Yet the steam engine had not then been launched upon the ocean, and had developed only half its energies.

So long as the arts continue to exert the influence, and to yield the rewards, which they have hitherto done, there will be no want of competent minds and hands, to carry forward their advancement. With their increasing consequence, there must also be an increasing attention to their study and dissemination. Curiosity keeps pace with the interest and magnitude of its objects. And unless the character of the present age is greatly mistaken, the time may be anticipated as near, when a knowledge of the elements and language of the arts will be as essentially requisite to a good education, as the existence of the same arts is to the present elevated condition of society.

ELEMENTS OF TECHNOLOGY.

CHAPTER I.

OF MATERIALS USED IN THE ARTS.

The mineral, vegetable, and animal kingdoms, respectively contribute to supply the substances which are necessary in the arts. Of these substances, many have been known and used from the time of the earliest records; others are of recent introduction, and additions are still making to the stock previously known. The value of a substance to the arts, may be estimated from the importance of the object it fulfils, its durability, the number of purposes to which it may be applied, and the facility with which it is convertible to use.

MATERIALS FROM THE MINERAL KINGDOM.

Stones and Earths.—*Marble.*—The class of stones denominated *calcareous*, is exceedingly numerous and abundant in nature. Of these, marble is the most important. It is a granular carbonate of lime, varying in color, texture, and hardness. Marble is extensively used for building, statuary, decorations, and inscriptions. In warm countries it is one of the most durable of substances, as is proved by the edifices of Athens, which have retained their polish for more than two thousand years. Severe frost, preceded by moisture, causes it to crack and scale. Great heat reduces it to quicklime. Marble is wrought by chiseling, and by sawing with smooth plates of iron, with sand and water. It is polished by rubbing with sand and water, and afterwards with putty and soft substances.

Numerous stones of the calcareous class, more or less approaching to marble in their character, have been converted to use in different countries. The Pyramids of Egypt are built of a greyish white calcareous stone, inclosing shells.* The Parthenon, and other structures of Athens, are of Pentelic marble, distinguished by slight greenish veins. The mosques of Constantinople are of a fine grained limestone from Pappenheim, the same which is now used in lithography. At Rome, a porous whitish limestone, called *tophus* by the ancients, and *travertino* by the moderns, is the material of the Coliseum, of St Peter's church, &c. The ruins of Pæstum are of a stone nearly similar. The building called the Tomb of Theodoric, at Ravenna, has a dome consisting of a single stone, which is thirtyfour feet in diameter. It is a grey limestone from Istria, and is computed to have weighed, when taken from the quarry, more than two million pounds.† Paris is built with calcareous stone, of which there are five kinds. The Portland stone of which St Paul's and other edifices in London are constructed, is a calcareous rock called *Oolite* by mineralogists. Specimens of marble abound in the United States, and are seen in the City Hall of New York, the United States and Pennsylvania Banks, Philadelphia, the Washington Monument, Baltimore, &c.

In statuary, the Venus de Medicis, and Diana venatrix, are formed of Parian marble. The Apollo de Belvidere, according to Dolomieu, is made of Luni marble; and if so, must be posterior to the time of Julius Cæsar, before which period that quarry was not opened.

Granite.—Granite is apparently the oldest and the deepest of rocks. It is one of the hardest and most durable which

* Brard. † Borgnis.

have been wrought, and is obtained in larger pieces than any other rock. Granite is a compound stone, varying in color and coarseness. It consists of three constituent parts; viz. *quartz*, the material of rock crystal; *feldspar*, which gives its colors, and which is the material of porcelain earth; and lastly *mica*, a transparent, thin, or foliated substance, which affords a flexible substitute for glass, when obtained in large pieces. Granite is chiefly used for building. It is split from the quarries by rows of iron wedges driven simultaneously in the direction of the intended fissure. This method is thought by Brard to have been known to the ancient Romans and Egyptians. The blocks are afterwards hewn to a plane surface by strokes of a sharp-edged hammer. Granite is also chiselled into capitals and decorative objects; but this operation is difficult, owing to its hardness and brittleness. It is polished by long continued friction, with sand and emery.

The largest mass of granite, known to have been transported in modern times, is the pedestal of the equestrian statue of Peter the Great, at St Petersburgh. It is computed to weigh three million pounds, and was transported nine leagues by rolling it on cannon balls.* Those of cast-iron being crushed, others of bronze were substituted. Sixty granite columns at St Petersburgh consist each of a single stone twenty feet high. The columns in the portico of the Pantheon at Rome, which are thirtysix feet eight inches high, are also of granite.† The shaft of Pompey's Pillar, so called,‡ in Egypt, is sixtythree feet in height, and of a single piece. It is said to be of red granite, but is possibly sienite. In the Eastern part of the United States, a beautiful white granite is found in various places, and is now introduced in building. The new Market House in Boston, the United States Bank, &c. are made of it.

* Carburi.

† Rondelet.

‡ The inscription on this pillar is said by the Earl of Mountnorris, in Brande's Journal, to belong to Dioclesian, and not to Pompey, as was formerly supposed.

Sienite.—This rock is related to granite, and resembles it in its general characters. It consists chiefly of feldspar and hornblende. Sienite is obtained in large pieces, and possesses all the valuable properties of granite; but being harder, it is somewhat more difficult to chisel. It is found in Egypt, and constitutes the material of many of the obelisks. The Romans imported it from that country. Sienite is found abundantly near Boston, and is introduced into many structures. The Washington Bank and the Bunker Hill Monument consist entirely of this stone. Its extreme hardness renders it one of the best materials for M'Adam roads. A railway is built at Quincy for transporting the stone from the quarry to the sea, and the name of *Quincy Stone* is now commonly applied to it.

Freestone.—Freestone consists of sand, or siliceous particles, united by a cement. It is also called *sandstone.* It varies in color, from greyish white to red and dark brown. It is of moderate hardness, in general, and easily wrought by the chisel. Varieties of freestone are used in building in different parts of Europe. In Africa, the temple of Hermopolis is composed of enormous masses of this stone. In America, the Capitol at Washington is of the Potomac freestone, likewise the façade of St Paul's Church in Boston. This stone is used for various other practical purposes, particularly the grinding of steel instruments, and the filtering of water.

Slate.—Slates are valuable for the property of splitting in one direction, so as to afford large fragments which are perfectly flat and thin. The best slates are those which are even, compact, and sonorous; and which absorb the least water on being immersed. Slates are much used as an incombustible covering for the roofs of houses. Tablets, gravestones, and writing slates, are also formed from them.*

* Various artificial compositions have been employed as substitutes for slate, in forming waterproof coverings for roofs. One of these, which appears to have been successfully used in the north of Europe, is formed of bolar earth, chalk, glue, pulp of paper, and linseed oil. *Franklin Journal*, iv. 89.

Soapstone.—This stone is usually of a greyish color, moderately soft, and having an unctuous feel, which is compared to that of soap. It is remarkable for bearing heat, and sudden changes of temperature, without injury. It receives a tolerable polish. Soapstone, on account of its softness, is wrought with the same tools as wood. It is sometimes used in building, but is not always durable. It is, however, of great importance in the construction of fireplaces and stoves, and is extensively used for this purpose. Slabs of good soapstone, when not exposed to mechanical injury, frequently last eight or ten years, under the influence of a common fire on one side, and of cold air on the other. It grows harder in the fire, but does not readily crack, nor change its dimension sufficiently to affect its usefulness. Owing to the facility with which it is wrought, its joints may be made sufficiently tight without dependence on cement. Among the best quarries for fire-proof stone, is that of Francestown, New Hampshire. Soapstone is manufactured into various vessels and utensils, and is advantageously employed for aqueducts. It is lately found to be one of the best materials for counteracting friction in machinery, for which purpose it is used in powder mixed with oil.

Serpentine.—Serpentine is a smooth, compact stone, more or less of a greenish color, composed chiefly of magnesia and silex. It is sufficiently soft to be scratched with a knife, and receives a polish like that of marble. It is used in building, in Florence and other parts of Italy, and, in Saxony, is wrought into many small articles of ornament.

Gypsum.—Gypsum, called in commerce *Plaster of Paris*, is a sulphate of lime, of which there are many varieties. When dried by heat, ground to fine powder, and mixed with water, it has the property of becoming hard in a few minutes, and of receiving accurately the impression of the most delicate moulds. It is extensively employed for *stucco* working, and plastering of rooms. It furnishes a delicate, white, and smooth material for casts of statues, architectural models, impressions of seals, &c. In the art of stereotyping, it is indispensable. It is used in agriculture to fertilize certain soils.

Alabaster.—Under this name, two substances are known in commerce. One is a carbonate of lime, deposited by the dripping of water in stalactitic caves. The other, and the most common, is a compact gypsum. This is softer than marble, translucent, and susceptible of a fine polish. Many beautiful ornaments, such as vases, statues, shades for lights, &c., are made from it. As alabaster of the last species is soluble in five hundred parts of water, Mr Moore has proposed an easy method of cleansing it, by immersing it for about ten minutes in water, and afterwards rubbing it with a brush dipped in dry, powdered plaster.

Chalk.—Chalk is a soft carbonate of lime, the properties of which are well known. It is used as the basis of various white pigments, and cementing substances. Common *whiting* is purified chalk, prepared by reducing the chalk to fine powder and agitating it with water. The sand and coarser particles first subside, after which the water is drawn off and the whiting suffered to deposit itself. Chalk by calcination furnishes excellent lime.

Fluor Spar.—This is a fluate of lime. The variety chiefly used is the Derbyshire spar, which is beautifully variegated with purple and other colors. Ornamental objects and utensils are made from it. Its acid, when disengaged, is sometimes used to corrode glass.

Flint.—Flint is found in roundish masses, and is composed almost wholly of silex. Its extreme hardness causes it to strike fire readily with steel, from which property its greatest use is derived. Gun-flints are formed by practised workmen, who break them out with a hammer, a roller, and steel chisel, with small repeated blows. Flints are used also in the manufactures of glass, porcelain, and Wedgewood's ware. For this purpose, they are reduced to fine powder by heating red hot and plunging them in water; afterwards by pounding, sifting, and washing. Flints are broken up to form M'Adam roads.

Porphyry.—Porphyry is a variegated stone, consisting of small crystals of feldspar or quartz, imbedded in a basis of a darker color. It receives a beautiful polish, but its extreme hardness renders it difficult to work. The ancients made columns and even statues of this material; but the moderns confine its use chiefly to smaller works, such as vases, boxes, mortars, &c.

Buhrstone.—This is a hard, siliceous stone, remarkable for its cellular structure; containing always a greater or less number of irregular cavities. Hence its surface, however worn and levelled, is always rough. This property renders buhrstone an invaluable material for mill-stones. When it is not found of sufficient size for this use, small pieces of it are fitted together, cemented, and bound with an iron hoop. It is imported from France, and is also found in some localities in the United States.

Novaculite.—This stone is commonly known under the names of *hone*, Turkey oilstone, &c. It is of a slaty structure, and owes its power of whetting or sharpening steel instruments, to the fine siliceous particles which it contains. Various other stones are used as whetstones, such as common slate, mica slate, freestone, &c.

Precious Stones.—These are better known as objects of luxury, than of use; yet their preparation gives rise to an extensive branch of industry. They are in general distinguished for their small size, and great brilliancy, permanency, and hardness. The latter quality renders them useful in the arts. The diamond is generally employed for cutting sheets of glass. The diamond, ruby, sapphire, and some others, are used by watchmakers for pivot holes to diminish the friction of their verges and axles. These stones are wrought by grinding them with emery and other hard powders. The diamond can only be cut with its own dust. Various hard, siliceous stones of less value, as the carnelian, jasper, agate, &c., are used by lapidaries for engraving seals, cameos, and other objects of ornament.

Emery.—The best emery is a variety of the corundum stone, obtained chiefly from the island of Naxos, in the Archipelago. Several other substances, however, are sold under this name. Emery is the hardest of all known substances, except the diamond, and its powder is extensively used in grinding and polishing metals, stones, and glass. It is reduced to powder by grinding it in a steel mill, and is afterwards assorted into parcels of different fineness, by agitating it with water, and separating the particles which deposit themselves at different times; the finest particles being the last which subside.

Sand.—Sand of the best quality, is that which consists of particles of pure quartz, and such only is used in the manufacture of fine glass. It is found in various localities, but is most commonly procured, in this country, from the banks of the Delaware. Impure sand answers only for bottles and inferior glass. For mechanical purposes, such as grinding glass and marble, sharp sand, the particles of which are angular, is best. The sand used for moulds, by brass founders, possesses a somewhat argillaceous character, sufficient to render it moderately cohesive when wet, in consequence of which quality it retains its shape. The sand used in mortar should be sharp, and free from all perishable or deliquescent ingredients.

Pumice.—This is a spongy, porous stone, of a fibrous texture, and so light as often to swim in water. It is considered to be of volcanic origin. It is employed to grind the surface of metals, and other minerals. On account of its lightness, it is sometimes used to construct domes, vaults, and other elevated parts of buildings. The dome of the mosque of St Sophia, at Constantinople, is said to be of this material.

Tufa.—This name is applied to a number of volcanic productions, some of which are aggregates of sand, ashes and fragments of scoria and lava united by a cement. The tufa which is found about Rome is of a reddish color, and is supposed to be the *lapides rubri* of Vitruvius. Its surface is easily decomposed by the atmosphere, yet some of the ancient Roman temples and aqueducts are built of it, and among others the temple of Fortuna virilis.

Peperino.—The *lapis albanus* of the ancients, now called peperino, appears to be a kind of tufa, or concretion of volcanic ashes, but somewhat more solid and durable than the other kinds. It is the material of some of the ancient Roman structures, and is found in the forum of Nerva and the temple of Antoninus and Faustina.

Tripoli.—This mineral resembles certain clays, but is rough and friable, and does not form a paste with water. It possesses a fine hard grit, and is used to polish metals and stones. Common *rotten stone* and *polishing slate* are varieties of tripoli.

Clay.—This abundant and useful earth is composed principally of alumine and silex. It possesses the valuable property of forming, when wet, a ductile and tenacious paste, which is changed by heat to a stony hardness. Common clay, of which bricks and coarse potter's ware are made, contains oxide of iron, which causes it to turn red in burning. The purer sorts, such as pipe clay, become whiter when exposed to a high heat. The earthy smell, which clays emit when breathed upon, appears also to be owing to oxide of iron. Absolutely pure clays emit no smell. *Refractory* clays are those which endure the greatest heat without melting. The best fire-proof bricks and crucibles are made from slate clay, and contain a good deal of sand. Sometimes they are made of old materials, which have been before exposed to high heat, pounded up and mixed with fresh clay. A mixture of two parts of Stourbridge clay and one part of coke, has been found very refractory.

Asbestus.—Asbestus is a mineral of a fibrous structure. One of its varieties, called Amianthus, is composed of very delicate, flexible filaments, resembling fibres of silk. It has been manufactured into cloth and paper, which possess the property of being incombustible. It is difficult, however, to find fibres of sufficient length and firmness, to produce objects of any great use. It is sometimes mixed with clay in pottery, to increase its strength. It has also been used for the packing of steam engines which are of high pressure, or in which steam is used at an elevated temperature.

Cements.—*Limestone.*—The substances made use of for the uniting medium between bricks or stones in building, are denominated cements. The calcareous cements, composed of a mixture of lime, sand, and water; in consequence of the facility with which they pass from a soft state to a stony hardness, have in common use superseded all others. Lime in the state of quicklime, is obtained by burning in kilns, any of those natural bodies, in which it exists in combination with carbonic acid; such as *limestone*, *marbles*, *chalk*, and *shells*. The effect of the burning, or calcination, is to drive off the carbonic acid. If quicklime, thus obtained, be wet with water, it instantly swells and cracks, becomes exceedingly hot, and at length falls into a white, soft, impalpable powder. This process is denominated the slaking of the lime. The compound formed is called a hydrate of lime, and consists of about three parts of lime to one of water. When intended for mortar, it should immediately be incorporated with sand, and used without delay, before it imbibes carbonic acid anew from the atmosphere. Lime, thus mixed with sand, becomes harder and more cohesive and durable, than if it were used alone. It is found that the sand used in common mortar, undergoes little or no change; while the lime, seemingly by crystalization, adheres to its particles, and unites them together.* Cements composed in this manner continue to increase in strength and solidity for an indefinite period, the hydrate of lime being gradually converted into a carbonate. The sand most proper to form mortar, is that which is wholly siliceous, and which is sharp, that is, not having its particles rounded by attrition.

Fresh sand is to be preferred to that taken from the vicinity of the sea shore, the salt of which is liable to deliquesce and weaken the strength of the mortar. The proportions of the lime and sand to each other, are varied in different places; the amount of sand, however, always exceeds that of the lime.

* See Brard and Vicat on this subject.

The more sand can be incorporated with the lime, the better, provided the necessary degree of plasticity is preserved; for the cement becomes stronger, and it also sets, or consolidates more quickly, when the lime and water are less in quantity and more subdivided. From two to four parts of sand are used to one of lime, according to the quality of the lime and the labor bestowed on it. The more pure is the lime and the more thoroughly it is beaten or worked over, the more sand it will take up, and the more firm and durable does it become.

Puzzolana.—Water cements, or hydraulic cements, often called, also, Roman cements, are those which have the property of hardening under water, and of consolidating almost immediately on being mixed. Common mortar, although it stands the effect of water very well when perfectly dry, yet occupies a considerable time in becoming so, and dissolves or crumbles away, if laid under water, before it has had time to harden. It is found that certain rocks which possess an *argillaceous* as well as siliceous character, if mixed with lime or mortar, communicate to them the property of hardening in a very few minutes after the mixture has taken place, as well under water as out of it. Substances of this sort have therefore been made the basis of water cements. The ancient Romans, who practised building in the water, and particularly in the sea, to a great extent, first availed themselves of a material of this kind. The Bay of Baiæ, from the coolness and salubrity of its situation, was a place of fashionable resort for the wealthy of Rome, during the summer months. They erected their villas, not only on the seashore, but on artificial quays and islands constructed in the water. To enable them to erect these marine structures, they fortunately discovered, at the town of Puteoli, a peculiar earth, to which they gave the name of *pulvis puteolanus*, and which is the same now known by the name of Puzzolana. This earth is a light, porous, friable mineral, various in color, and evidently of volcanic origin. When reduced to uniform powder by beating and sifting, and thoroughly mixed with lime, either with or without sand, it forms a mass of great tenacity, which in a short time concretes to a stony hardness, not only in the air, but likewise when wholly immersed in water.

Tarras.—A substance denominated tarras, terras, or trass, found near Andernach in the vicinity of the Rhine, has been discovered to possess the same property with puzzolana, of forming a durable water cement, when combined with lime. It is said to be a kind of decomposed basalt, but resembles puzzolana. It is the material which has been principally employed by the Dutch, whose aquatic structures probably exceed those of any other nation in Europe. Tarras mortar, though very durable in water, is inferior to the more common kinds, when exposed to the open air.

Other Cements.—It has been found that various other substances, such as baked clay reduced to powder, or the common greenstone calcined and pulverized, afford the basis of very tolerable water cements, with lime. Some of the ores of manganese are also useful for the same purpose.

There are some limestones which have the property of forming water cements when calcined and mixed with simple sand and water. This is usually in consequence of these stones containing a certain portion of argillaceous earth, united with the lime. A water cement found in New York, was used in constructing the locks of the great canal in that State. Another hydraulic cement, containing lime, silex, and alumine, has been found and applied to use in the Union Canal of Pennsylvania.*

The cause by which these compounds become hard under water, is not satisfactorily known. It has been supposed, how-

* M. Berthier states that with one part of common clay and two parts and a half of chalk, a very good hydraulic lime may be made. He concludes from many experiments, that a limestone containing six *per cent.*, of clay, affords a mortar perceptibly hydraulic. Lime containing from fifteen to twenty *per cent.*, is very hydraulic, and with from twentyfive to thirty *per cent.*, it sets almost instantly.

According to M. Bruyere, an excellent artificial puzzolana may be formed by heating together three parts of clay, and one part of slaked lime, for some hours, to redness.

ever, and not without reason, that the great attraction for moisture existing in certain argillaceous earths, causes them to absorb immediately the superabundant moisture from the lime, and thus to expedite its solidification. This explanation is rendered more probable, by the fact, that burnt clays, which form good hydraulic cements; cease to do so, if the burning is carried so far as to vitrify them.*

Maltha.—The name of *maltha*, or *mastich*, is given to those cements into which animal and vegetable substances enter, such as oil, milk, mucilage, &c. Some of these mixtures have afforded, both to the ancients and moderns, cements of great hardness and permanency, but they are not much used.

METALS.—*Iron.*—Of all the metals, iron is the most useful, and one of the most abundantly diffused. Besides its common occurrence in earths and rocks, it is held in solution by mineral waters, it enters largely into the composition of meteoric stones, and it circulates in the blood of animals, and the sap of vegetables. Pure iron is of a bluish white color, of great hardness, malleable, ductile, and tenacious. For its fusion, it requires an intensely high temperature, equal to one hundred

* M. Vicat, who has experimented extensively upon the subject, has arrived at the conclusion, that the solidification of hydraulic cements formed of ordinary mortar, and calcined clays, is the result of a true chemical combination, in which the lime is neutralized by the silica and alumina. But in those formed of hydraulic lime and pure sand, the solidification does not appear to result from chemical combination.

Clays which by slight calcination become good hydraulic cements, have also the same property, though in a less degree, in their natural state. It has been asserted, by M. Treussart, that the free access of air during the calcination of argillaceous cements, is of great consequence to the tenacity of the mortar and the quickness with which it hardens. To determine whether a stone will furnish hydraulic lime, M. Vicat recommends to calcine it by heat, then to slake it in the common way, and make a paste of it, which is to be placed at the bottom of a vessel of pure water. If at the end of eight or ten days it has become hard, and resists the finger, it will furnish hydraulic lime; but if it remains soft, it has the character of common lime.

See Brande's Journal, vol. x, p. 407.—vol. xix, 329.—vol. xx, 50.—vol. xxii, 214. Also Franklin Journal, ii, 371 and 287.—iii, 305, 355.

and fiftyeight degrees of Wedgewood's pyrometer. When combined with carbon, it forms *steel*, and is increased in hardness. At a red heat, it becomes soft and more malleable; and at a white heat, may be joined by *welding*. It is strongly attracted by the magnet, acquires itself the magnetic power, and when in the form of steel, retains it permanently. Cast iron is brittle, and fusible without difficulty, owing to the carbon which it contains. Wrought iron is flexible, and has the properties of the pure metal. In the arts, iron is applied to innumerable uses where strength and hardness are required. It is, however, deficient in durability, being readily corroded with rust, when exposed to the weather, unless protected with a coating of paint. Metallic iron is wrought, while hot, by hammering, rolling, stamping, chiseling, punching, &c.; and when cold, by the same means, also by filing, turning, drilling, cutting, and drawing. Cast iron is commonly melted, when its form is to be changed; but it is finished with common tools when cold, and may be cut with a saw when red hot. Cast iron is now the most common material used in the fabrication of machines, and in Europe it is applied to the construction of bridges, and of roofs. Even small ships have been made of iron.

To the chemical compounds of iron, we are indebted for copperas, writing ink, prussian blue, &c.

Copper.—Copper is a metal of a light red color, ductile, and malleable, emitting a disagreeable odor when rubbed. It melts at twentyseven degrees of Wedgewood. When exposed to the atmosphere, it loses its lustre, and becomes covered with a green coating, which is carbonate of copper. This coating preserves the remainder from decay, and is the source of some of its most important uses. Copper is employed to cover the bottoms of ships, and tops of houses; to form various culinary and manufacturers' vessels, also for pumps, and water pipes, for engravers' plates, and for coining. When combined with acids, or oxygen, it becomes more or less poisonous, on which account culinary vessels are coated on the inside with tin. It is this poisonous property, in part, which prevents marine animals from attaching themselves to the bottoms of coppered ships. Copper forms many valuable alloys, among which are *brass*, which consists of copper and zinc, and *bronze*, which is made of copper and tin. Its chemical compounds furnish verdigris, blue vitriol, &c. It is wrought by the same modes as iron, but is more easily malleable than that metal when cold.

Lead.—Lead has a light bluish color, with a bright lustre which becomes quickly tarnished on exposure to the air. It is soft, heavy, very malleable, and melts at six hundred degrees of Fahrenheit's thermometer. By exposure to the heat of a furnace, it is converted into a red oxide. Lead is used for the covering of roofs, for aqueducts, for lining cisterns and tight cavities, for weights, bullets, and shot. Some of its alloys are very valuable, such as pewter, type metal, &c. Its oxides and salts afford paints of different colors, and of great use. Lead is deleterious in its influence on health, and requires great caution in those who work it, or use it, in any other than the metallic state. Injury is most frequently received, by inhaling the dust which rises in the manufactories of red and white lead. In leaden aqueducts a carbonate of lead occasionally forms; but this is insoluble in water, and subsides by its weight.

Tin.—Tin is a white metal, somewhat harder than lead, and producing a peculiar crackling sound when it is bent. It is very malleable, and is beaten for tinfoil into leaves $\frac{1}{1000}$ part of an inch in thickness. Its ductility and tenacity are not great. Tin is very fusible, melting at about four hundred and fortytwo degrees of Fahrenheit's thermometer. Exposed to the atmosphere, its surface becomes slightly tarnished, but undergoes no further change. On this account it is largely employed for coating other metals, which are more liable to oxidation. Copper vessels are lined with it, as already stated. *Tin plates* are sheets of iron coated with tin. Tinfoil with mercury forms the silvering of looking glasses. Block tin is used to form vessels not intended for exposure to heat. Some of the salts of tin are very valuable in dyeing. The *putty* used for polishing glass, stones, and metals, is an oxide of lead and tin.

Mercury.—Mercury, or quicksilver, is fluid at common temperatures, and on this account is used in many philosophical and chemical instruments. Attempts have been made to introduce it in certain forms of the steam engine; but it is objectionable for this purpose, from its tendency to combine with oxygen, and from the unhealthiness of its use to persons occupied about it. Mercury is employed in silvering mirrors, and large quantities are consumed in extracting silver and gold from their ores. Its alloys with other metals are called *amalgams.* It amalgamates readily with gold, silver, tin, lead, and zinc; difficultly with copper and antimony, and scarcely at all with iron and platina.

Gold.—The value derived from its scarcity, prevents the extensive use of gold in the arts. The power with which it resists tarnishing, and all changes from exposure to air and moisture, renders it desirable for many purposes, and has given rise to the art of gilding. The gold leaf used in gilding is often not more than $\frac{1}{282000}$ part of an inch thick, owing to the extreme malleability of the metal. Gold is used in coining, in jewelry, and in coloring porcelain.

Silver.—Silver possesses the same valuable properties as gold, but is more liable to tarnish, especially when exposed to sulphurous vapors, which convert its surface into a sulphuret. Silver is very ductile, but less so than gold, and the leaves into which it is hammered, are usually three times thicker than those of gold. Its uses are well known.

Platinum.—Platinum is the heaviest substance at present known, its weight being twentyone times and a half, that of water. Like gold, it resists tarnishing from oxidation by the air, and it is furthermore capable of resisting an extremely high temperature without melting. It is very malleable, approaches to iron in hardness, and like that metal, may be welded when hot. It is used for small crucibles, and philosophical instruments.

Zinc.—Zinc or *spelter* is a bluish white metal, imperfectly malleable and ductile, but rendered more so by a heat somewhat above that of boiling water. It melts below a red heat, at seven hundred degrees of Fahrenheit. When ignited it burns with a white flame, throwing off an oxide called *flowers of zinc.* Zinc is used as a constituent in brass, and in some other alloys. It is an important material in galvanic combinations. It is easily oxidated, and therefore unfit for purposes which require durability.

Antimony.—Antimony is a brittle, whitish metal of a plated or scaly texture. It is tarnished, but not otherwise altered by exposure to the air. In type founderies it is much used to give hardness to lead, in the alloy called *type metal.*

Bismuth.—Bismuth is a metal of a reddish white color and brittle consistence, not readily oxidated by the air. It is very fusible, requiring little more heat than tin to melt it. It enters into various alloys, one of which is the *fusible metal,* composed of eight parts of bismuth, five of tin, and three of lead, which melts at a heat less than that of boiling water.

Arsenic.—Arsenic in its metallic state is of a bluish white color, easily tarnishing, brittle, and volatile at a low heat. In the state of acid, called *white arsenic,* it is well known as a violent poison. Arsenic is used in the manufactures of glass, and of shot, and furnishes the basis of several brilliant pigments.

Manganese.—Manganese is a metal of a dull whitish color, brittle, extremely difficult to melt, and speedily turning to a dark oxide in the air. The native black oxide of this metal is of great use to chemists in furnishing oxygen. In the arts, it is employed in bleaching, pottery, and glass making.

COMBUSTIBLE SUBSTANCES, &c.—*Bitumen.*—This is an inflammable mineral substance, resembling tar or pitch in its properties and uses. Among different bituminous substances, the names *naphtha,* and *petroleum,* have been given to those which are fluid; *maltha,* to that which has the consistence of pitch, and *asphaltum,* to that which is solid.

Amber.—Amber is a yellowish, translucent, inflammable mineral, hard enough to receive a fine polish, capable of being wrought into various ornamental articles, and forming an ingredient in some varnishes and lacquers.

Coal.—This well known combustible is composed essentially of carbon, with a proportion, greater or less, of bitumen, a little sulphur, and a remainder of earthy and incombustible matter. True coal burns with a white flame, a black smoke, and bituminous odor. Some kinds, as the Cannel coal, burn readily, with a large flame, and without softening or concreting. Others, as the Newcastle, Liverpool, and Orrel, concrete, or cake, during combustion, and last longer. The poorer coals have usually a large admixture of foreign and incombustible substances. Coal is of great value as a fuel, both in the arts, and for domestic purposes. As it contains more combustible matter in a given volume, than wood, it is capable of evolving and sustaining more heat than that fuel, within the same furnace, or other cavity. When coal is exposed to heat, but prevented from burning, by the exclusion of the air, it loses its moisture and bituminous portion, and is converted into coke, a fuel bearing the same relation to coal, as charcoal to wood. Coal has of late years been usefully applied to the production of inflammable *gas*, for the purposes of illumination.

Anthracite.—This combustible, of which the Lehigh, Schuylkil, and Rhode Island coal are specimens, is harder, heavier, and less black, than the true, or bituminous coals. It burns slowly, without smoke, and with a faint flame. It is more difficult to kindle than most fuels, owing to its greater conducting power, and the high temperature necessary for its combustion; but when once on fire it produces an intense and lasting heat. It is more durable than the bituminous coals, but requires to be burnt in masses large enough to sustain a high temperature. Anthracite has now become a common fuel in many parts of the United States, and is highly valuable both for domestic and manufacturing purposes. It is burnt in various furnaces, forges, stoves, and grates constructed for the purpose. In iron works it is found to occasion less oxidation and scaling of the metal, than other fuel. But in reverberating furnaces, where a blaze is required, it does not answer the requisite purpose. Most of the anthracites afford inflammable gas, not, however, suitable for purposes of illumination.*

Graphite.—This mineral, otherwise called *plumbago* and *black lead*, is composed of carbon, with a portion of iron. It is unctuous to the touch and soils the fingers. It is used for pencils and crayons, and, mixed with clay, is formed into crucibles. Black lead pencils are made, by inserting the straight edge of a plate of graphite, into a groove made in the wood, and sawing it off, leaving a slender rod of the lead inclosed, which is afterwards covered with wood.

Peat.—Peat is a substance of vegetable origin, dug from bogs and marshes, and capable of reproducing itself in places from which it has been removed. Peat, when dry, is combustible, and is used as such, where better fuel cannot be obtained.

Sulphur.—Sulphur is a simple inflammable body, melting at two hundred and twenty degrees, and taking fire at five hundred, of Fahrenheit. When kept melted for some time, at about three hundred degrees, Fahrenheit, it becomes thick and viscid, and if poured into a basin of water, it becomes ductile like wax. In this state it is used for taking impressions of seals. It is also used to form moulds for plaster casts. Sulphur is an ingredient in gunpowder, and enters into many chemical compounds, which are of great use in the arts. Sulphur is burnt to produce sulphuric acid.

MATERIALS FROM THE VEGETABLE KINGDOM.

Wood.—The woody portion of the trunks of trees, is made up of minute tubes or vessels, running longitudinally, having their parietes strengthened with rigid fibres, and their inter-

* See a valuable paper on the Anthracites, in Silliman's Journal, vol. x. p. 331, by the editor.

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stices filled with cellular substance. In the common trees of temperate climates, these vessels are arranged in concentric layers or cylinders; one layer being added for each year of the tree's growth. The outer layers, being those which transmit the sap, are more porous, soft and perishable, and are known by the name of *alburnum* or *sap wood.* The inner layers are commonly darker colored, more solid, compact, and durable; and are known by the name of *heart wood.* The heart wood is preferred for most purposes in the arts, its vessels having become in part obliterated by age, and its density and strength increased. Boards are least liable to warp when they are cut through the centre or pith of the trunk. All wood shrinks in drying, and decays when exposed to the weather; but different trees vary greatly from each other in this respect.

Bark.—Bark is the external investment of the trunks and branches of trees, and consists, when young, of three coats or layers, called the *cuticle*, the *cellular integument*, and the *liber* or inner bark. But during every season, a new liber grows on the inside of the former ones, and pushes them outward, so that old bark is found to consist of numerous *cortical layers*, each of which was originally a liber. The outermost of these layers gradually become dead and dry, and merely augment the thickness of the bark, without adding to its usefulness in the arts.

Oak.—Numerous species of the oak tree are found in the United States. They are generally distinguished for great strength, but are coarse grained, and prone to warp and crack under changes from moisture to dryness. The live oak of the Southern States (*Quercus virens*) is prized in ship-building, beyond any native timber. The white oak (*Quercus alba*) is employed for the keels, side timbers, and planks of vessels, also for frames of houses, mills and machinery requiring strength; for wagons, parts of carriages, ploughs, and other agricultural instruments. Large quantities are consumed for the staves and hoops of casks, for which they furnish one of the best materials. The bark of the black oak (*Quercus tinctoria*) furnishes the *quercitron* used by dyers. Most of the species of oak are employed in tanning, and they all furnish a valuable fuel.

Hickory or Walnut.—The wood of the different species of native walnut or hickory (*Juglans, seu Carya*) is eminently distinguished for weight, tenacity, and strength. It has, however, important defects. It warps and shrinks greatly, decays rapidly when exposed to the weather, and is very liable to the attacks of worms. On these accounts it is never used for house or ship building, but is chiefly employed for minor purposes, where strength is the chief requisite; as in the teeth of mill wheels, screws of presses, handspikes, capstan bars, bows, hoops, and handles of tools. As fuel, the hickory stands at the head of native trees, and commands a higher price than any other wood.

Ash.—The white ash (*Fraxinus Americana*) and some other species, are of great utility in the arts. Ash wood is strong, elastic, tough, and light; and splits with a straight grain. It is also durable, and permanent in its dimensions. It furnishes the common timber used in light carriages, for the shafts, frames, springs, and part of the wheels. Flat hoops, boxes, and the handles of many instruments are made of it. It is almost the only material of oars, blocks of pullies, cleats, and similar naval implements, in places where it can be obtained.

Elm.—The common American elm (*Ulmus Americana*) is valued for the toughness of its wood, which does not readily split. On this account it is chiefly used for the naves, among us commonly called *hubbs*, of carriage wheels.

Locust.—The common locust (*Robinia pseudacacia*) is one of the hardest, strongest, and most valuable of native trees. The larger pieces of its timber are used in ship-building, and the smaller pieces are in great request to form the treenails* or pins which confine the planks to the timbers. This tree is

* Commonly pronounced *trunnels*.

liable, in the Northern States, to be perforated by an insect, so that it is often difficult to procure sound pieces of any considerable size. Locust wood is exceedingly durable, when exposed to the weather; and forms excellent fuel.

Wild Cherrytree.—The wood of this tree (*Prunus Virginiana*) is of a deep color, hard, durable, and, when properly seasoned, very permanent in its shape and dimensions. In the manufacture of cabinet work, it is much used as a cheaper substitute for mahogany. On the Western rivers it is sometimes used in ship building.

Chesnut.—The American chesnut (*Castanea vesca B.*) is a large tree of rapid growth. Its wood is coarse and porous, very liable to warp, and seldom introduced into building or furniture. It is chiefly used for fencing stuff, to which use it is fitted by its durability in the atmosphere. Chesnut is an unsafe fuel, in consequence of its tendency to snap, and throw its coals to a distance.

Beech.—The wood of the red beech (*Fagus ferruginea*) is liable to decay when exposed to alternate moisture and dryness. It does not, however, readily warp, and being smooth grained it is used for some minor purposes, such as the making of planes, lasts, and card backs. It forms a very good fuel.

Basswood.—The American linden or basswood tree (*Tilia Americana*) produces a fine grained wood, which is very white, soft, light, and flexible. It is sometimes employed for furniture, but its chief use is to form the pannels of coach and chaise bodies, for which its flexibility makes it well suited.

Tulip tree.—(*Liriodendron tulipifera.*) The boards of this tree are sold under the name of *white wood*, and erroneously under that of *poplar*. Its wood is smooth, fine grained, easily wrought, and not apt to split. It is used for carving and ornamental work, and for some kinds of furniture. In the Western States, where pine is more scarce, the joinery, or inside work of houses, is commonly executed with this material, and sometimes the outer covering. In common with basswood, it forms an excellent material for coach and chaise pannels.

Maple.—The rock maple, (*Acer saccharinum*) also several other species, affords wood which is smooth, compact and hard. It is much used for cabinet furniture, and is a common material for gunstocks. The wood in some of the old trunks, is full of minute irregularities, like knots. These, if cut in one direction, exhibit a spotted surface, to which the name of *bird's eye* maple is given; while if cut in another direction, they produce a wavy or shaded surface, called *curled* maple. This last effect, however, is more frequently produced by a mere serpentine direction of the fibres. The distinctness of the grain may be increased by rubbing the surface with diluted sulphuric acid. Maple wood forms a good fuel. It is not very lasting when exposed to the weather. The sap of the rock maple and of one or two other species, yields sugar on being boiled.

Birch.—The white or paper birch (*Betula papyracea*) has properties similar to those of the maple, and is appropriated to the same uses. Its cuticle or outer bark, is made by the Indians into canoes. The lesser white birch (*B. populifolia*) is a perishable tree, of little value. The black birch, (*B. lenta*,) known for its aromatic bark, affords a firm, compact, dark colored wood, much valued for furniture, and sometimes used for screws and implements requiring strength. The yellow birch (*B. lutea*) is applied to the same uses as the last, and makes good fuel.

Buttonwood.—The buttonwood or plane tree (*Platanus occidentalis*) is in some of the Northern States improperly called *sycamore*. It is one of the largest inhabitants of the forest, and Michaux states that trees are found in the Western States which measure forty feet in circumference. This majestic tree is chiefly valuable for its shade, as the wood is perishable, and prone to warp.

Persimmon.—(*Diospyros Virginiana.*) The heart wood is dark colored, compact, hard, and elastic; and is used in the Southern States for screws, shafts of chaises, and various implements.

Black Walnut.—(*Juglans nigra.*) This tree is rarely found north of New York. Its heart wood is of a violet color, which, after exposure to the air, assumes a darker shade, and finally becomes nearly black. This wood when deprived of its white part, or sap, remains sound for a long time, even if exposed to air and moisture, and is not attacked by worms. It is very strong and tenacious, and when seasoned is not liable to warp, or split. It is used in the Middle and Western States for furniture, for gunstocks, for naves of wheels, and to a certain extent, in house and ship building.

Tupelo.—Different species of the genus *Nyssa* have received, in the United States, a great variety of common names, among which *tupelo*, *pepperidge*, and *gum tree* are the most common. In Massachusetts the name *hornbeam* is improperly applied to one of them. Their wood is smooth grained, and remarkable for the decussation or interweaving of the fibres, which renders it almost impossible to split the logs. This quality causes several of the species to be in demand for naves of wheels, hatters' blocks, and implements requiring lateral tenacity.

Pine.—The American pines exceed all other native trees for the value and variety of their uses. The white pine (*Pinus strobus*) has a very tall, straight trunk, the wood of which is light, soft, homogeneous, and easy to work. It is remarkably exempt from the common fault of timber, that of decaying in the open air, and of changing its dimensions with changes of weather. On these accounts it is extensively employed for most of the common purposes of timber. In the Northern States, masts of vessels are commonly made of it. Frames of houses and of bridges are also formed of it; its defect of strength being more than balanced by its steadiness and durability. Its boards form almost the only material used in the Northern States for the joiner's work, or inside finishing of houses; and for this use it is exported to other countries. Ornamental carving is commonly executed in this material. The southern pitch pine (*Pinus palustris L.*) covers extensive *barrens* in the Southern States, and yields vast quantities of tar and turpentine. Its wood is appropriated to the same objects as that of the white pine, but is harder and stronger, and therefore preferred for planks, spars, floors, decks, &c. Many other species of pine exist on this continent, partaking qualities like those already described, but most of them harder than the white pine.

Spruce.—The black and white spruce belong to the race of trees commonly called *Firs.* They are both valuable, but the black spruce (*Pinus nigra*) unites in a peculiar degree the qualities of strength, elasticity, and lightness, together with the power of resisting exposure to the weather. It is much sought after for the smaller spars of vessels, such as the booms, yards, and topmasts.

Hemlock.—The hemlock tree (*Pinus Canadensis*) is inferior to the other firs in quality, though it grows to a large size. It is coarse grained, often twisted, and cracks and shivers with age. It furnishes an inferior sort of boards, used in covering houses. Its bark is valuable in tanning.

White Cedar.—This tree (*Cupressus thuyoides*) occupies large tracts denominated cedar swamps. The wood is soft, smooth, of an aromatic smell, and internally of a red color. It is permanent in shape, and very durable; and esteemed as a material for fences. Large quantities of shingles are made of it. It is a favorite material for wooden wares, or the nicer kinds of cooper's work.

Cypress.—The cypress tree of the Southern States (*Cupressus disticha*) is light, soft, and fine grained; and at the same time elastic, with a considerable share of strength. It sustains heat and moisture for a long time, without injury. In the Southern States and on the Mississippi, it is much employed for fences, and for the frames, shingles, and inside work of houses.

Larch.—The American Larch (*Pinus microcarpa*) is called *hackmatack* and *tamarack*, in different parts of the Union. Its wood is strong, elastic, and durable; and is highly prized, in places where a sufficient quantity can be obtained, for naval and civil architecture.

Arbor Vitæ.—This tree (*Thuya occidentalis*) is of the middle size, and frequently called white cedar. The wood is reddish, fine grained, very soft, and light. It bears exposure to the weather with very little change, and is esteemed for the posts and rails of fences.

Red Cedar.—(*Juniperus Virginiana.*) The name of *savin* is in some places improperly applied to this tree. Unlike the white cedar, it grows in the driest and most barren soils. The trunk is straight, and knotted by small branches. The heart wood is of a bright red color, smooth and moderately soft. It exceeds most other native trees in durability, and is in particular request for posts of buildings, though it is difficult to obtain it of large size.

Willow.—The most common kinds of *Salix* or willow about our seaports, are European species which have become naturalized. Their wood is soft, light, and spongy. Willow charcoal is used in the manufacture of gunpowder. The osier and some other species, with long slender shoots, are extensively cultivated to form wicker work, such as baskets, hampers, and the external coverings of heavy glass vessels.

Mahogany.—In the manufacture of cabinet furniture, mahogany (*Swietenia mahagoni*) has taken precedence of all other kinds of wood. Its value depends not so much on its color, as on its hardness, and the invaluable property of remaining constant in its dimensions, without warping or cracking, for an indefinite length of time. The same qualities which render it suitable for furniture, have given rise to its employment for the frames of philosophical instruments, and of delicate machinery. Mahogany is imported from the West Indies, and different parts of Spanish America.

Boxwood.—The box tree (*Buxus sempervirens*) is imported from the south of Europe. Its wood is of a well known yellowish color, hard, compact, smooth, tough, and not liable to crack. Musical wind instruments are commonly made of it;

also mathematical measuring instruments. The handles of many tools, and various articles of turners' work, consist also of this material. Wood engravings are cut upon the end of the grain of boxwood.

Lignum Vitæ.—The wood of the *Guiacum officinale* is employed in the arts under this name. It is dark colored at the heart, strong, exceedingly hard, and so heavy as to sink in water. It is impregnated with resin, and on this account durable in liquids. Handles of tools, boxes of gudgeons, wheels of pullies, castors, balls, stopcocks, mallets, &c., are made of it. It is imported from the West Indies and South America.

Several other tropical woods are imported for use by cabinet makers, such as *rose wood*, *ebony*, *satin wood*, &c. They are generally hard, colored woods, susceptible of a fine polish. Satin wood (*Sweitenia chloroxylon*) is thought poisonous to the hands of the workmen.

Cork.—Cork is a fungous substance growing on the bark of a species of oak (*Quercus suber*) in the south of Europe. Its lightness and elasticity give it an aptitude for certain purposes, in which it would be difficult to find a substitute.

Hemp.—Hemp is the fibrous portion of the bark of an annual plant, (*Canabis sativa*) and is of great use in the manufacture of cordage and canvass. The fibres are separated from the rest of the stalks, by the decomposition of the latter. In the process of *dew rotting*, the hemp is exposed on the grass for a number of weeks to the weather. In that of *water rotting* it is immersed for a part of the time in water, and subsequently exposed to the weather. By these processes, the solid parts of the hemp decay; while the flexible fibres remain strong and but little impaired. The decayed portion is afterwards broken up, by the operations of an instrument called a brake; and sometimes by a mill or stone roller. The chaff is separated from the fibres by the strokes of a wooden scotching, or swingling knife; and the fibres still further cleansed by combing them on an instrument called a heckle.

Flax.—Flax is also the fibrous bark of an annual plant, (*Linum usitatissimum,*) which is smaller and finer than hemp; and constitutes the material of linen cloth. Flax is rotted, and subsequently dressed, much in the same manner as hemp. When, however, it is intended for finer uses, as for cambric, lace, &c., it is scraped with a blunt knife upon leather, and the fibres separated and straightened with a brush. A method has been introduced in England, of dressing flax by machinery, in its recent state, *without rotting.* This method is represented as highly economical, affording more flax, and of a stronger texture, than that produced in the common way.* The fibres of flax and hemp are long, straight, and unyielding, so that they cannot be spun by the same machinery which is used for cotton and wool.

Cotton.—Cotton is the product of the *Gossypium herbaceum,* an Oriental plant, now cultivated in most parts of the world, which possess a sufficiently warm climate. It grows in pods, forming a light, woolly investment to the seeds; and seems intended by nature to assist in their dispersion by the winds. The fibres of cotton are extremely fine, delicate, and flexible. When examined by the microscope, they are found somewhat flat, and two-edged or triangular. Their direction is not straight, but contorted; so that the locks can be extended or drawn out without doing violence to the fibres. These properties render cotton peculiarly adapted for the operations of machinery, and have given employment to a vast amount of manufacturing skill and industry, both in Great Britain and this country.

Cotton, after being gathered, is cleansed from the seeds by a machine called a *gin,* of which there are two kinds. The *roller gin* consists essentially of two small cylinders revolving in contact, or nearly so, with each other. The cotton is drawn between these rollers, while the seeds, being too large to pass, are left behind, and fall out on one side. The *saw gin,* invented by Mr Whitney, is intended for those sorts of cotton, the seeds of which adhere too strongly to be separated by the for-

* See Brande's quarterly Journal, vol. iv. p. 329.

mer method. It consists of a receiver, having one side covered with strong parallel wires, placed like those of a cage, and about an eighth of an inch apart. Between these wires enter an equal number of circular saws, revolving on a common axis. The teeth of these saws entangle the cotton and draw it out through the grating of wires, while the seeds are prevented by their size from passing. The cotton thus extricated is swept off from the teeth of the saws by a revolving cylindrical brush; and the seeds fall out at the bottom of the receiver.

Turpentine.—Turpentine is the juice which exudes from pine trees. The Southern pitch pine furnishes most of that used in commerce. It is procured by making incisions, or cavities, in the trunk, and dipping out the turpentine which collects. *Tar* is an impure turpentine obtained by burning. The resinous parts of the wood called *lightwood*, are collected in pits, and being set on fire at the top, a part of the turpentine is burnt, while the rest is melted and flows out at the bottom. *Pitch* is tar inspissated by boiling, or burning. If turpentine be distilled, the volatile portion, which passes over, is the *oil* or *spirit* of turpentine, while the solid part left behind is *rosin.*

Caoutchouc.—This substance, called also *elastic gum* and *India rubber*, is obtained from different vegetables, but chiefly from the *Jatropha elastica.* It exists in the form of juice, and is dried by applying it, in successive coatings, to clay moulds of various shapes. After it is dry, the clay is crushed and shaken out. This substance is wonderfully flexible and elastic, and restores itself instantly, after being extended to many times its original dimensions. It is inflammable and used by the inhabitants of Cayenne for lights. It is insoluble in water, and in alcohol; but dissolves in ether, and in oils. These solutions have been used for varnishes, but have the disadvantage that they do not readily dry. A mixture of oil of turpentine and alcohol,* is a solvent which has the property of drying more readily and restoring the elastic properties of the

* Chaptal. Chimié appl. aux Arts.

gum. The purified naptha from coal tar has the same property.* The crude juice may also be imported, and manufactured into articles here.† Slips of India rubber may be made to cohere by boiling them in contact for a certain time in water, and in this way some articles are made. Caoutchouc is of great use in the formation of many instruments, which require to be elastic, and impenetrable to water. Shoes are now made of it in great numbers, and are found to exclude perfectly the wet. The solution of this gum, spread upon leather and cloth, renders them water-proof, and even air-tight. Its adhesiveness and friction are the properties by which it erases black lead from paper.

Oils.—Oil is an inflammable liquid, which does not unite with water. *Volatile oils* are those which evaporate, or may be distilled without change, by a moderate heat. Of these, the oil of turpentine is an example. They are used in the arts for solvents, and in varnishes. *Fixed oils* are those which do not evaporate without decomposition, or chemical change. They produce an unctuous stain, which is not discharged by heat. They do not boil at a temperature much short of that of melting lead. They unite with alkalies, forming soaps. Some of them are called *fat oils*, which do not lose the unctuous character on exposure to the atmosphere, but assume a state like that of tallow; such for example as Olive oil. Others are called *drying oils*, which become solid in the air, after

* Turner's Chemistry.

† Mr Faraday states that the liquid caoutchouc, or juice, as it came from the south of Mexico, was a pale, yellow, thick, creamy looking substance, of a uniform consistency, with a disagreeable acescent odor. When exposed to the air in films, it is soon dried, leaving caoutchouc of the usual appearance and color. One hundred parts of the sap left nearly fortyfive of solid matter. Heat caused an immediate coagulation of the sap, the caoutchouc separating in a solid form. When the sap is purified by repeated washings with water, the caoutchouc rises each time to the surface, it is obtained of a white color, and afterwards, when perfectly dry, it becomes transparent, colorless, and elastic. A solution of caoutchouc in oil was obtained by mixing the juice with olive oil, and heating the mixture so as to drive off the aqueous parts. This promises to be a useful element in varnishes. See Brande's Journal, No. xli. page 19.

exposure for a certain time, and remain transparent. This is the case with linseed oil. Fat oils are used in the arts, to give flexibility to other materials; to diminish their friction, and to protect them from water. Drying oils are largely consumed as ingredients in paints, printers' ink, and varnishes.

Resins.—Various resinous substances are employed in the arts. They are fusible, inflammable, soluble in oil and alcohol; but insoluble in water. For ordinary purposes the *rosin* of the pine is employed, being the cheapest. For varnishes, *copal*, *mastic*, *animé*, and some others are used. The basis of sealing wax is the resin called *lac*, which is deposited on trees in India by an insect.

Starch.—Starch or *Fecula*, is a white substance, obtained from farinaceous grains and roots. It is insoluble in cold water, but dissolves readily in hot water. In alcohol it does not dissolve. In Europe, starch is commonly made from wheat. In this country it is prepared, for manufacturing purposes, from potatoes. For this object the potatoes are rasped, or ground up, by a machine, to a pulp. This pulp, when washed with cold water, yields a white powder, which, on subsiding, proves to be pure starch. It is heavier and goes further, for practical purposes, than the starch of wheat. Starch is largely consumed in cotton factories in the process of dressing, &c.

Gum.—The true gums are those which dissolve in water, either hot or cold, and form with it a thick, mucilaginous solution. They do not dissolve in alcohol, nor melt by heat. The species principally used are the *gum arabic*, *gum tragacanth*, and *gum senegal*. Gum, in the state of mucilage, is employed to give firmness and lustre to linen. Calico printers use it in great quantities, to give their colors such a degree of consistency, as will prevent them from running upon the cloth. It is made to form an ingredient in writing ink, and in water colors, for the same reason.

MATERIALS FROM THE ANIMAL KINGDOM.

Skins.—The *cutis*, or true skin of animals, from which leather is made, is composed of fibres irregularly situated, and closely interwoven. They are capable of being dissolved by long boiling in water, and are found to consist almost wholly of gelatin, or glue. The skins of a great variety of animals are used in the manufacture of leather. It has been found that those skins which are most flexible, and most easily dissolved, afford the poorest leather and the weakest glue; while those which are tough, and difficult of solution, yield leather and glue of the best quality.

Hair and Fur.—The hairs of animals consist of slender, flexible tubes, having a consistence like that of horn, and possessing the chemical properties of coagulated albumen. The surface of hairs are covered with minute scales or asperities, which give them a rough feel when they are rubbed upward; and which cause them to entangle each other in the processes of *felting* and *fulling*. *Fur* consists of very fine hair, thickly set, and commonly contorted. It is a very slow conductor of heat, and is provided by nature for the clothing of animals in high latitudes. Hair is a durable and very elastic substance, and is converted to many useful purposes. By means of a linen warp, it is woven into cloth for furniture. It forms the most elastic stuffing for cushions and mattresses. It is combined with mortar in plastering, to increase its cohesiveness. Furs are converted to important uses, in clothing and in felting.

Quills and Feathers.—The structure of the quills and feathers of birds is remarkably fitted to combine strength and elasticity with lightness; the mechanism of the tube, shaft, and feathering, being all adapted to this purpose.* The tube, or barrel of a quill, consists of two laminæ or layers, the out-

* See Chapter II

ermost of which has transverse fibres, and the inner, longitudinal. It is the first of these which is scraped off to prepare the quill for splitting. Quills are rendered transparent by exposing them to heat and moisture. The process recommended by M. Schloz, is to expose the quills to hot steam, by suspending them in a covered vessel which contains water in the bottom, and is kept boiling for four hours, the quills being immersed in the vapor only. At the end of this time they are withdrawn, and the next day cut, wiped, and dried with a moderate heat. *Feathers*, as they are obtained from common birds, and *down*, which is procured from the aquatic birds of northern climates, are among the most elastic substances known, and also the slowest conductors of heat. These properties are the foundation of their usefulness. The chemical composition of feathers is nearly similar to that of hair.*

Wool.—Wool is a fine, soft, long, and contorted hair, derived chiefly from the sheep. It is said to be the result of cultivation, and not to be found in the wild sheep, which is covered with short hair. Removal to a tropical climate causes the fleeces of sheep to fall off, and to be succeeded by a covering of short hair. Wool is an invaluable material in the clothing of civilized nations. The fineness and position of its fibres enable it to be drawn out like cotton, and to be spun by machinery. Their roughness and tendency to curl cause the fibres to be consolidated in the process of felting.

Silk.—Silk is spun by the larvæ or caterpillars belonging to different species of *Phalæna*. It forms the ball or *cocoon* in which the silk worm envelopes himself in passing to the chrysalis state. The fibre, which constitutes this ball, is so small, that a single thread, when unwound, is often twelve hundred yards in length. The original threads are too fine for manufacturing purposes, and therefore in winding or reeling them off from the cocoons, the ends or threads of several

* Feathers are purified by exposing them to heat; also by immersing them in lime water for several days, and afterwards washing them with pure water, and drying. This process extracts the animal oil.

cocoons are joined together, and reeled out of warm water, which softens their natural gummy covering, and causes them to cohere into a single thread. Silk, as it is spun by the animal, is of a color varying from white to reddish yellow. Its texture is very strong and elastic. It communicates to water a mucilaginous character, owing to the solution of its gummy part; but the silk itself is insoluble in water or alcohol.

Bone and Ivory.—The bones of animals are composed of a white, hard, lamellar substance, consisting chiefly of phosphate of lime, with a small portion of other earths, and impregnated with oily and gelatinous matter. Exposure to heat causes them to soften and crumble. Bone is used in the arts for the handles of cutlery, and various articles of turners' work. It is whitened by exposure to the sun and weather, and sometimes by the use of chlorine gas. It is wrought by sawing, turning, &c., and polished with pumice and tripoli. *Ivory* is the material of the elephant's tusks. It agrees with bone in its principal properties, but is more compact, hard, and white, and receives a finer polish. When burnt in close vessels and afterwards reduced to powder, it furnishes the pigment called *ivory black*. The *shells* of marine animals differ from bone in being composed of carbonate, instead of phosphate of lime.

Horn.—Horn differs from bone, not only in its texture, which is softer, but also in its composition, being composed chiefly of animal matter resembling coagulated albumen, and containing but little lime. Horn when heated becomes soft, flexible, and plastic, capable of being cemented and pressed by moulds into a great variety of shapes.

Tortoise Shell.—This substance exists in the form of plates on the outside of the shell of a species of sea turtle (*Testudo imbricata.*) It resembles horn in its general properties, and like that article may be wrought by softening it in boiling water, and subjecting it, while hot, to pressure in moulds. The edges of different pieces, by pressing them with heated irons, may be joined together and made to cohere firmly.

Whalebone.—This substance is obtained from the mouth of several species of whale, where it exists in the form of plates arranged on the outer edge of the upper jaw. These plates terminate in a kind of hair. Whalebone, in its texture and chemical properties, is very similar to horn. It is strong, light, and elastic; on which accounts it is applied to various mechanical uses. Whalebone, when heated by steam, or boiling water, becomes more flexible, and if bent into any shape, retains its form on cooling. Hence it has been manufactured into various woven fabrics.* It may be cemented in the same way as horn or turtle shell.

Glue.—The skins, tendons, membranes, &c. of animals, are composed principally of a substance known in chemistry by the name of *gelatin.* This substance is not soluble in cold water, but dissolves freely in boiling water, and on cooling assumes the state of jelly. It has great affinity for *tannin*, which exists in astringent barks; and on this affinity depends the manufacture of leather. Common glue is impure gelatin, obtained from hoofs, ears, and refuse portions of hides. These are first cleansed, then boiled to a jelly, which, on cooling, is cut into squares and dried upon nets. *Size* is a finer kind of glue, made with more care, from select materials. *Isinglass* is a still more delicate sort, prepared from the swimming bladders of fish. Glue is a cementing material of unequalled strength, for wood and fibrous substances. It is employed in different states of purity, by carpenters, hatters, paper makers, linen manufacturers, gilders, painters in distemper, and refiners of liquors. In the state of a stiff jelly, it forms, with treacle, the elastic cylinders, used to distribute and apply the ink, in printing.

Oil.—The oil of animals belongs to the class of fixed and fat oils. The oil of those animals which live in a cold medium, as whales, remains fluid at common temperatures; but that of most land animals becomes solid, when cooled below the heat of the living body. *Tallow*, the hardest kind, is obtained from ruminating quadrupeds. Animal oils are appropriated to the

* Repertory of Arts, 1807, page 411.

same purposes as the vegetable; but their great use is to furnish light, by their combustion.

Wax.—Wax, in its crude state, is obtained by melting the honeycomb of the bee. It is commonly classed with vegetable substances; but the experiments of Huber have shown, that it is produced by the bees themselves, and not gathered by them directly from plants, as was formerly supposed. Wax melts with a gentle heat, at one hundred and fortytwo degrees of Fahrenheit, is inflammable, dissolves in boiling alcohol, ether, and fixed oils; but is insoluble in water. Beeswax is deprived of its coloring matter by bleaching. To effect this, the melted wax is suffered to run through holes in the bottom of a vessel, upon the surface of a cylinder which is kept revolving in water, by which means the wax is spread out, and cooled in the form of thin laminæ or ribbands. It is then exposed to the light and air upon frames, and occasionally wet, till the bleaching is completed. Bayberry or myrtle wax is a harder substance than beeswax, obtained from the berries of the *myrica cerifera*, by boiling them in water.

Phosphorus.—Phosphorus is a simple combustible body, usually obtained from animal bones. It is of a soft, waxy consistence, and is luminous in the atmosphere at common temperatures. At one hundred and fortyeight degrees of Fahrenheit, it takes fire and burns with great brilliancy. On this account it should be kept in water. Phosphorus is the agent, in some kinds of apparatus, for procuring fire.

REFERENCES. Among the works, which may be usefully consulted on the subjects of this chapter, are CLEVELAND's Mineralogy, 2 vols. 8vo. 1822;—BRARD, *Minéralogie appliquée aux Arts*, 3 tom. 8vo. Paris, 1821;—EVELYN's Sylva, 2 vols. 4to. edit. of 1812;—MICHAUX, North American Sylva, 3 vols. 8vo. 1817;—TREDGOLD's Elementary Principles of Carpentry, 4to. 1820;—THOMSON's Chemistry;—URE's Dictionary;—VICAT, *Recherches sur les Chaux, &c.*

CHAPTER II.

OF THE FORM, CONDITION, AND STRENGTH OF MATERIALS.

When materials are employed for mechanical purposes, the power or strength with which they resist external force, depends not merely upon the nature of the material, but upon its shape, its bearings, and upon the manner in which force is applied to it. It is, therefore, important to consider not only the qualities of individual substances, but likewise the laws, which are common to different materials, by which they act in resisting mechanical change, from forces applied to them.

Modes of estimation.—Two methods are employed in estimating the strength of materials, in different forms and situations; one by mathematical computation, the other by actual experiment. The first supposes the structure of given bodies to be homogeneous, so that the cohesion of their particles shall be equal throughout. In the second, a single specimen is taken as the representative of a class; or at most the average of a number of specimens, is so taken. Neither method, therefore, is to be looked upon as precisely accurate in its results; yet these results furnish approximations to truth, which, in many cases, it is useful to understand.

Stress and strain.—Professor Robison, and some other writers on the strength of materials, have enumerated four modes, commonly called strains, by which any force or stress acting upon a solid body may operate to overcome the cohesion of its particles. These are, 1. By *extension*, producing a tendency to rupture; as in the case of ropes, tie-beams, king-posts, &c. 2. By *compression*, tending to shorten or crush the material; as in columns, walls, and foundations. 3. By *transverse strain*, tending to produce flexure or fracture; as in beams, rails, and oars. 4. By *torsion* or twisting; as in screws, rudders, and axles fixed to wheels. To these Dr Young has added another, viz;—*detrusion*, or pushing aside, as in the case of a pin operated on by the blades of scissors. The changes called *flexure*, or bending; *fracture*, or solution of continuity; and *alteration*, or permanent change of form without separation; are to be included in the effects of force exerted on materials.

Resistance.—To these disturbing influences, bodies oppose certain qualities, which depend, in part, upon the nature of the material, and in part on its form, condition, and connexion. These are their *strength*, by which they resist all permanent changes resulting from mechanical force, but more particularly fracture. Their *hardness*, by which they resist impressions, or superficial changes. Their *stiffness*, by which they resist flexure or bending. Their *elasticity*, by which they regain their original size and form, after any force producing mechanical change in them has ceased to operate. Their *tenacity*, by which they undergo permanent alteration without fracture. This quality is called *ductility*, when exposed to extension, and *malleability*, when exposed to compression. Some authors add the term *resilience*, to express the quality by which a body resists impulse, like that of a blow, in contradistinction from strength, by which it resists pressure.

Extension.—When a bar of any material is drawn in the direction of its length, its resistance, or strength, will be proportionate to its size at the weakest point; *i. e.* to the area of its cross section at that point. The tie-beam of a roof, the posts of a printing press, and the shaft or piston rod of a pump, are exposed to this kind of strain; and their weakest point is commonly found at the place where they are perforated, or mortised, to connect them with the other parts. Various experiments have been made to determine the comparative strength with which different substances resist tension. Although they do not fully agree in their results, they nevertheless, when taken collectively, afford approximations of some use for practical purposes. An idea of the relative strength of the metals, when extended, may be obtained from Mr Rennie's experiments detailed in the Philosophical Transactions for 1818. His experiments were made with bars six inches long, and a quarter of an inch square. The average number of pounds avoirdupois, which they supported respectively, is, in round numbers, as follows. Steel, about 8000 pounds. Hammered iron, about 4000. Gun metal and wrought copper, 2000. Cast copper and brass, 1000. Tin, 300. Lead, 100. Experiments have been made on the longitudinal strength of the wood of different European trees; and similar experiments, sufficiently varied, on the trees of this continent, might be a valuable addition to our knowledge.

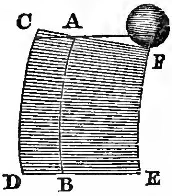
Compression.—When a bar or beam is compressed in the direction of its length, it resists more powerfully than in any other way.* If the beam be long, and its strength be overpowered by pressure, it bends, and then breaks; but if its thickness be as much as a seventh part of its length, it commonly swells in the middle, splits, and is crushed. When a stone block or pillar is crushed, the parts nearest to the force break away, and slide off diagonally at the sides, leaving a pyramidal base. The lower stories of buildings, the piers and piles of bridges, the spokes of carriage wheels, and the legs of furniture, are subjects of this force. According to Mr Tredgold,† a cubic inch of malleable iron will support, without alteration, a weight of about 17000 pounds; cast iron, 15000; brass, 7000; oak and mahogany, nearly 4000; tin, 3000; lead, 1500. Granite is crushed by 11000 pounds to the square inch; white marble, by 6000; Portland stone, by 4000.

When a force acts on a straight column in the direction of its axis, it can only extend or compress it equally through its whole substance. But if the direction of the force is not in the

* *Modulus of elasticity.*—This term has been introduced as a measure to express the elastic force of any substance. The Modulus of elasticity of a substance is a column of the same substance, capable of producing a pressure on its base, which is to the weight causing a certain degree of compression, as the length of the substance is to the diminution of its length.

† Essay on Cast Iron, p. 269, etc.

axis, but parallel to it, the extension or compression will then be partial. In a rectangular column or block, when the compressing force is applied to a point more distant from the axis than one sixth of the depth, the remoter surface will be no longer compressed, but extended. In this case, the distance from the axis of the neutral point, or that which is neither compressed nor extended, will be inversely as that of the point to which the force is applied. For example, a weight or compressing force being applied on one side of the block or column C D E F, and acting in a direction parallel to its axis, the compression will extend only to the line A B, the parts beyond this being extended.



Lateral strain.—When a beam is acted on transversely, or by a lateral force, the effect produced is the joint result of extension and compression. For if it be moved or bent by such a force, from its original direction, the part which becomes convex is extended, while the part rendered concave is compressed. The properties by which a beam resists lateral pressure, are its stiffness and its strength.

Stiffness.—The stiffness of any substance is measured by the force required to cause it to bend or recede through a given small space in the direction of the force. It appears to be governed by different laws from those of the strength which resists fracture. When a force is applied to a beam transversely, its stiffness is directly as the breadth, and the cube of the depth of the beam, and inversely as the cube of its length.* Thus if we have a beam which is twice as long as another, we must make it, in order to obtain an equal stiffness, either twice as deep, or eight times as broad. When a beam is supported at both ends, its stiffness is twice as great as that of a beam of half the length inserted in a wall, or otherwise firmly fixed, at

* Gregory's Mathematics for practical men, 389, also Young's Nat. Philosophy, i. 139, and Tredgold's Elements of Carpentry, 31.

one end. If both ends are firmly fixed, the stiffness is quadrupled.*

Tubes.—A tube or hollow beam is much stiffer than the same quantity of matter in a solid form. The stiffness is indeed increased nearly in proportion to the square of the diameter; since the cohesion and repulsion are equally exerted, with a smaller curvature, and act also on a longer lever. We see this principle applied in nature in the stems of reeds, and the bones and quills of animals.

Strength.—The strength of beams of the same kind, and fixed in the same manner, in resisting a transverse force which tends to break them, is simply as their breadth, as the square of their depth, and inversely as their length. Thus if a beam be twice as broad as another, it will also be twice as strong; but if it be twice as deep, it will be four times as strong; for the increase of depth not only doubles the number of the resisting particles, but also gives each of them a double power, by increasing the length of the levers on which they act. The increase of the length of a beam must obviously weaken it, by giving a mechanical advantage to the power which tends to break it; and some experiments appear to show, that the strength is diminished in a proportion greater than that in which the length is increased.

The strength of a beam supported at both ends, like its stiffness, is twice as great as that of a single beam of half the length, which is fixed at one end; and the strength of the whole beam is again doubled, if both the ends are firmly fixed.

* The quantity of timber being the same, a beam will be stronger in proportion as the depth is greater; but there is a certain proportion between the depth and breadth, which, if it be exceeded, the beam will be liable to overturn and break sideways. To avoid this, the breadth should never be less than that given by the following rule, unless the beam be held in its position by some other means.

Divide the length in feet, by the square root of the depth in inches, and the quotient multiplied by the decimal 0.6 will give the least breadth that should be given to the beam.—*Tredgold's Carpentry*, p. 32.

Place of strain.—If a weight or other stress be placed on any given point of a horizontal bar which is supported at both ends, the strain on that point will be proportional to the rectangle of the two segments into which the point divides the bar. Hence the place where the strain would be greatest is in the middle of the bar, and a given weight would be most likely to break it in that place.

Incipient fracture.—An incipient or partial fracture, at the place of strain, weakens a beam more, than if the whole side of the beam were cut away to the same depth as the fracture. This is because the sound, or stronger parts of the beam tend to straighten themselves, and thus increase the curvature at the point which is weakened. The same cause occasions the breaking of glass in the direction of a cut made by a diamond, or of a crack which has commenced. Mr Emerson asserts that a triangular beam, which is so strained that the greatest extension takes place at one of its angles, is rendered stronger, rather than weaker, by cutting away this angle to a small depth, so as to convert the beam into a four-sided figure; thus producing the seeming paradox of a part being stronger than the whole. A sharp angle is indefinitely weak, and fracture is more likely to begin in an angle than in a broad surface.

Resilience.—The property which resists pressure, is called *strength*, and that which resists impulse, is termed by Dr Young, *resilience.** The resilience is measured by the product of the mass, and the square of the velocity of a body capable of breaking it, while the strength is merely measured by the greatest pressure that it can support in a state of rest.

The resilience of a prismatic beam, resisting a transverse impulse, follows a different law from that which determines its strength; for it is simply in proportion to the bulk or weight of the beam, whether it be shorter or longer, narrower or wider, shallower or deeper, solid or hollow. Thus a beam ten feet long, will support but half as great a pressure without breaking, as a beam of the same breadth and depth, which is only

* Nat. Philosophy, pp. 143–147.

five feet in length; but it will bear the impulse of a double weight, striking against it with a given velocity, and will require that a given body should fall from a double height in order to break it.*

Shape of timber.—It may be inferred from the consideration of the nature of the different kinds of resistance, that if we have a cylindrical tree a foot in diameter, which is to be formed into a prismatic beam by flattening its sides, we shall gain the greatest stiffness by making the breadth or thickness six inches and the depth ten and a half; the greatest strength by making the breadth seven inches and the depth nine and three quarters, and the greatest resilience by making the beam square.†

Torsion.—The kind of strain called torsion or twisting, consists in the lateral displacement or detrusion of the opposite parts of a solid, in opposite directions; the central particles only remaining in their natural state. The strength, or rather stiffness, with which the shaft of a wheel, or crank resists torsion, increases in a rapid ratio to its diameter. Professor Robison has calculated, that the power of resisting torsion is as the cube of the diameter; and the more recent estimates of M. Duleau make it as the fourth power of the diameter. If the length vary, the resistance to the force of torsion will be inversely as the length, for obvious reasons. It is advantageous in machinery to increase the diameter of shafts which are exposed to this strain, the amount of material remaining the same. For this purpose they are sometimes made hollow, and sometimes winged with lateral projections.

Limit of bulk.—It is important to recollect that when the bulk of a substance employed, becomes very considerable, its own weight may bear so great a proportion to its strength, as to add materially to the load to be supported. In most cases, the weight of bodies increases more rapidly than their strength, and thus causes a practical limitation of the magnitude of our machines and edifices. Thus a roof, or a bridge, may be very

* Young's Nat. Philosophy, p. 148. † Ibid. p. 149.

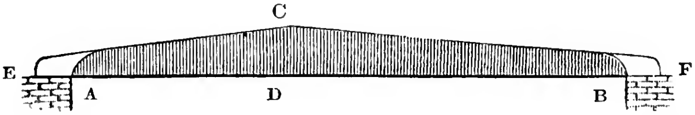
strong, when of small, or moderate size; but if the size be extended beyond a certain limit, although the materials and proportion of parts remain the same, yet the structure will not support its own weight. We see also a similar limit in nature; for if trees and animals were made many times larger than we now find them, and of the same kinds of substance, they would not sustain their own weight. Small animals endure greater comparative violence, and perform greater feats of strength in proportion to their size, than large ones. It has been observed that whales are larger than any land animals, because their weight is more equally supported by the pressure of the medium in which they swim.

Practical Remarks.—In frames of houses, and for various other purposes, beams are used of a prismatic form, having straight, parallel sides. But such beams, when exposed to a lateral strain, are not of equal, or duly proportioned strength throughout; and therefore a part of them is superfluous. This consideration is not of much importance in ordinary practical cases. But in cases where economy of the material is important, as in cast iron railroads, also in machinery where it is desirable that the moving parts should be as light as possible, consistently with the requisite strength; it becomes of consequence to ascertain the best form for resisting a force with the smallest amount of material. Mathematicians have calculated the forms of different beams, which are suited to give them, at all points, a strength proportionate to the pressure they sustain, supposing the material to be of uniform texture. But the outline which answers merely to mathematical truth, is in many cases too scanty for actual employment; so that in order to obtain sufficient length for a secure connexion of the beam with its bearings, it is necessary to include the mathematical figure in a somewhat similar one, of larger dimensions. The following rules are, most of them, given in substance by Mr Tredgold.*

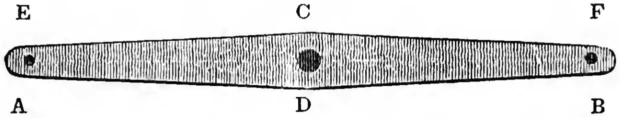
If a beam be supported at both ends, and the load applied

* Essay on Cast Iron, Art. 21. *et seq.*

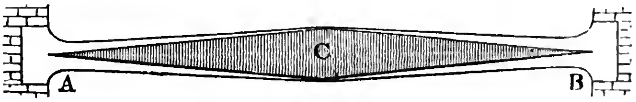
at some one point between the supports, and always acting in the same direction, the best plan appears to be, to make the extended side, or that opposite the load, perfectly straight; and to make the breadth equal throughout the whole. Then the mathematical form of the compressed side will be that which is formed by drawing two semi-parabolas, A C D and B C D, their vertices being at A and B, and C being the point where the force acts. Now since the curve terminates at A, it is necessary, in applying it to use, to add some such parts as are indicated by the lines extending to E and F at the extremities, for the sake of better support.



The same form is proper for a beam supported in the middle, as the beam of a balance. If the beam be strained, sometimes from one side and sometimes from the other, as in the beam of a steam engine, then both sides should be of the same form, and E A and F B should each be equal to half C D.

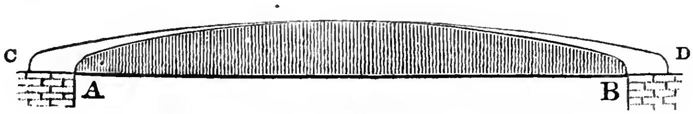


It is sometimes desirable to preserve the same depth throughout; and in this case the section through the length of the beam, made perpendicular to the direction of the straining force, should be a rhombus or trapezium, as in the annexed figure, the force acting perpendicularly at C, and the points of support being at A and B. To give this figure stability, the ends may be formed as shown in the continued outline.



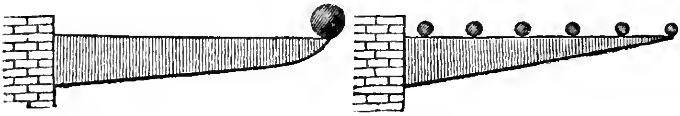
If a beam be intended to support a weight uniformly distributed throughout its length, or a load rolling over it, as in a railway, the line bounding the compressed side should be a semi-ellipse, the other side being straight. In practice the semi-ellipse may be included in a portion of a circle, to give the requisite bearings.

A, B, ends of the elliptic curve. C, D, ends of the circular curve.

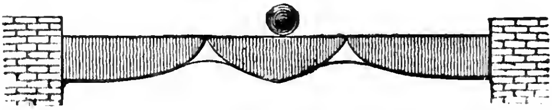


Where it is necessary that the upper side should be straight, the above form may be inverted, and the ends adapted to the bearings.

Beams which are fixed at one end only and support weights, should decrease as they recede from the wall, or point of fixture. If the weight be at the extremity, the outline, in a beam cut from a vertical plank, should be parabolic; but if equally distributed throughout, it may be straight.



If a beam be firmly fixed at both ends, and supports a weight in the middle, it should be largest at the ends and in the middle, the outlines being parabolic. In the annexed figure the shaded part shows the mathematical form, and the outline the form for practical purposes.



For resisting a cross strain, it is advantageous that the edges of a beam should be made thicker than the rest of its substance, so that a section of the beam would be nearly such as is seen in the adjoining figure.*

It must be recollected that the foregoing rules prescribe only a general form, the proportions of which must vary with the nature of the material, and the degree of resistance, or load to be supported.

Works which treat of the strength of materials.—ROBISON's Mechanical Philosophy, 4 vols. 8vo. 1822; vol. i. p. 369, &c.;—BARLOW on Timber, 8vo. 1823;—YOUNG's Natural Philosophy, 2 vols. 4to. 1807; vol. i. p. 135, &c; vol. ii. art. 333, &c.;—RENNIE, in the Philosophical Transactions, 1818;—DULEAU, *Annales de Chimie*, tom. xii.;—TREDGOLD's Elementary Principles of Carpentry, 4to. 1820;—TREDGOLD's Essay on Cast Iron, 8vo. 1824;—EMERSON's Mechanics;—GREGORY's Mechanics, 3 vols. 8vo. edit. 1826;—GREGORY's Mathematics for Practical Men, 8vo. 1825.

* For the form best suited to resist longitudinal pressure, see the article *Column* in Chap. VII.

CHAPTER III.

THE ARTS OF WRITING AND PRINTING.

Letters.—THE arts of writing and printing, although comparatively simple in their processes, are superior to most other arts in the importance of their consequences. Before the invention of letters, the growth of knowledge was opposed by insurmountable obstacles. Tradition, which was the earliest mode of transmitting knowledge, depended upon the memory and the will of individuals, and was of course uncertain of continuance. The principal adventitious aids brought to the assistance of traditionary knowledge, were the erecting of monuments, the celebration of periodical days or years, the use of poetry, a language more captivating and more easily remembered than mere narration of facts; and finally, an approach to written characters in symbolical drawings and hieroglyphic sketches.* All these methods, however, have failed in the object for which they were intended. The ancient founders of many stupendous structures have not been able to convey to us their names, and the productions of the earliest sages and poets can never be appreciated from acquaintance. History must have remained uncertain and fabulous, and science been left in perpetual infancy, had it not been for the invention of written characters.

Invention of Letters.—The credit of the first introduction of letters, was claimed by the Egyptians and Phœnicians, Jews, Chinese, and other nations. Their origin is extremely ancient,

* The recent investigations of M. Champollion have led to the discovery that a great part of the hyeroglyphic characters upon the antiquities of Egypt are in reality the letters of an alphabet; and considerable progress has been made in decyphering their import.

and of course preceded all authentic history which was not inspired. If we believe Pliny, sixteen characters of the Grecian alphabet were introduced by Cadmus the Phœnician, 1500 years before Christ. Four more were added by Palamedes during the Trojan war, and four afterward by Simonides. It is not probable, however, that the Greek was the oldest alphabet. Mr Astle considers the Phœnicians as having the strongest claim to be considered the first inventors of letters.

Arrangement of Letters.—The mode of arranging letters has been subject to considerable variation, some nations having written in perpendicular lines, others from right to left, and others in lines alternately reversed, as in the βουστροφηδὸν of the ancient Greeks.* The mode of writing from left to right, now generally pursued, is the most natural; because the hand, as it advances in this direction, leaves constantly uncovered that portion of the page upon which writing has been made.

Writing Materials.—The most ancient materials employed for writing, appear to have been the surfaces of stones and bricks. The ten commandments were written upon stone, and the arrow-headed alphabet, as it is called, belonging to an extinct language, is only known to us by the pages of inscriptions which remain on the Babylonian bricks. After these, plates of metal, of various kinds, were employed. The Romans wrote upon tables of brass thinly coated with wax, using an iron pencil with a sharp point denominated *Stylus*. Lead was also used by them, and at the seige of Modena a correspondence was carried on by Decimus Brutus, and the consul Hirtius, upon plates of lead. Pausanius mentions books of Hesiod, and Pliny speaks of public records, inscribed on the

* The bustrophedon was disused by the Greeks about 450 years before the christian era; but a similar method appears to have been in use among the Irish at a much later period. The following example of the Greek bustrophedon is from an inscription on a marble in the national museum at Paris.

NEKHΘE NEM ΣOΛΛΥ
ΑΡΙΣΤΟΚΥΔΕΣ ΝΟΗΣΕΝ
em decalp sullyH
Aristocydes designed me.

same material. A less durable, but more cheap receptacle for written characters, was found in the leaves of trees and their inner bark, denominated *liber* by the Latins. These were used for the more temporary or perishable writings.*

Papyrus.—As the literature of antiquity advanced, it became necessary to find a material adapted for works of magnitude, which, besides permanency and enlarged size, should have a fineness of texture sufficient to permit a large surface to be folded into a compact form. A species of reed, growing in Egypt, was found capable of being manufactured into a substance of this sort. Sheets and rolls were prepared from it of the finest texture, and of any dimensions, and it became the receptacle on which a great part of the ancient manuscripts were written. This was the celebrated Egyptian papyrus. The discovery of its manufacture, though it afforded a substance far inferior to modern paper, was nevertheless a great auxiliary to ancient learning, and became the means of a much more extensive multiplication of manuscripts than could have taken place had it remained unknown. The papyrus was an aquatic reed growing on the banks of the Nile.† The manufacture of paper was performed by divesting this reed of its outer covering and then carefully separating the internal membranes or laminæ by the point of a needle or knife.‡ These laminæ were spread parallel to each other on a table, having their edges

* Pliny says that tables of wood were in use for writing before the time of Homer. In the Slonian library at Oxford, there are some specimens of ancient Arabic writing on boards about two feet long and six inches wide.

The edicts of the Roman Senate were written on tablets of ivory, thence denominated *libri elephantini*.

According to Pliny, the most ancient mode of writing, was upon the leaves of Palm trees, afterward upon the inner bark of trees. This method is still common in Tanjore, and some other parts of the East Indies where the Palmyra leaf is used.

The old Egyptians frequently wrote on linen, and specimens of this kind are sometimes found enclosed in the garments or swathing clothes of mummies.

† Cyperus papyrus. L.

‡ The delicate substance now imported from India under the name of *rice paper*, is a cellular membrane of the *Artocarpus incisifolia*, or Bread-fruit-tree. *Brewster's Journal*, iii. 136.

in contact, in sufficient numbers to form a sheet. A second stratum was then laid, with the strips crossing those of the first at right angles. The whole was moistened with water, and subjected to pressure between two polished surfaces. Upon drying, the mass was found agglutinated into a smooth and uniform sheet. The adhesion of the strips of papyrus to each other was doubtless owing to the glutinous juice of the reed, though the Romans, who were ignorant of the Egyptian mode of manufacturing it, attributed this effect to a peculiar quality in the waters of the Nile. The most delicate paper, which was made from the inner membranes or tunics of the reed, was rendered extremely white, and polished by rubbing it with a shell, or tooth of an animal.

Herculaneum Manuscripts.—The papyrus continued in use as late as the tenth or twelfth century, when it was superseded by parchment and cotton paper. A few ancient manuscripts written on it are preserved as curiosities in different libraries of Europe, though they are less numerous than those of parchment and vellum. The most interesting collection of papyri is undoubtedly that found at Herculaneum, and was probably buried with that city in an eruption of Vesuvius which happened during the reign of Titus. In the excava tions which the moderns have made into the earth which cov ers that city, these rolls of papyri, nearly 1700 in number were found in a house, the roof and floors of which had been crushed in by the substances ejected from the volcano. The rolls were found in a state so near to decomposition that the least violence causes them to break and crumble ; their color is so nearly black that the characters are distinguishable from the paper only by a slight shade of difference ; and the whole roll is cemented together, so as not to be separable into layers without great difficulty. This state has been supposed to be produced by the carbonization, or converting into coal, of the papyri, by the heat of the ashes and lava, in which they were buried. Sir Humphrey Davy, however, has given a different opinion of the state of these manuscripts. He supposes that their present condition is not the result of carbonization or of heat applied to them, but is the consequence of their remaining for so many ages under ground, until the vegetable matter of which they are composed, has undergone a spontaneous change, and become converted into a substance analogous to peat, or Bovey coal. This conclusion is the result of chemical examination, and is likewise inferred from the fact that some specimens of gilding, and of vermilion, which remained on the walls of the apartment, were not changed in color, which could not have been the case, had the heat been sufficient to convert vegetable matter into charcoal.

About ninety of these manuscripts have been unrolled by a very tedious process, which consists in glueing pieces of gold beaters' skin to the outside of the rolls, and suffering them to dry on. They are then gradually raised by means of screws, lifting with them a layer of the papyrus, which is copied and the process renewed. Several days, in this way, are requisite for a single page. Sir Humphrey Davy thinks a more expeditious way might be adopted, by subjecting the rolls to the action of a chemical solvent, capable of destroying the adhesion of the folds to each other. He supposes that of the manuscripts which remain, not more than from eighty to one hundred and twenty are in a state to be unrolled, the rest being too much defaced, by crushing or otherwise, to render it probable they will ever be decyphered.

Parchment.—Next to the papyrus, the skins of animals, in the form of parchment and vellum, were extensively used for writing, by the ancients, from a remote period. When Eumenes, or Attalus, attempted to found a library at Pergamus, 200 years B. C., which should rival the famous Alexandrian library, one of the Ptolemies, then king of Egypt, jealous of his success, made a decree prohibiting the exportation of papyrus. The inhabitants of Pergamus set about manufacturing parchment as a substitute, and formed their library principally of manuscripts on this material; whence it was known among the Latins by the name of *Pergamena*. The term *membrana* was also applied by them to parchment.

Paper.—Paper like that used at the present day, composed of flexible fibres reduced to a pulp by minute division, and cemented into sheets by means of size or glue, began to be known in the East in the beginning of the tenth century. It was first composed of cotton or silk, and called *bombycina*, and was not made from linen rags until the fourteenth century. Coarse brown paper was first manufactured in England in 1588; writing and printing paper in that country not till 1690, previously to which, it was imported from the continent.

Instruments.—While writing was practised upon hard substances, as stone and metal, a hard metallic point was the instrument with which letters were formed. The *stylus*, which the Romans employed for writing on brass tablets covered with wax, was acute at one end for writing, and flattened or blunt at the other, for erasing what was written. For writing in colored fluids, or ink, the *calamus* was used, a reed sharpened at the point, and split like our pens. Quills were not introduced till the fourth or sixth century.*

Some of the eastern nations still write with reeds, canes, and bamboos, instead of quills. The Chinese write with small brushes like camel's hair pencils.

Inks.—The *ink* of the ancients consisted of a carbonaceous substance, such as lampblack, soot, or pulverized coal, united with a viscid or gummy liquid. The black liquor of the cuttle fish (*Sepia*) was sometimes employed. Colored inks of vermilion, red lead, and purple, were also used. The eastern emperors signed their edicts with red ink, the use of which was prohibited to others, under pain of death.

* The earliest notice of the use of quills, is by an anonymous author of the life of Constantius, who says that Theodoric, the Ostrogothic king of Rome, was so illiterate, and so dull of intellect, that, during the ten years of his reign, he could not learn four letters to sign at the bottom of his edicts; so that they were cut for him in a plate of gold, through which he traced the letters with a quill. One of the oldest certain mentions of the use of quills, is by Isidore, who died in 636.

Modern ink is essentially a tanno-gallate of iron suspended by mucilage. It may be made from salts of iron, and infusions of various astringent vegetables. But as many products of this kind are apt to fade by time, it is not safe to trust to any which have not had the testimony of long experience in their favor. The best materials are the nutgall and sulphate of iron, with gum arabic. Other ingredients are sometimes added, such as logwood, sulphate of copper, and sugar. When ink fades, it is commonly from the fugitive nature of the gallic acid and tannin; and it may be revived by moistening the page with a fresh infusion of galls. When ink grows thin from freezing, or dilution, so that its particles subside, they may again be suspended, by agitating it with sugar, or gum. If writing with common ink has been obliterated by chlorine, it may be again rendered legible, by the vapor, or solution, of sulphuret of ammonia. *Indelible* ink is produced by writing with dissolved nitrate of silver on a surface impregnated with carbonate of soda.

Copying Machines.—Various modes have been devised, for making extemporaneous copies of written pages. Dr Franklin's method consisted in covering the writing, while yet moist, with fine powdered emery; and afterwards passing the sheet through a press, in contact with a plate of pewter, or copper; which thus became marked with the letters, so as to yield impressions, as in the common mode of copperplate printing. Mr Watt's *copying machine* consists of a press, in which a thin, bibulous paper, previously moistened, is forced into close contact with the page, while newly written. A part of the ink, sufficient to produce legible characters, is thus transferred to the thin paper. The writing is of course reversed, but the thinness of the paper permits it to be read on the opposite side, which restores the order of the letters. Mr Hawkins' *polygraph* is a machine carrying two or more pens in different places, which are so connected as to pursue a similar path with each other, and execute two or more copies at once. Lithography likewise offers a ready method of multiplying copies.

PRINTING.

The art of printing, as it is now practised, by the composition of moveable types, is so simple and obvious in its principles, that it is truly wonderful the process was not earlier known. The ancients many times made near approaches to the discovery, but by some singular fatality, they were kept from its profitable use. Arts far more curious, and sciences far more difficult, were known, and carried to perfection, by the patient industry of the ingenious and enterprising in former times. But this art, which was to give permanency to all the rest, and which now seems to be at the root of all human knowledge, was never in useful operation in Europe until three or four centuries ago.

Types.—Printing at the present day is executed with moveable types, which are oblong square pieces of metal, each bearing a letter in relief at one extremity. The metal of which they are made, is an alloy, which consists essentially of lead and antimony. The lead is selected in preference to other metals, because it is fusible at a low temperature, and retains accurately the shape it receives from the mould. But as lead alone is too soft to sustain the friction and pressure to which it is liable in use, about a fifth part of antimony is added. This gives it a superior hardness when cast; and as this alloy has the property of shrinking less than most other metals as it cools, the type receives all the sharpness and finish, which it can acquire, by filling every part of the mould. In making types, the letter is first cut by an artist upon the end of a steel punch, answering to the shape of the intended type. This punch is driven into a piece of copper, which forms the *matrix* or bottom of the mould intended to produce the letter. As many varieties of punches must be made of steel, as there are sizes and species of characters required. In casting, the types are formed with great rapidity, owing to the quickness with which the metal cools. An expert operator will make 2000 or 3000 types in a day. Some machines have been introduced, for casting types, which operate with much greater rapidity. The characters upon types are of course reversed, so that in arranging them for the press, the *compositor*, or printer who sets the types, begins at the right hand of each line.

Case.—Before the types are applied to use, they are arranged in the cells or compartments of a long wooden receptacle, called a *case;* each species of letter, character, or space, by itself. In arranging the compartments, the collections of letters do not succeed each other in alphabetical order, nor are they all of equal size. Those letters which occur most frequently in printing, are required in greater numbers. They are therefore made to occupy the largest compartments, and are placed nearest to the compositor. Thus the letter e, which is of frequent occurrence, fills a large compartment, and is nearest the compositor, while the letter x, which occurs much less frequently, is provided in small numbers, and placed at the extremity of the case. In a *bill* or collection of types of the size called pica, weighing in all 800 pounds, the number of the letter e is 12000; of t, 9000; of a, 8500; of i, n, o, and s, 8000 each; of c, there are 3000; of b, 1600; k, 800; x, 400; z, 200. This is for the English language. In other languages, the comparative frequency must be different.

Sizes.—Different names are given to the various sizes of types, of which the following are most employed in common book printing.

Pica.—a b c d e f g h i j k l m n o p q r s t u
Small Pica.—a b c d e f g h i j k l m n o p q r s t u v w
Long Primer.—a b c d e f g h i j k l m n o p q r s t u v w
Bourgeois.—a b c d e f g h i j k l m n o p q r s t u v w x y z
Brevier.—a b c d e f g h i j k l m n o p q r s t u v w x y z
Minion.—a b c d e f g h i j k l m n o p q r s t u v w x y z
Nonpareil.—a b c d e f g h i j k l m n o p q r s t u v w x y z

Composing.—The compositor is first provided with an instrument called the *composing stick.* This is a plate, commonly of iron or brass, surrounded with ledges, one of which is moveable, so that the length of the lines may be adjusted to the width of the page. The compositor selects from their places the letters successively, to constitute the first word, which are arranged in an inverted order from that in which they are to appear on the printed page, beginning at the right. At the end of the word a *quadrat* is inserted to produce a space between this word and the next following. The quadrats, of which there are various kinds, differently named from their width, are blunt types, bearing no letter on their extremities. In printing, they do not come up to the surface, and of course yield no impression. As the beauty of the page depends upon the evenness of the margin produced by the equality of the lines, these quadrats are used to swell out the shorter lines and bring them to an equality with the rest. When one line is finished, the printer shifts the *rule* from below it to the top, and commences setting the types for a second line. The rule is a thin brass plate used to make the types slide easily, and not catch upon the line below them.

The quickness with which an expert compositor advances in his work, is greater than would appear possible from a first consideration of the subject. The familiarity with the situations of the letters and their arrangement, produced by long habit, is such, that to select the types and place them, does not require a thought to be bestowed on the process. It is only necessary to perceive the meaning of each word, and the putting it together follows as mechanically as writing. It is even possible for a printer to compose in the dark, for the exact situation of each letter in the case before him being known, and the upper side of each being known by notches in the type, they can be selected and arranged by the sense of feeling alone.

Imposing.—When a sufficient number of lines, as six or eight, are formed in the composing stick, they are *emptied* into another instrument called the *galley*, which is a flat board or plate, partly or wholly surrounded by a rim. In this galley, the types are accumulated, generally in the form of long columns, which are afterwards divided into pages, each page being tied together with a string to prevent the types from falling asunder. When a sufficient number of pages are completed to constitute what is called a *forme*, or in other words, to fill one side of a sheet, they are arranged upon an *imposing stone*, and strongly *locked up*, or wedged together, in an iron frame, denominated a *chase*, to prepare them for the press.

Signatures.—A sheet intended for a folio, has two pages on a side, and will form two leaves. A quarto has four; an octavo, eight; a duodecimo, twelve, &c. These pages are so arranged in the forme, that in the impression they will assume their true order, after the sheet is folded. The sheets are marked at the bottom of certain pages with successive numbers, or capital letters; the object of which is to afford the necessary instructions for the order of folding and gathering them. These are called *signatures*.

Correcting the Press.—The first impression taken from the types is called a *proof*. This is carefully read over, and the errors and inaccuracies marked. To correct them, the wedges or *quoins*, are knocked out, so as to loosen the types; the erroneous letters are drawn out, and the proper ones substituted, and the whole is again wedged into the frame.

Many of the errors of the press, which remain uncorrected in books, arise from a want of understanding between the author, or corrector, and the printer, in the characters used in correction. It is not enough that the author should detect these errors and note them in the margin. He must express, by intelligible marks, how these defects are to be altered, and unless he uses such marks as are employed by printers themselves, his attempts at correctness will be defeated. Every person who has occasion to appear in print, should first know how to correct the press.*

* If the error is confined to a letter or word, it is easily corrected. But if it involves the addition or erasure of a sentence or a number of lines, the correction is more difficult. The whole forme must be deranged, and as the adding or expunging of lines affects the length of the page, it must be adjusted at the

The following signs for correcting the press, are employed by printers themselves.

When a wrong letter is discovered, a line is drawn through it, and the true letter written in the margin, thus;

To be, or not to be, that i~~t~~ the question. *s*

If a letter is found to be omitted, a caret is placed under its place, and the letter written in the margin, thus;

To be, or not to be, th‸t is the question. *a*

If a superfluous letter is detected, it is crossed out, and a character which stands for *dele*, introduced in the margin.

To be, or not to~~o~~ be, that is the question. ♂

If two words are improperly joined together, a character indicating a space, or quadrat, is used.

To be, or not to‸be, that is the question. #

If syllables of the same word are improperly separated, they are joined by a horizontal parenthesis.

To be, or not to be, that is the ques‿tion. ⁀‿

When words are found to be transposed, they are connected by a curved line, and the letters *tr.* written in the margin.

To be, or not to be, (is that) the question. *tr.*

expense of the next following page; so that all the subsequent pages may be disturbed, before the necessary correctness is obtained. An author who corrects the press for his own works, will very much abridge the labor of the printer, if, in all cases of an erased word, he will substitute another of nearly the same length in its neighborhood, or, if a new word is added, by striking out one in the paragraph which can be better spared.

When a letter is inverted, it is expressed by a character of this sort in the margin.

Marks of punctuation, if of small size, are inclosed in circles, thus ; ⊙

A comma is placed after a short stroke, an apostrophe before it. |, ,|

Words intended to be printed in Italics, are marked beneath with a single line ; if in small capitals, with two lines ; and if in large capitals, with three. Thus a line marked in this manner,

Oh thou, in Hellas deemed of heavenly birth.

would be printed thus ;—

OH THOU, in HELLAS deemed of *heavenly* birth.

In correcting with these marks, the abbreviations ***Ital. Rom.*** *Caps.* &c. should also be written in the margin.

Corrections themselves sometimes require to be corrected. Thus if a word has been improperly altered, and it is afterwards thought best to retain it, dots are placed beneath and the word *stet* written in the margin.

When lines are crooked, or letters have been disturbed from their places, or blemishes appear, it is sufficient to call the attention of the printer, by a dash of the pen, at the place.

Press work.—After the sheet is corrected and revised, it is then ready for the press, to which it is accordingly transferred. The ink is first applied over the whole surface of the types ; the paper, previously moistened, is then laid down upon them, the whole is passed under the press, and the paper being brought into forcible contact with the types, receives from their surface the ink necessary for a distinct impression. Printers' ink is composed chiefly of lampblack and oil inspissated by boiling and burning. Oil is necessary, that the ink may not dry during the operation, and it is reduced by boiling, to prevent it from spreading on the paper. It is applied to the types by large elastic balls made of leather and stuffed with wool, or by elastic rollers, like those used in printing machines.

Printing Press.—The common or old printing press, derives its power from a screw, which is turned by a lever, and acts perpendicularly on the *platten*, or level part, which transmits the pressure. Various improvements have been made in the printing press, by Lord Stanhope, and other inventors, in most of which a cast-iron frame is substituted for a wooden one, being more inflexible; and a combination of levers is used, so arranged as to cause the platten to descend with decreasing rapidity, and consequently with increasing force, till it exerts the greatest power at the moment of contact of the paper with the types.

Stereotyping.—In stereotype printing, instead of moveable types, blocks or plates are used, each containing all the characters requisite to form a page. The process of stereotyping is simple. A page of any work proposed to be stereotyped, is set up in the usual manner with moveable types. From this page, when corrected, a mould in plaster, is taken off, and from this mould a plate of type-metal is cast, having all the characters in relief, and being a fac-simile of the original page. From this plate the printing is executed, and there must be, of course, as many plates cast, as there are pages in the book to be printed. It will thus be seen, from the accounts already given, that the stereotyped letter press constitutes the sixth time that the character has been formed, viz. 1, in the steel punch; 2, in the matrix; 3, in the moveable type; 4, in the plaster cast; 5, in the stereotyped character, and 6, in the printed page.

The plaster used for forming the moulds is pulverized gypsum, dried by heat, and mixed with water; to which is added a little whiting to diminish the tendency of the plaster to shrink and crack. After the forme of types has been slightly oiled, and surrounded with a brass frame, fluid plaster is applied over the surface with a brush or roller, so as to fill every cavity of the letters. A quantity of plaster mixed with water to the consistence of cream, is then poured on the type, and the superfluous part scraped off. When the plaster has become hard, it is lifted off by the frame, and detached from it. It is then baked to dryness in an oven, and when quite hot, it is placed in an iron box or casting pot, which has also been heated in an oven. The box is now plunged into a large pot of melted type-metal, and kept about ten minutes under the surface, in order that the weight of the metal may force it into all the finer parts of the letters. The whole is then cooled, the mould broken and washed off, and the back of the plate turned smooth in a lathe, or planed by a machine. The earlier stereotype founders, as Didot and others, formed their moulds with a soft metal, or a metal at the point of congelation, instead of plaster.

Stereotype printing is chiefly useful for standard and classical works, for which there is a regular demand, and of which the successive editions require no alteration. It is now executed with such increased economy, as to be applicable to works even of less durability.

Machine printing.—Printing by machinery, is one of the latest achievements of art, having had its origin within the present century. It has produced a very great improvement in the expedition with which work is executed, and is now extensively applied to the printing of newspapers and even of books. Various machines are already introduced into use, most of which perform the processes of inking the types, conveying the paper, and giving the impression. For distributing the ink on the types, elastic cylinders are employed, called inking *rollers*, made of a composition of glue and treacle, which combines the properties of smoothness, elasticity, and sufficient durability. These transmit the ink to the types by rolling over their surface. The impression is performed in most of the English machines, by large cylinders which revolve upon the types, having the sheet of paper confined to their surface by bands of tape. The types are arranged in some machines in the common flat form; in others, the characters are placed in a convex form upon the surface of cylinders. To produce the latter effect, Mr Nicholson proposed to cast the body of the types with a tapering or wedge form, like the stones of an arch, but Mr Cowper has produced the same object more expeditiously, by curving stereotype plates into the required shape. Messrs Donkin and Bacon placed their types on the four sides of a revolving prism, while the ink was applied by a roller which rose and fell with the irregularities of the prism, and the sheet was wrapped on another prism so formed as to meet the surfaces of the first. A common printing press gives about 250 impressions per hour, whereas of the *Times*, a London newspaper, printed by Applegath and Cowper's machine, it is stated that 4000 per hour are printed on one side. The first *working* machine which printed by steam, was erected by Mr Koenig, in 1814.

In this country, Treadwell's power press is the machine most employed. In this invention, the types are inked by elastic rollers, and the distribution of the ink rendered equal, by a revolving table which passes in contact with the rollers. The impressions are made by a flat surface or platten, instead of a cylinder, so that cleaner and better impressions are supposed to be obtained from it than from any other machine.

History.—The art of printing was first carried into successful operation, a little before the middle of the fifteenth century. The honor of having given birth to the invention, is claimed by the cities of Haerlem, Mentz, and Strasburgh, in each of which the art was successfully practised at an early period. The best authors, however, agree in considering that the original inventor of printing, was Laurentius, otherwise called Coster, of Haerlem, who made his first attempt in 1430, with separate wooden types. He died ten years after, having printed the 'Horarium,' the 'Speculum Belgicum,' and two different editions of Donatus, which were the first books. After his death, printing was carried on at Mentz, by John Gensfleisch, who had possessed himself of some of Laurentius' types, and who, like his master, printed in wood. This man, with the assistance of his brother who is usually called Guttenberg, afterward invented cut metal types, with which was printed the earliest edition of the bible. This edition appeared in 1450, having taken seven or eight years for its completion.

Guttenberg used none but wooden or cut metal types. The art received its consummation soon after, from Peter Schoeffer, who invented the mode of casting types in matrices. The celebrated Faustus, who has often been considered as the inventor of printing, was in partnership with the persons already mentioned, and furnished funds to defray the expenses of the enterprise, the processes being kept secret. The well known tale of the practice of necromancy, by Faustus, was owing to his carrying a parcel of his bibles to Paris, and offering them for sale as manuscripts. The French, finding so great a number of books resembling each other exactly, and more so than it was possible for any chirographer to have made them, concluded there was witchcraft in the case, and by inditing Faustus as a conjuror, compelled him to disclose the secret in his own defence.

After the invention of printing with fusible types, it spread rapidly into many of the cities of Europe, and was practised at an early period at Tours, Rome, and Venice. It was first carried on in England by Caxton and Corsellis, about 1470, and the earliest press was established at Oxford.

It is remarkable that this important art, after becoming once established, underwent no essential improvement for a period of more than 300 years. Having remained stationary for three centuries, it has received a fresh impulse within the last few years, by the invention of stereotyping, and of printing by machinery.

Although printing with moveable types is exclusively a modern art, yet there are some steps in the discovery, which have claim to greater antiquity. The Chinese have printed with their characters for more than 900 years; but as the nature of this character requires that much should be expressed by a single figure, they are obliged to cut each character with all its complications in a block of wood, so that their method resembles a limited kind of stereotype printing.

Among the relics of ancient Rome, there have been found letters, cut in brass and raised above the surface, exactly like our printing types. Some of these contain the names of individuals, and, from their shape and appendages, were evidently used for the purpose of signature, the letters being small, smooth, and even, while the ground beneath them is unequal, and rough, so that they must have been employed, not for impressions into soft substances, but for printing with colored liquids, on a surface like parchment or paper. Had the individuals, whose names were thus printed, been visited with the thought that by separating the letters, they might print the name of another, it is probable that the art would have been at once discovered, and that the dark ages might never have happened.

Works of Reference.—Astle, on the Origin and Progress of writing, 4to. London, 1803;—Fry's Pantographia, 4to. London, 1799; —Townley's Illustrations of Biblical Literature, 1821;—Stower's Printers' Grammar, 8vo. London, 1808;—Thomas' History of Printing, 8vo. Worcester, U. S. 1810;—Meerman, *Origines Typographicæ Hagæ*, 1765;—Cowper, in Brand's Journal of Science, 1828;—Hansard's Typographia, large 8vo. 1825.

CHAPTER IV.

ARTS OF DESIGNING AND PAINTING.

DESIGNING is the art of delineating or drawing the appearance of natural objects, by lines on a plane surface.* Painting may be considered as the same art, so extended as to include coloring, and whatever else is necessary to produce complete or finished resemblances. It is obvious, that if the art of painting was carried to perfection, these resemblances could not be told, at sight, from their originals; since we are supposed to discern objects by the medium of their pictures painted on the retina of the eye, and since a polished mirror gives us every appearance of reality, in the forms reflected from it, though they all proceed from the same plane.

Divisions.—To produce perfect representations of nature, three things must receive attention, and the study of these may be considered as constituting distinct departments in the art of painting. These are, 1. The *perspective*, by which the outlines of figures are placed on the picture in situations depending on their position in regard to the eye. 2. The *chiaro oscuro*, or light and shade, by which the prominence and depression of different parts of the piece are made to appear. 3. The *coloring*, by which the hues and tints of the painting are made conformable to those of the original.

Perspective.—Perspective is the art of delineating the outlines of objects on any given surface, as they would appear to the eye, if that surface were transparent, and the objects themselves were seen through it from a fixed position. It is the foundation of correctness in painting, and a strict attention to

* Rees' Cyclopedia.

its rules, is indispensable to perfection in the art. The first attempts at drawing, have, in all countries, consisted of diagrams, and sketches, representing merely the plans, or profiles of objects, without regard to their perspective relations. But a continued attention to their actual appearance or images, combined with the application of a few geometrical and optical principles, has furnished the means of fixing the outlines of objects, in their true situation on a perspective plane.

If we look through a window at a mass of buildings, or any external objects, and observe that part of the glass to which each object, line, or point, appears opposite, we find that their apparent situation is very different from their real. We find that horizontal lines sometimes appear oblique, or even perpendicular, that circles, in certain situations, look like ellipses, and squares like trapezoids or parallelograms. High objects are seen beneath low ones, and large bodies are exceeded, in apparent magnitude, by small ones. The foundation of all these appearances exists in the rectilinear motion of the rays of light passing from the object to the eye.

Field of Vision.—When the eye is fixed, the rays entering it from the whole field of vision, constitute a cone having its apex in the eye. The field presented to the eye, and occupying the base of the cone, cannot well subtend an angle of more than 90 degrees, and we cannot have a convenient and agreeable view of a field occupying more than 60 degrees. Even the most satisfactory views of objects are obtained at such distances as cause them to subtend an angle of 30 or 40 degrees. *Panoramic* views subtend a larger angle than those which have been specified, and of course cannot be taken in by the eye at a single view. It becomes, therefore, necessary to take successive views with the eye, in different directions.

Distance and Foreshortening.—Of objects situated within the field of vision, those necessarily appear largest, *cæteris paribus*, which are nearest to us, because they subtend a larger angle at the eye. Objects or surfaces situated obliquely in regard to the axis of the eye, are altered in apparent shape by the shortening of their oblique diameters. This is what is technically called *foreshortening.* If several objects, for example, of equal size, be placed at different distances, and in different positions [See Plate III. Fig. 5.] the one nearest the eye, as X, will subtend the largest angle, and its comparative length in the picture will be represented by the line A B. The object Y, being further off, subtends a smaller angle, and will be represented by the line A C. The object Z, being still further removed, and also foreshortened by its oblique position, will produce an image no longer than from A to D.

A simple instrument may be formed by any person, to represent the effect of distance and of foreshortening in perspective. Let four straight, stiff wires [Pl. III. Fig. 6.] be connected at one end, at A, by a string or socket, which will allow them to diverge. Let a thin, square board, or tin plate, be attached at the other end, at C, by loops at its four corners, through which the wires pass. Let a string of elastic gum be placed around the wires at B, about half way between A and C. The elastic string will represent the picture, the board the object, and the wires the rays passing from the object to the eye at A. If now the board be moved upon the wires toward the eye, the elastic string will be extended, or the picture enlarged. The reverse will happen, if the board be carried away from the place of the eye. The board may also be turned into various oblique positions, and the elastic string will represent the figure produced by the foreshortening.

Definitions.—There are used in perspective a certain number of terms peculiar to the art, definitions of which are necessary to an intelligent use of them.

The *original object* is that which is made the subject of the picture.

Original planes or *lines* are the surfaces or lines of original objects.

The *point of view* is the situation of the eye.

The *point of sight* is the point in the perspective plane which is nearest to the eye. As far as the picture is concerned, these two points coincide, so that some authors have used them indiscriminately one for the other. The point of sight is also called the *centre* of the picture.

A *visual ray* is a line from the object to the eye. If the object is a point, there is but one visual ray; if it is a line, the visual rays form a triangle; if it is a square, they form a pyramid; if a circle, a cone, &c. The *principal visual ray* is that from the nearest point in the picture, or point of sight.

The *perspective plane* is the surface on which the picture is delineated; or, it is the transparent surface through which we suppose objects to be viewed.

The *directing plane* is a plane supposed to pass through the eye of the spectator, parallel to the perspective plane.

The *ground plane* is the earth, or the plane surface on which the spectator and objects are situated.

The *horizon*, or *horizontal plane*, is one parallel to the ground plane, and at the height of the spectator's eye.

The *horizontal line* is the intersection of the picture or perspective plane with the horizontal plane.

The *ground line* is the intersection of the perspective plane with the ground plane; or, it is the line on which the picture is supposed to stand.

The *perpendicular* is a line on the perspective plane, drawn though the point of sight, perpendicular to the ground line and horizontal line.

The *points of distance* are points on the perspective plane, set off from the point of sight, sometimes on the horizontal line, and sometimes on the perpendicular, at the same distance from the point of sight, that the eye is supposed to be at, from the perspective plane.

To render the foregoing definitions more obvious, a diagram [Pl. II. Fig. 2.] is introduced, in which the several planes are supposed to be *visible*, and themselves, or a part of each of them, seen in perspective. X is the eye of a spectator, or point of view. S T, the original object. X T, and X S, visual rays. X Y, the principal visual ray. A B O P, the picture, or part of the perspective plane. V W, the image of the original object in the picture, or perspective plane. D, the point of sight, or centre of the picture. H N R Q, the ground plane. I K L M, the horizon or horizontal plane. A B, the ground line, or bottom of the picture. F G, the horizontal line. C E, the perpendicular. E, a point of distance. Other points of distance would be at F and G, if equally distant from D with X or E. In Fig. 1, corresponding letters are used.

The *vanishing point* of the image of a right line is the point in which a line parallel to it, passing through the eye, cuts the perspective plane. Lines which in the original are parallel, in the picture converge to the same vanishing point. Thus the parallel railings of a bridge, or the parallel rows of windows in a building, all appear to converge to the same point. In Pl. III. Fig. 8. *c*, is the vanishing point of the lines *y x*, *f k*, and of all lines parallel to them. All lines which are perpendicular to the perspective plane, have for their vanishing point the centre of the picture. Thus D, in Pl. II. Fig. 1, is the vanishing point of all such lines.

Plate II.—A general idea of the nature of perspective may be derived from the inspection of Pl. II. Fig. 1. In adjusting this plate for use, the folded or thick part must be raised perpendicularly, the rest being kept level. The part thus raised will represent the perspective plane, while the rest of the plate is the ground plane. The spectator is supposed to stand upon Z, with his eye at a height equal to that of D, above the ground plane. If now the perpendicular part be supposed to be transparent, so that the lines or objects beyond, can be seen through it, the appearance which they present on this perpendicular plane, will be their true perspective representation. This may be rendered obvious, by placing upon Z, a chess man, or any other object, the height of which is equal to C D, representing the height of the spectator's eye from the ground plane. If then straight wires or threads, representing rays, were carried from the top of this object to any of the large letters upon the black lines of the ground plane, they would pass through the perspective plane in the points indicated by the corresponding small letters. The lines also which connect these letters, will assume the situations represented in the diagram.

Problems.—Since the figures of all objects are contained within definite lines, it is evident that the whole art of perspective consists in a method of finding the situation of all lines upon the perspective plane, and of cutting those lines in any given proportion, according to the length required. The same diagram [Pl. II. Fig. 1.] will serve to illustrate several of the most obvious problems.

I. Suppose, for instance, that it is required to find the perspective situation of straight lines, such as H I and O P, situated on the ground plane, and *parallel* to the ground line. It is first obvious, that if they are parallel to the ground line, they are also parallel to one another, and to the picture. We then know that the line H I is to be drawn parallel to A B, and we only require to know at what distance it must be drawn from it.* To ascertain this, we measure the perpendicular distance C M, of the given line from the perspective plane, and set off this distance from C to *q*. We then draw the line G *q*, cutting the line C D in *m*, and the line *h i*, drawn through *m*, parallel to the ground line A B, is the perspective situation of the line H I, required.

The reason of this will appear evident, from considering that G being situated at the height of the eye from the ground line A B, and G D being equal to the distance of the eye from the perspective plane; the line D C may be imagined to be the perspective plane seen edgeways; and then any point *q*, situated at a given distance beyond it, must appear at *m*, in a straight line drawn from the eye at G, to it. Therefore *m*, is the proper distance from C, at which that point in the line required must be drawn. In like manner, the situation of the point *k*, determining the perspective distance of the line *o p*, may be found.

II. If it is required to find the perspective place of a line on the ground plane that is *perpendicular* to the ground line, we measure its distance from the perpendicular C E, and setting it off from C upon the ground line, we draw a line from the point, thus set off, to the point of sight D, which will give the situation required. Thus, for example, if we wish to find the perspective appearance of a line Q D, which is perpendicular to the ground line A B, and parallel to C D, we take the distance Q C, and set it off from C to *q*, and then D *q* is the line required. For the same reason, D *r* represents the line D R; also D *s*

* Such lines are considered parallel by writers on perspective, because a line parallel to them, passing through the eye, can never cut the perspective plane. Therefore they can have no vanishing point on the perspective plane.

represents D S, and D *t* represents D T. Since all lines perpendicular to the ground line, when infinitely produced, seem to meet on the perspective plane, in the point of sight D, it is the vanishing point of those lines.

III. If it is required to find the perspective situation of a line which is *vertical*, i. e. perpendicular to the ground plane, having first ascertained the point upon which it stands in the ground plane, we draw from the corresponding point in the perspective plane, a line perpendicular to the ground line. Thus if we have ascertained that the place at which a vertical line stands on the ground plane, is at W, we find the corresponding point *w* in the perspective plane, and from it raise a line *w x*, perpendicular to A B, and somewhere in that line continued, will the required line terminate. The reason of this will appear, when we recollect that vertical lines are parallel to the picture, and perpendicular to the ground line.

IV. If circles or curved lines are to be put in perspective, this may be done by describing squares about them, and putting these in perspective. This will assist the judgment in completing the curved lines. Or we may find the perspective situations of a number of points in the curve, and join these with a steady hand.

A great number of problems, founded on the principles of perspective, are to be found in works on that science, and constitute an interesting study. But in practice, artists find it convenient to resort to some more direct and compendious method of obtaining the perspective situation of objects, without the trouble of mensuration.

Instrumental Perspective.—The rules usually laid down for drawing in perspective, suppose a previous knowledge of the real distances, magnitudes, and relative positions of all the objects that are introduced into the picture. But, in many cases, a person may be so situated, that this knowledge cannot be obtained; and in many cases, likewise, the labor, which this method requires, is troublesome and discouraging. Dr Priestley has described a method of drawing objects in true perspective, without moving from the place in which they are viewed. It consists simply in taking observations of the various points of an object, so as to determine their elevation above the horizon, and their declination from a perpendicular.

To supply the place of actual mensuration, an *azimuth quadrant* or a *theodolite*, is used, or any instrument by which the elevation of an object can be found, and likewise its angle of declination from the perpendicular which goes through the point of sight.

The artist having this instrument, and placing himself at what distance he thinks most convenient, from any objects that he proposes to draw, lays down upon the paper of his drawing-board, two lines, crossing each other at right angles; one of them F G, [Pl. III. Fig. 8.] to represent the horizon, and the other C E, the perpendicular, passing through the point of sight D. He must also choose any distance he may think proper to work at, and set it off from D to E.

Having thus prepared for the operation, he pitches upon any point in the object in sight, as, for instance, that which corresponds to *x*; and, by the help of the instrument, first of all, finds its declination from the perpendicular to the right or left hand. Supposing it to be 10 degrees to the right, he sets off the angle D E *a*, equal to ten degrees, and concludes, that the point he wants to fix must be somewhere in the perpendicular *a e*. To find in what part of this line the point is, he must take its elevation above the horizon, and, supposing it to be 20 degrees, he makes *a b* equal to *a* E, and the angle *a b x*, equal to twenty degrees; which finds *x* the point required.

In this method may the situation of any other point be found, and these points, being joined by lines, the whole object will be delineated.

But if the objects to be represented, contain many *right lines*, that are parallel to each other, such as occur in buildings, machines, &c. there will be no occasion to take many points; because the situations of the lines may be determined by *vanishing points*, found by the help of a few of them. Thus having found *y*, in the same manner as we found *x*, and knowing that the line *x y* is parallel to the horizon, we produce it till it touches the horizontal line in *c*, which is, therefore, the vanishing point for that line, and all that are parallel to it, several of which are represented in the figure. The distance at which these parallels are drawn, may either be guessed by the eye, or be determined with more accuracy by finding a point at one of their extremities, in the manner just described.

Also, if we know the angle that any line, as *y z*, makes with another line, as *x y*, the situation of which is known, there is no occasion to take any point, in order to determine the direction of it. In this figure, *x y z* represents a right angle, which is that which most frequently occurs in buildings, machines, &c. To determine, therefore, the situation of the line *y z*, we consider that *c*, the vanishing point of *y x*, makes the angle D E *c*, equal to 20 degrees, the complement of which, from 90, is 70. We therefore make the angle D E H equal to 70 degrees, and a line E H, produced till it meets the horizontal line in a place without the bounds of this figure, gives the vanishing point of *y z*, and of every other line parallel to it which is at right angles with the line *x y*. To this point, therefore, we draw the line *y z*, and all the others in that plane that are parallel to it.

The point *x*, is to the right hand of the perpendicular, and it has an elevation above the horizon; but it can require no additional instruction, to be able from this, to fix any point to the left hand of the perpendicular, and one that has a depression below the horizon.

If we would introduce *measures* into a drawing made in this manner, or find a *scale* for the picture, we measure some one line in the original, as *k f*. In order to this, from *c*, the vanishing point of the line *k f*, we take *c d*, equal to *c* E, which gives *d* the measuring point of the line, and from this point, we draw two lines, one from each extremity of the line *k f*, to *i h*, in the line that bounds the picture, or any other line drawn parallel to the horizontal line. Then we divide the line *i h*, in the same proportion as *k f;* and by this means get a scale, by which we can measure any other line in the picture, or insert in it other objects of any given magnitudes.

Mechanical Perspective.—To avoid wholly the delay and trouble of computation, artists frequently make use, in practice, of some mechanical method of perspective drawing, by which the outlines of objects can be obtained with expedition, and sufficient correctness. Thus the *camera obscura* and *camera lucida*, cast upon paper a perspective image, which can be immediately traced. A method of drawing by squares is likewise easily practised. For this purpose, the paper, or surface which is to receive the picture, is divided by pencil lines into a certain number of squares. A small frame, of corresponding size, is divided into a like number of squares by threads, or by lines drawn upon glass. This frame is placed perpendicularly between the eye and the object, and kept at a stationary distance from the eye, which is also fixed. The outlines and parts of objects which appear in particular squares of the frame, are transferred to corresponding ones on the paper, and in this way the principal points of the perspective view may be obtained.

Perspectographs.—Various instruments have been invented under the name of *perspectographs*, to be used in obtaining the points and outlines of original objects. They commonly consist of a fixed part, perforated with a small hole in the point of view, and a moveable part situated in the perspective plane, and capable of traversing any part of it. This moveable part may consist of any minute substance, or, which is better, a moveable point may be obtained by the intersection of two threads. Any points in the perspective plane may thus be found, and transferred to the picture, by bringing the part of the instrument which contains them, into contact with the paper.

A simple and very useful perspectograph may be made by erecting a pane of glass upon one end of a board, or short table, and a moveable piece with an aperture for the eye at the other end.* The moveable piece is to be fixed at any convenient distance, and the object is to be viewed from it, through the pane of glass. The outlines, as they appear, are traced upon the glass with a stick of wax sharpened like a crayon, and they may be afterwards rendered very plain, and transferable, by sprinkling them with any black powder.

The geometrical and mechanical methods which have been described, will enable a person not previously conversant with the art, to obtain correct perspective representations of any object. But by long practice, in drawing from nature, a certain tact is acquired by painters, which enables them, by the accuracy of the eye and judgment alone, to make correct views of objects, without the aid of any computation or mechanical process. Thus miniature painters produce the nicest resemblance of the human countenance, in any position, with no other guide, than the faculty obtained by experience, of estimating the exact shape and proportion, which each part of the original should bear upon the picture.

Projections.—The projections of a body, are the different modes by which it may be delineated on a plane surface. That which has already been described, is called the *scenographic* projection, and represents objects as they actually appear to the eye, at limited distances. The *orthographic* pro-

* No method fixes the eye so effectually, as to rest the teeth upon a solid or fixed body.

jection represents objects as they would appear to the eye at an infinite distance, the rays which proceed from them being parallel, instead of converging. The shadow, which a body casts in the rays of the sun, may be considered as an orthographic projection. In this projection, lines which are parallel in the original, are parallel in the picture, and do not converge to any vanishing point. Their comparative length, also, is not affected by difference of apparent distance. The orthographic projection is much used in delineating buildings, machinery, &c., because those parts of the drawing which are not foreshortened, maintain their true relative size, so that measures can be taken from them. In Pl. III. Fig. 7, No. 1 is the scenographic, and No. 2, the orthographic projection of a cube. In addition to these, the term *ichnographic* projection is sometimes used to express the horizontal delineation, or ground plan of an object. A *bird's eye* view is a scenographic or orthographic projection, taken from an elevated point in the air, from which the eye is supposed to look down upon the objects.

Isometrical Perspective.—This name has been introduced by Professor Farrish, to express a kind of drawing peculiarly convenient in delineations of machinery, and bodies of regular figure. It is a species of orthographic projection, in which three planes, at right angles with each other, appear similar and equal. An idea of it may be formed, by supposing a cube to be so placed, that one of its angles will appear in the centre, while its outline will be a true hexagon. In this projection, the sides of the cube appear equal, and all sections of the cube parallel to either side, will also be equal. All right angles are represented by angles of 60 degrees, or the supplement of 60 degrees. All circles parallel to either of the three planes, will be represented by similar ellipses. Figures not parallel to either of the planes, may be calculated by easy rules. It is therefore the easiest and most expressive kind of drawing for the wheelwork, axles, and regular frames of machinery; for philosophical instruments, and for many architectural designs.*

* For the principles of isometrical drawing, see the Cambridge Philosophical Transactions; or Gregory's Mathematics for Practical Men, p. 179.

In Pl. III. fig. 9, is an isometrical view of a cube, with circles inscribed on its sides, and the axes of those circles projecting a short way.

CHIARO OSCURO.

Next to correct perspective, the most important circumstance in painting, is the correct distribution of light and shade. To the skilful management of these, we are indebted for the strength and liveliness of pictures, and what is technically called their *relief*, or the elevation which certain parts appear to assume above the plane upon which the picture is made.

Light and Shade.—Light and shade, as they appear to us upon natural objects, are the consequences of the rectilinear motion of the rays cast upon them by luminous bodies. If an object be exposed to the rays of the sun, or of a single lamp or candle, those parts or surfaces which are presented directly to these rays, become strongly illuminated, and acquire a lighter cast, approaching to white. Those surfaces, which stand obliquely to the light, receive less of the rays, and of course have a deeper tinge. Those lastly, which are averted from the light, and receive no rays but such as are reflected to them from other objects, acquire a very dark shade, approaching, when contrasted with the others, towards black.

The distribution of light and shade upon any object, is always proportionate and correspondent to its shape. An even or plane surface, exposed to the sun's rays, will be equally illuminated throughout, since whatever be its position, its parts will all make a similar angle with the rays. But uneven or irregular surfaces will be unequally illuminated, the prominent parts receiving most light, and the depressed portions most shade, an effect which will be increased, if the light falls obliquely or sideways. If the irregularities of surface be sharp and strong, the changes from light to shade will be sudden, and the contrast great. On the other hand, if they are smooth and rounded, the transition will be soft and gradual.

Association.—As bodies are never seen, except when they are illuminated, the manner in which light and shade are distributed upon them, forms by association a part of our ideas of their shape. Painters have learned to imitate this arrangement of light and shade, by varying the quantity and intensity of their coloring substances, so as to produce in the mind the same associations of shape from a plane surface, as would arise from the falling of light on the original object itself. This art constitutes what is technically called the *chiaro oscuro*, from the Italian words signifying *clear* and *obscure*. Next to perspective it is the most important part of painting, and there are many cases in which perspective alone would wholly fail to convey to us a correct idea of the form of objects, were it not assisted by appropriate insertion of lights and shades. Thus a circle, a sphere, and a cone, viewed vertically, may all have the same perspective outline; but their difference of figure becomes apparent, as soon as we consider their distribution of light and shade.

Direction of Light.—The most distinct perceptions of shape are produced when the light falls in one direction, *e. g.* when it is received immediately from the sun, or from a single window or candle. The distinctness of an object is always impaired, when it is situated between cross lights, or when it is illuminated by a variety of windows or candles on different sides of the room. An object may even be so surrounded with lights, that it shall be impossible to discover its exact shape. Its outline indeed will be discernible, but the equal illumination on all sides, will exclude the existence of shadow, and of course we shall lose the power of appreciating the comparative distance of its parts from the eye. In most paintings, we find that the principal mass of light falls in one direction. An oblique or a sideway direction, is most common, though a front, and even a back light, is managed to produce very striking effects. Painters also exercise their skill with the introduction of cross lights, from different windows, or lamps; but the successful execution of a piece of this sort is more difficult, than with a single light.

Reflected Light.—Owing to the reflection which takes place from all terrestrial bodies, we find that objects, in most situations, have not only a principal or direct light, but also a secondary or reflected one. Hence the darkest part of globular and cylindrical bodies, is not that which is most remote from the original light. This part receives from the reflection of objects beyond it, a faint illumination, so that the darkest part will be found between it and the part on which the light directly falls. See the sphere represented, Pl. III. Fig. 4.

Sharp lights, or such as are intense and sudden, indicate polished surfaces, and are employed to represent them. Where they are accompanied by very deep shades, they express great elevation above the common surface. Faint lights, on the contrary, imply a dull surface, obscure illumination, or small elevation.

Expression of Shape.—Light and shade are not adequate, in all cases, to give us certain indications of the forms of bodies. Surfaces which appear concave in one direction of the light, may appear convex, if the light is introduced from the opposite side. In contemplating an undulating object, like a curtain, or its picture upon paper hangings, we are often at a loss to distinguish the elevated, from the depressed portions; and by a little effort of the imagination, we can persuade ourselves that a particular part is at one time elevated, and at another, depressed. *Cameos* and *intaglios* may be mistaken for each other, and any of the figures [Pl. III. fig. 4.] may appear prominent or depressed, in the same part, by reversing the direction in which the light is supposed to strike upon them.

In cases of this sort, our final ideas of shape are derived, not only from the object itself, but from its relations with contiguous objects.

Eyes of a Portrait.—The influence which the association of contiguous objects has upon our ideas, is strikingly exemplified in the eyes of a portrait. We estimate the direction of the eyes, not only from the position of the ball in regard to the eyelids, but also from the relative position of the remaining features of the face. Dr Wollaston has shown, that the same eyes in a picture, which looks at us, may be made to appear averted from us, if we apply new features to the lower half of the face. [Pl. III. Fig. 3.] The reason, why the eyes of a portrait appear to follow us, in all parts of the room, is simply, that the relative position of the features cannot change, so that if the picture appears to look at us once, it must appear to look at us always. If we move to one side of a portrait, the change, which happens, is unlike that which would take place in a bust, or living face. The picture is merely foreshortened, so that we see a narrower image of a face, but it is still that of a face looking at us. And if the canvass be transparent, the same effect takes place from the back of the picture.

Shadows.—Shadows are cast in the direction opposite to that by which we suppose the light to enter, and their introduction in pictures, always heightens the effect. A painted object, is relieved, or raised from the surface, by the expression of light and shade on itself. But the relief is greatly increased, if the shadow which it makes on the ground, or other surface, be also introduced. Shadows are commonly softened off at the edges, or terminate gradually. When, however, the light is strong, or the shadow very near to the object, its termination is more abrupt.

Aerial Perspective.—This name is given by painters, to the mode of producing the effect of distance, by a diminution in the distinctness and brightness of objects, according to their remoteness from the eye, and the condition of the medium through which they are seen. It is well known, that distant objects appear indistinct, and of a greyish or blueish tinge, from the effect produced by the intervening atmosphere. Their indistinctness is increased, if the atmosphere is hazy. Their appearance is also modified by the degree of their illumination, and by the character of the light which falls on them. The painter, therefore, finds it necessary to consider the depth of atmosphere which is interposed between him and his object, the condition of this atmosphere, and the quantity and color of the light which falls on it, and on the objects. A want of attention to these circumstances, gives rise to the defect called *hardness* in painting.

COLORING.

By the aid of perspective, and the *chiaro oscuro* alone, very good representations of objects may be obtained. All our common engravings, wood cuts, drawings in Indian ink, in black crayons, &c., derive their expressiveness from these only. But a still nearer approach to the appearance of nature, is made, by the employment of *colors* analogous to those which are found to exist in the objects represented.

Colors.—From the science of optics, we learn that the solar beam is divisible into seven primary colors, white being the mixture, and black the privation of all of them. These colors, are violet, indigo, blue, green, yellow, orange, red.* Three of these are capable of producing all the rest, by their intermixture and degree, viz. blue, red, and yellow.

The color belonging to different natural objects, was supposed, by Newton, to be occasioned by a power which their surfaces possess, to reflect certain rays, while they absorb all the rest. This power is so infinitely diversified in nature, that we find not only every kind of primary ray reflected, but likewise every possible tint, and intermediate grade, which can be produced by the admixture of two or more original colors. To represent these various hues, it is necessary that the painter should possess coloring substances analogous to them all, or capable of producing them all by mixture, and that he should apply them in such a manner, that the true color may remain distinct, independently of the lights and shades necessary to place the objects in relief.

* Dr Wollaston found the spectrum formed in looking through a prism at a narrow line of light, to consist of four colors, red, green, blue, and violet, with a narrow stripe of yellow. The three simple colors, red, green, and violet, may produce yellow, by the admixture of red and green; crimson, by red and violet; blue, by green and violet, and white by the combination of all three.

Shades.—In a colored painting of an object which has any rotundity of form, there are usually, at least, three tints, or degrees of color. These are the *light*, the *middle tint*, and the *shade*. Of these, the middle tint is the one which represents the true color of the object, and occupies an intermediate situation between the light and shade. Thus in the painting of a red fruit, for instance the cherry, the middle tint is vermilion, or some similar color, being that which the surface of the fruit would have, if it were perfectly flat. The part of the fruit nearest the light, has a very bright color, partaking of white while the remote parts are shaded with lake or some darker red. In like manner, a yellow fruit, like the lemon, has not only the true color of the rind, but is lightened at the top with straw color or white, and shaded with brown toward the edges. It is necessary that the colors used for dark shading, should be in some degree correspondent with the middle tint, and not diametrically opposite to it. Thus, in single objects, yellow cannot be shaded with blue, nor red with green.

Tone.—Pictures differ from each other in the respective depth of color, which pervades the whole piece. The word *tone*, borrowed from the art of music, signifies, in painting, the peculiar cast, or governing hue, which a picture, or a color, possesses. Thus if dark masses of color, with feeble lights, predominate, the piece has a deep or low tone, while if the reverse exists, a bright or light tone is produced. It is essential to harmony that a picture should have the same tone throughout, or that its lights and shades should correspond in their intensity to the tone which governs the whole.

Harmony.—When different objects are grouped together in the same view, each one possesses two kinds of color, the *original* color, and the *adventitious*. The original color, often called among painters the *local* color, is that which belongs to the object itself, independent of situation. The adventitious color, is that which is reflected upon it from neighbouring objects, and which of course depends upon situation. For example, the color of the human face is that which we call flesh color, and, if painted alone, may be represented by the shades of that color. If, however, it is surrounded by a purple drapery, it receives a purplish tinge, and requires to be so represented. In like manner, a yellow dress communicates to it a yellowish cast, &c. An attention to this adventitious coloring, combined with a uniformity of tone, constitutes the basis of what is technically called *harmony* in painting. Harmony requires that strong and glaring colors should never be forcibly contrasted with each other, but that each object should partake at its edges of a certain portion of the color which predominates in objects near to it. This rule not only produces effects most grateful to the eye, but an observance of it gives, in fact, the only true representation of nature.

Contrast.—Colors are divided, by painters, into the *warm* and the *cold*. Warm colors are those in which red and yellow predominate. Cold colors are blue, grey, and others allied to them. Neutral colors are intermediate tints, or mixtures. Of the various pigments or coloring substances, which painters employ, none have the genuine brilliancy of the prismatic rays; and all fall short of the hues produced by nature in living objects. The petal of a flower, the feather of a bird, and the wing of an insect, are tinged with a richness and splendor, which no factitious colors can equal. Painters can only approach, when necessary, towards the brightness of natural colors, by availing themselves of the effect of contrast, and by heightening one color by the introduction of others, which prepare the eye for its more perfect and favorable reception.

Remarks.—The power of giving true representations of objects, is derived, originally, from an attentive study of the colors and appearance which they actually exhibit in nature; afterwards from a comparison of the success of different artists, and an attention to the means they have employed. What belongs to the philosophical part of painting, can hardly be said to extend beyond the correct imitation of nature. But the inventive part, the design and composition of great pieces, such as have not necessarily any originals in nature, requires not only

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philosophic accuracy, and practical skill, but also demands original genius, strength and fertility of imagination, and a strong perception of sublimity and beauty, whether natural or moral. To paint a portrait or landscape from nature, requires no more than a faculty of correct imitation. But to express on the canvass a scene of history or of fiction, to create forms of ideal beauty exceeding the realities of life, and to express, by attitudes and lineaments, passions, which tell the events they accompany,—this excellence is attained by few; it is not to be taught by any rules of art, but, like poetry, and eloquence, it is within the reach of those only, whom a strong and exclusive interest in the pursuit has qualified to feel deeply, and to express powerfully.

Note.—For the modes of painting in water, oil, fresco, &c., also for coloring substances, see Chapter XVIII.

MALTON'S Treatise on Perspective, fol. 1779;—PRIESTLEY'S Introduction to Perspective, 8vo. 1770;—WOOD'S Lectures on Perspective, with an Apparatus, 1809;—BLUNT'S Essay on Mechanical Drawing, 4to. 1811;—LUCAS' Progressive Drawing Book, Baltimore, 1827;—BURNET, on Light and Shade, 4to. 1827;—BURNET, on Coloring, 4to. 1827;—VALLEE, *Traité de la Science du Dessin*, 4to. Paris, 1821;—MILLIN, *Dictionnaire de Beaux Arts*, 3 tom. 8vo. 1806;—ELMES' Dictionary of Fine Arts, 8vo. 1826;—Works of Sir J. REYNOLDS,—OPIE,—FUSELI,—BARRY,—WEST,—DE PILES, &c. &c.

CHAPTER V.

ARTS OF ENGRAVING AND LITHOGRAPHY.

THE arts of engraving and lithography, bear the same relation to drawing, that the art of printing does to that of writing; the first being intended for the expression of original designs, the latter for the multiplication of copies of the design, when made.

ENGRAVING.

Origin.—The origin of copperplate engraving appears to have been in the fifteenth century, previously to which time it was probably unknown. The first inventors of engraving, were the *goldsmiths*, who, from the habit of marking ciphers and little devices on their wares, acquired a dexterity and despatch in the use of the graving tool, and at the same time, a power of producing subjects of such neatness and delicacy, that a desire was naturally excited in them, to preserve and increase the products of the art, by transferring them to paper. This object was effected by the use of a suitable pigment, and the aid of the rolling press.

Materials.—Common engraving differs from printing, in having its subjects or devices cut into, or below, the surface of a metallic plate, instead of being elevated or raised above it, as in types, and wood cuts. For the purpose of engraving, a variety of metals have been employed, and various combinations or alloys. *Copper* has, however, been selected by common consent, as uniting the greatest number of desirable qualities; having sufficient softness to permit it to be cut when cold, and sufficient hardness and tenacity, to resist the action of the press, and the wearing of continued friction. A plate of the best copper is selected, about one fourth of an inch thick, having one side finely polished, and its edges rounded, to prevent it from cutting the paper. The engraver works opposite to a window, having a screen interposed to soften the light, and the plate placed on an oblique table in the most convenient position for seeing.

Instruments.—The instruments employed in the practice of the art, are the following. 1. The *graver*. This is a small steel bar, of a prismatic form, having one end attached to an oblique handle, and the other ground off obliquely, so as to produce a sharp point at one angle. In working, this instrument is held in the palm of the hand, and pushed forward, so as to cut out a portion of the copper. 2. The *dry point*. This is a strong bluntish needle, fixed in a handle, and intended for drawing the finer lines. It is held in the fingers, in the same way as a pen or pencil. 3. The *scraper*, a triangular instrument, with concave sides, and sharp edges, intended for removing or scraping off portions, which are accidentally raised above the surface. 4. The *burnisher*. This is merely a blunt smooth tool, for rubbing out blemishes, and smoothing the surface of the copper. Various kinds of varnish, rosin, wax, charcoal, and mineral acids, are also employed in different parts of the operation, according to the subject and the style of engraving which is adopted.

Styles.—The principal varieties, or styles, of engraving on copper, are the following. 1. Line engraving. 2. Stippling. 3. Etching. 4. Mezzo tinto. 5. Aqua tinta. Lithography, and some other modes of multiplying designs, are imitations and substitutes, rather than species of engraving.*

Line Engraving.—Line engraving, called by the French, *Gravure en taille douce*, is one of the most common species of engraving; and though less elaborate than the second mode,

* Musical characters are sometimes executed in a mode different from all these, by making impressions wtih a punch upon pewter, or some other soft metal.

has produced most of the finest and boldest specimens of the art. In this species, the surfaces and figures, the lights and shades, are produced by the multiplication of minute lines, cut in by the graver and dry point, approaching each other so nearly, that the inequality produced by the admixture of black and white does not offend the eye, nor interrupt the harmony of the piece. The effect and beauty of line engravings, depends much upon the smoothness of the lines, their gradual swell and decrease, and their evenness or parallel situation.

For engraving in this manner, the artist transfers the outlines of his original drawing, by tracing them with black lead, on an oiled paper,* and afterwards passing this paper through the press in contact with the copperplate, which is previously covered with a thin coating of wax. A sufficient quantity of the lead adheres to the copper, to enable him to engrave the outlines with great accuracy. The graver is then held in the palm of the hand, and pushed forward with a strong but steady and regular motion until a line is completed. The graver, by its operation, removes a thread of copper from the line, and at the same time raises the surface on each side of it, forming what is called a *burr*. This burr is subsequently removed by the process of scraping and burnishing. After the outlines are finished, the dark surfaces are introduced by means of close parallel lines cut in, in the same manner as before. Gradations of light and shade are produced by the gradual and simultaneous tapering of all the lines which constitute the dark portions, and the softness and regularity with which this is accomplished, greatly affects the beauty of the piece. Very dark shades are produced by lines crossing each other, either in squares or lozenges, which are varied according to the na-

* Paper rendered transparent with spermaceti, is useful in tracing figures with a lead pencil. If paper be varnished with a mixture of Canada balsam, and oil of turpentine, very distinct lines may be traced on it with the dry point only, and these may be again transferred, by varnishing the copper, and tracing them upon it, through the paper. This method is now much employed by engravers.

ture of the subject. Very light shades, on the contrary, are left untouched, or covered with broken lines. Lines which swell or taper, are first cut of a uniform size, and afterwards deepened by a second or third stroke of the graver. Mistakes or blemishes, are erased from the plate, either by burnishing, with the proper instrument, or by rubbing with charcoal.

Stippling.—The second mode of engraving, is that called *stippling*, or engraving in dots. This resembles the last mentioned method in its processes, except that instead of lines, it is finished by minute points or excavations in the copper. These punctures, when made with the dry point, are circular, when made with the graver, they are rhomboidal or triangular. The variations and progressive magnitude of these dots, give the whole effect to stippled engraving. This style of work, is always more slow, laborious, and of course more expensive, than engraving in lines. It has, however, some advantages in the softness and delicacy of its lights and shades, and approaches nearer to the effect of painting, than the preceding method. A more expeditious way of multiplying the dots, has been contrived in the instrument called a *roulette*, a toothed wheel, fixed to a handle, which by being rolled forcibly along the copper produces a row of indentations. This method, however, is less manageable than the other, and generally produces a stiff effect.

Etching.—Etching is the third mode of engraving, and is performed by chemical corrosion. It is apparently the easiest mode of engraving, requiring least practice in the operator. In fact, any person who can draw, may etch coarse designs tolerably well, after having acquainted himself with the theory only. Hence we find that engineers, naturalists, surgeons, &c. sometimes etch their own plates, especially of light subjects.

A plate for etching, is prepared in the same manner as for common engraving. It is then covered throughout its whole surface, with a very thin coating of varnish made of wax, mastic, and asphaltum ; sometimes of rosin, and animal oil, or of linseed oil inspissated by boiling. This varnish is blackened by the smoke of a lamp, in order that the operator may see the progress and state of his work. The instrument used in etching, is a needle, resembling the dry point, but of different sizes, according to the nature of the work. The plate being prepared, the operator, supporting his hand on a ruler, begins to make his drawing with the needle in the coat of varnish, taking care to penetrate always to the copper. In the use of the needle, those lines which require to be deepest, must have the greatest force bestowed on them, but it is not possible to produce so perfect an effect in this way, as by incisions of the graver. After the design is completed, the operator proceeds to the second part of the process, the corrosion, or as it is technically called, *biting in*. For this purpose, the plate is surrounded with a wall of soft wax, to prevent the escape of fluid from its surface. A quantity of diluted nitric acid, is then poured upon it, and suffered to remain for some time. A chemical action immediately takes place in all the lines or points where the copper is denuded by the strokes of the needle, while the rest of the surface is defended by the varnish. In the mean time, the operator brushes the surface frequently, with a feather, to clear away the bubbles and saturated portions of the metal. After the first biting is continued for a sufficient length of time in the judgment of the operator, the acid is poured off, and the plate examined. The light shades, if found sufficiently deep, are then covered with varnish, to protect them from further action of the acid, or as it is technically called, *stopped out*. The biting is then continued for the second shades, which are next stopped out, and these processes are alternately repeated till the piece is finished. The plate is then freed from varnish, by melting and wiping it off, and cleansed by washing with oil of turpentine. It must, in this state, be carefully examined or proved, and any deficiencies in the lines owing to the accidental presence of varnish, must be finished with the graver. The plate is then ready for the press.

The productions of the etching needle, can never have the smoothness and beauty of *mechanical* engravings. Notwithstanding all the care which may be taken, the lines will have an irregularity and roughness, owing to the unequal action of the acid. There are, nevertheless, subjects, to which this very irregularity renders etched work peculiarly suited. Those objects which in nature are rough, and coarse, are well represented by this species of engraving. The trunks of trees, broken ground, rocks, walls, cottages, &c., especially when executed on a large scale, receive a more natural aspect from the rough effect of etching than they could do without great labor from the softer touches of the graver. In landscape engraving we commonly find a mixture of methods, the coarser parts being etched, while objects of more delicacy are cut with the graver. Letters and written characters, are mostly cut, and but seldom etched.

Mezzo Tinto.—Engraving in *mezzo tinto*, or *mezzotint*, is the fourth species. This method is the reverse of all those hitherto mentioned, and consists in bringing up lights from a dark ground. The mezzo tinto was invented by Prince Rupert, in 1649. Since his time, it has been greatly improved, and though not calculated for general use, it has been applied to various subjects with great success. For engraving in mezzo tinto, the whole surface of the copperplate is first roughened or covered with minute prominences and excavations, too small to be obvious to the naked eye; so that if an impression be taken from it in this state, it has an uniform velvety black appearance. This roughness is produced mechanically, by the operations of a small toothed instrument denominated a *cradle.* This instrument, by continual turns and impressions, which occupy a great length of time, gradually breaks up and produces an uniform roughness on the whole surface of the plate. That the ground, as it is called, may be of the requisite fineness, the operation must be repeated a considerable number of times, the position of the plate in regard to the instrument, being varied each time. This is the most tedious part of the labor. When the plate is prepared, the rest of the process, to a skilful engraver, is easy, when compared with cutting or stippling.

It consists in pressing down or rubbing out the roughness of the plate, by means of the burnisher and scraper, to the extent of the intended figure, obliterating the ground for lights, and leaving it for shades. Where a strong light is required, the whole ground is erased. For a medium light it is moderately burnished, or partially erased. For the deepest shades, the ground is left entire. Care is taken to preserve the insensible gradations of light and shade upon which the effect and harmony of the piece essentially depend.

Engraving in mezzo tinto, approaches more nearly to the effect of oil paintings than any other species. It is well calculated for the representation of obscure pieces, such as night scenes, &c. Some individuals have applied it with good success to the engraving of portraits. The principal objection to the method is, that the plates wear out speedily under the press, and of course yield a comparatively small number of impressions.

Aqua Tinta.—Engraving in *aqua tinta*, is the only remaining mode. This is done by a process partly chemical, and partly mechanical. It consists in producing chemically, a rough ground covering the surface of the figure to be engraved, and afterwards introducing the lights and shades by mechanical means. It may, however, be executed by a process wholly chemical. For engraving in aquatint, the surface of the copper, after having the outline engraved or etched in the usual way, is covered throughout with minute particles of resin, invisible to the naked eye, detached from each other and adhering to the surface of the metal. This process, called *laying the ground*, is effected in different ways. One method, is to inclose a quantity of finely powdered rosin or mastic, in a flannel or linen bag. This is held at a certain height above the plate, and beat with a stick. A fine cloud of dust issues from the bag, and settles upon the surface of the plate, with the same uniformity as the dust of the atmosphere settles upon furniture in dry weather. This dust is fixed to the surface, by heating the plate till the resin melts. The ground is thus laid. A second mode, is to cover the plate with a coat of very thin spirit varnish prepared for the purpose. This varnish is so fluid, or contains so little resin, that when it dries by the evaporation of the spirit, the whole surface breaks up, or cracks into an infinite number of particles, all adhering to the plate. After the ground is completed, the vacant parts of the plate, or those not intended to be occupied by the figure, are *stopped out; i. e.* covered by a thick varnish, impenetrable to acid. The plate is now surrounded by a wall of wax, as for etching, and diluted nitric acid is poured on. A chemical action immediately commences in all the interstices between the resinous particles; and the face of the plate, for the desired extent, is converted into a porous surface, made up of little prominences and excavations. The lighter shades are stopped out at an early stage of the process, and the corrosion continued for the dark ones. After the plate is judged to be sufficiently bitten in, it is cleaned and proved by an impression. If the ground is good, *i. e.* not too faint, too coarse, or too uneven, the work is then finished by burnishing the shadings to give them greater softness, and if necessary, by cutting deep lines or dots in the darkest parts.

Engraving in aqua tinta has the greatest resemblance to paintings in water colors, or in Indian ink. When well executed, the white points which diversify the surface, are nearly invisible to the naked eye, so that a uniform surface is presented. The art was first invented by a Frenchman, by the name of Leprince, who for some time kept his art a secret, and sold his impressions for original drawings. It is a mode of engraving well adapted to light subjects, sketches, landscapes, &c., and for subjects of which only a few copies or impressions are wanted. Owing to the fineness of the ground, the plates wear out rapidly, and seldom yield, when of the ordinary strength, more than 600 impressions.

Aqua tinta is the most precarious kind of engraving, and requires much experience and attention on the part of the artist, to succeed well. If the ground is laid too thick, or too thin, the result is imperfect. If the corrosion by the acid is not continued long enough, the ground is too faint; if continued too long, the acid acts laterally, and destroys the whole surface. It is often necessary to repeat the whole process, and to go through the operations of laying the ground, stopping out, and biting, a number of successive times, before a ground is obtained of sufficient strength and regularity to answer for the press.

Copperplate Printing.—Copperplate printing is performed by means of a rolling press, in which the plate and paper are strongly compressed together between a cylinder of wood and a sliding platform. The ink employed for copperplates, is made of a carbonaceous substance called Frankfort black, and linseed oil, inspissated by boiling. Oil must be used, instead of water, that the ink may not dry during the process; it is boiled till it becomes thick and viscid, that it may not spread upon the paper. Previously to the operation, the paper is wet, as for printing with types. The printer, having warmed his plate over a bed of coals, proceeds to cover its surface with ink by an instrument resembling a printer's roller. When the cavities of the engraving are thoroughly charged with ink, the smooth surface of the plate is wiped as clean from ink as possible. The latter part of the wiping is always performed by the palm of the hand, aided by a little dry powder, commonly whiting. The ink remains only in the crevices of the engraving, into which the hand does not penetrate in wiping the surface. The plate is next laid on the sliding plank, with its face upward, and the paper laid upon it. An elastic substance, commonly folds of woollen cloth, is placed above and below. A turn of the cylinder carries the plate under a very strong pressure, by which portions of the paper are forced down into all the cavities of the engraving. The ink, or a part of it, leaves the copper and adheres to the paper, giving an exact representation of the whole engraving.

Colored Engravings.—Colored engravings are variously executed. The most common are printed in black outline, and afterward painted separately in water colors. Sometimes a surface is produced by aqua tinta, or stippling, and different colors applied in printing to different parts, care being taken to wipe off the colors in opposite directions, that they may not interfere with each other. But the most perfect as well as elaborate productions, are those which are first printed in colors and afterwards painted by hand.

Steel Engraving.—The process of steel engraving, introduced by Mr Perkins, depends on the property, which steel has, of being softened, by losing a part of its carbon ; and afterwards of being hardened, by regaining it. If a steel plate, prepared for engraving, be inclosed in a box with iron filings, and exposed to a white heat for some hours, the surface loses a portion of carbon and becomes sufficiently softened to be cut with the graver. If then the plate, after being engraved, is re-exposed to heat in a box with animal charcoal, the surface becomes again carbonated, and an engraved steel plate is thus obtained.

The great advantage of steel plates consists in their hardness, by which they last for an indefinite time, and yield an almost unlimited number of impressions ; whereas a copperplate wears out after two or three thousand impressions, and even much sooner, if the engraving be fine. An engraving on a steel plate, may be transferred in relief to a softened steel cylinder, by pressure ; and this cylinder, after being hardened, may again transfer the design, by rolling it upon a fresh steel plate ; and thus the design may be multiplied at pleasure.

Steel engraving is of use, where a great number of impressions are called for ; as it saves the expense of engraving the plate anew, and furnishes copies more exactly resembling each other, than can be obtained by any other mode. Of course, it affords the greatest security against counterfeiting.

Etching on steel plates, is practised with various chemical agents, one of which consists of a mixture of six parts of acetic acid, with one of nitric acid. Another menstruum is made by dissolving an ounce of corrosive sublimate, and a quarter of an ounce of alum, in half a pint of water.

Wood Engraving.—Engravings in wood are differently executed from those already described, the subjects being cut in relief; so that they require to be printed in the same manner as common types, and not with the rolling press. The material used is boxwood, which unites the properties of hardness, fineness, and density. It is cut across the grain into pieces of the height of common types, in order that the engraving may be made upon the end of the grain, for the strength and durability. The surface being planed very smooth, the design is drawn upon it with a black lead pencil. The lines of this design are left untouched, but the whole of the intermediate spaces between the lines are cut away with a common graver, or chisel. Wood engravings have the advantage that the blocks may be inserted in a page with common types, and printed without separate expense. They are exceedingly durable, and may, if desired, be multiplied by the process of stereotyping.

LITHOGRAPHY.

Lithography is the art of taking impressions from drawings or writings made on *stone*, without engraving.

Principles.—This art is founded on the property which stone possesses, of imbibing fluids by capillary attraction, and on the chemical repulsion which oil and water have for each other. A drawing is first made on stone with an ink, or crayon, of an oily composition, and the surface is washed over with water, which sinks into all the parts of the stone, not defended by the drawing. A cylindrical roller, charged with printing ink, is then passed over the surface of the stone. The drawing receives the ink, which is oily, while the other parts of the stone repel it, being defended by the water. The process, therefore, depends entirely on chemical principles, and is thus distinct from letter-press or copperplate printing, which are mechanical. On this account, it has, in Germany, been called *chemical printing*.

Origin.—The invention of lithography is generally ascribed to Alois Senefelder, the son of a performer at the Theatre of Munich, who received his education at the University of Ingoldstadt. Having become an author, and being too poor to publish his works, he tried many plans with copperplates, and compositions, and accidentally with stone, as substitutes for letter-press, in order to be his own printer. His first essays to print for publication, were some pieces of music, executed in 1796, after which he attempted various drawings and writings. The first productions of the art were rude and of little promise. Its progress, however, has been so rapid, that it now gives employment to a vast number of artists, and works are produced which rival the finest engravings, and even surpass them in the expression of certain subjects.

Lithographic Stones.—As calcareous stones will all imbibe oil and water, and receive the action of acids, they are all capable of being used for lithography. Those, however, are best adapted to the purpose, which are compact, of a fine and equal grain, and free from veins, or imbedded fossils or crystals. A conchoidal fracture is considered a good characteristic.

The quarries of Solenhofen, near Pappenheim, in Bavaria, furnished the first plates, and none have as yet been found to equal them in quality. They are of a uniform, pale yellowish or bluish white color, and the fracture is perfectly conchoidal. Generally, the hardest are considered best, provided they are uniform in texture. Such are necessary for fine chalk drawings, while softer ones answer for ink, or for coarser drawings in chalk.

In France, stones have been found near Chateauroux, of a similar color to those of Solenhofen, and even harder, and of a finer grain, but they are full of spots of a softer nature, so that it is difficult to procure pieces of the necessary size. In England, a stone has been used for lithography, which is found at Corston, near Bath. It is one of the white *lias* beds, but not so fine in grain, nor so close in texture as the German stone, and therefore inferior. In the extensive limestone tracts of the United States, there is little doubt that future observation will bring to light stones of a suitable character for lithography.

To bear the pressure used in taking impressions, a stone twelve inches square, should be an inch or two thick; and the thickness must increase with the size of the stone.

Preparation.—The stones are first ground to a level surface, by rubbing two of them face to face with sand and water. To prepare them for *ink drawings*, they are next polished with pumice-stone. But when they are intended for *chalk drawings*, they are merely ground with fine sand, which has been passed through a sieve, and which produces a smooth and uniform surface, which is grained and not polished, this surface being best adapted for holding the chalk.

Lithographic Ink and Chalk.—For these materials, the union of several qualities is required, to obtain which, it is necessary to combine several substances together.

For lithographic *ink*, a great many different receipts have been given, one of the most approved of which is a composition made of equal parts of tallow, wax, shell lac, and common soap, with about one twentieth part of the whole, of lampblack. These materials are mixed in an iron vessel. The wax and tallow are first put in, and heated till they take fire, after which, the other ingredients are successively added. The burning is allowed to continue until the composition is reduced about one third.

Lithographic *chalk* should have the qualities of a good drawing crayon; it should be even in texture, and carry a good point. The following proportions are among the best. Soap, $1\frac{1}{2}$ oz.; tallow, 2 oz.; wax, $1\frac{1}{2}$ oz.; shell lac, 1 oz.; lampblack, $\frac{1}{4}$ oz. The manipulation is similar to that for the ink.

Mode of Drawing.—With these materials, the artist proceeds to work on the prepared stone, after wiping it with a dry cloth. The ink being rubbed with warm water, like Indian ink, is used on the *polished* stone, and a gradation of tints can be obtained, only by varying the thickness of the lines, and the distance at which they are placed apart. It is necessary to mix the ink to such a consistency, that, while it works freely, it shall yet be strong enough to stand perfect, through the process of printing. A consistency, a little greater than that of writing ink, is sufficient for this purpose. The instruments used for drawing with ink, are steel pens, and fine camel's hair pencils.

The *chalk* will not hold upon the *polished* stone. But the *grained* stone prepared for chalk, may be drawn upon with the chalk crayon, as easily as paper. The subject may be traced on the stone, with lead pencil or red chalk, but it should be done so lightly, as not to fill up any of the grain of the stone. In drawing, the degree of pressure of the hand will vary the strength of the tint, and it is desirable to give the requisite strength at once, as the surface of the stone is a little altered, by receiving the chalk, and hence it does not take any additional lines with the same equality. Practice is necessary to give a command of the material, as it does not work quite like the common crayon, there being great difficulty in keeping a good point. There is also difficulty in obtaining the finer tints perfect in the impression; and for the light tints, the chalk must be used in a reed, as the metal port-crayon is too heavy to draw them, even without any pressure from the hand. A scraper is used to correct errors, and also to produce lights.

It is necessary to observe that the grain with which the stone is prepared, should vary with the fineness of the drawing. Several pieces of chalk should be prepared to use in succession, as the warmth of the hand softens it. It is useful to cut the chalk to the form of a wedge, rather than a point, as it is less likely to bend in that form. Small portions of the point will break off during the drawing; these must be carefully removed with a small brush.

Etching the Stone.—After the drawing is finished on the stone, as before described, it is sent to the lithographic printer, who proceeds to *etch* the drawing, as it is called. The stone is placed obliquely on one edge over a trough, and very dilute nitric or sulphuric acid is poured over it. The degree of strength, which is little more than one *per cent.* of acid, should be such as to produce a very slight effervescence. The object of this slight etching appears to be to produce a chemical, rather than a mechanical change of surface, and it is by some considered superfluous, except to discharge the alkali of the soap.

The stone is now carefully washed, by pouring clean rain water over it, and afterwards gum water; and when not too wet, the roller, charged with printing ink, is rolled over it in both directions, till the drawing takes the ink. It is then well covered with a solution of gum-arabic in water, of about the consistency of oil. This is allowed to dry, and preserves the drawing from any alteration, as the lines cannot spread, in consequence of the pores of the stone being filled with gum.

Printing.—When the stone is ready for the press, the printing ink is applied to it, by means of an elastic roller, covered with leather. In the lithographic press, the paper is first brought in contact with the stone, and protected by a tight cover of strong leather. The whole is then passed under the edge of a blunt wooden scraper, which is powerfully pressed down by a double lever, and thus every part of the paper is successively brought into forcible contact with the stone, and an accurate impression received of the drawing. The ink is then reapplied to the stone, and the process repeated for each impression.

Printing Ink.—This is composed, as other printing inks are, of oil-varnish, and fine lampblack. To prepare the varnish, a vessel is about half filled with pure linseed oil, and heated till it takes fire from the flame of a piece of burning paper. It should then be allowed to burn, till it is reduced to the degree of density required.

Remarks.—The great distinction of lithography from engraving is, that it gives a fac-simile of the original drawing, which retains the freedom and touch of the artist's own hand, while, on the contrary, an engraving must be a copy. This character in a lithographic print, arises from the facility with which the drawing is produced, as the process is exactly that which the artist would follow, in making a common drawing. A further advantage, derived from the same cause, is, that the drawing being made at once on the stone, the whole expense of engraving is saved.

The more finished drawings in ink, however, have not the same advantages; for the gradations can only be obtained by the variations in the breadth and the distance of the lines, which is the same principle as that on which the engraver works; and hence the labor is more nearly equal in the two methods.

The number of impressions, which can be taken from a lithographic chalk drawing, will vary according to the fineness of the tints. A fine drawing, will give 400, or 500; a strong one, 1000, or 1500. Ink drawings, and writings, give considerably more than copperplates. The finest will yield 6000, or 8000; and strong lines, and writings, many more. Upwards of 80,000 impressions have been taken at Munich, from one writing, of a form for regimental returns.

A method has been introduced, by which copies of valuable engravings may be multiplied indefinitely. An impression on paper, is taken, in the usual manner, from the copperplate, and immediately laid with its surface upon water. When sufficiently wet, it is carefully applied to the surface of a stone, prepared in the usual manner, and pressed down upon it by the application of a roller, till the ink leaves the paper, and adheres to the stone. It is then printed in the common way. Autographic writings may be transferred from paper to stone, and printed in a manner nearly similar.

Landseer's Lectures on Engraving, 8vo. London, 1807;—Meadows' Lectures on Engraving, London, 1811;—Partington's Mechanic's Gallery, 8vo. 1825;—Rees' Cyclopædia, under the various heads;—Hulmandel's Treatise on Lithography, 8vo, 1817;—Senefelder's Complete Course of Lithography, 4to.;—London Journal of Arts, *passim*;—De Lasteyrie, *Journal de Connaisances usuelles*, translated, Franklin Journal, vol. iv.

CHAPTER VI.

OF SCULPTURE, MODELLING, AND CASTING.

Subjects.—Sculpture in its most general sense, is the art of producing resemblances of visible forms, out of solid materials. The required shapes are produced by *carving*, when the material is solid and brittle; and to this sense the term sculpture is sometimes limited. They are also formed by *modelling*, when the material is soft; and by *casting*, when it is liquid or fusible. The productions of this art are known under various denominations, according to their character and subject. Of these, the most important are *statues*, which are entire resemblances of living objects. *Busts* consist of the upper portions of statues. *Bas-reliefs*, in the common acceptation of the term, are partial sculptures, or lateral views of figures, raised upon a plane surface. Their different degrees of prominence are distinguished by the Italians, under different names. These are, *alto relievo*, or high relief, when the figures are nearly complete, or appear to issue from the back ground; *mezzo relievo*, or middle relief, in which they are half raised from the surface; and *basso relievo*, low relief, or bas-relief properly so called, when the figures have not the prominence which their outline requires, but appear as if compressed. The principal remaining objects of sculpture, are *vases*, *armatures*, or trophies, and the decorative parts of architecture.

Modelling.—Before any object is executed in stone, it is the practice of sculptors to complete a representation of their design, by modelling it in clay, or some other soft material. The genius of the artist is displayed altogether in the model; for the process of afterwards copying the model in stone, is chiefly mechanical, and may often be executed by another person, as well as by the sculptor himself. When a clay model is undertaken, if the proposed figure be large, a frame of wood or iron is erected to give support to the limbs and different parts of the figure. Upon this frame, a proper quantity of wet clay is distributed, and wrought into the form of the intended statue. The moulding of the clay is performed with the hands, and with various instruments of wood and ivory. When the model is completed, copies may be taken from it, either by casting them in plaster, or in metal; or by chiseling them in marble.

Casting in Plaster.—Copies are most frequently taken, both from new models, and from old statues, by casting them in plaster. For this purpose, a mould in plaster is first made from the surface of the statue, or figure, itself; and this mould is afterwards used to reproduce the figure by casting. Plaster is prepared for use by pulverizing common gypsum, and exposing it to the heat of a fire until its moisture is wholly expelled.* While in this dry state, if it be mixed with water to the consistence of cream or paste, it has the property of hardening in a few minutes, and takes a very sharp impression. The hardness afterwards increases by keeping, till it approaches the character of stone.

Moulds are formed in the following manner. The statue or figure to be copied, is first oiled, to prevent it from cohering with the gypsum. A quantity of liquid plaster sufficient for the mould, is then poured on, immediately after being mixed, and is suffered to harden. If the subject be a bas-relief, or any figure which can be withdrawn without injury, the mould may be considered as finished, requiring only to be surrounded with an edging. But if it be a statue, it cannot be withdrawn, without breaking the mould; and on this account it becomes necessary to divide the mould into such a number of pieces, as will separate perfectly from the original. These are taken off from the statue, and when afterwards replaced, or put together,

* The heat requisite for this purpose must be greater than that of boiling water. Care must be taken not to raise the heat too high, as in that case the sulphate of lime would be decomposed.

without the statue, they constitute a perfect mould. This mould, its parts having been oiled to prevent adhesion, is made to receive a quantity of plaster, by pouring it in at a small orifice. The mould is then turned in every direction, in order that the plaster may fill every part of the surface; and when a sufficient quantity is poured in to produce the strength required in the cast, the remainder is often left hollow, for the sake of lightness, and economy of the material. When the cast is dry, it is extricated by separating the pieces of the mould, and finished by removing the seams and blemishes with the proper tools.* If the form or position require it, the limbs are cast separately, and afterwards cemented on.

Moulds and busts are obtained in a similar manner from living faces, by covering them with new plaster, and removing it in pieces as soon as it becomes hard. It is necessary that the skin of the face should be oiled, and, during the operation, the eyes are closed, and the person breathes through tubes inserted in the nostrils.

Elastic moulds have been formed by pouring upon the figure to be copied, a strong solution of glue. This hardens upon cooling, and takes a fine impression. It is then cut into suitable pieces and removed. The advantage of the elastic mould is that it separates more easily from irregular surfaces, or those with uneven projections and under cuttings, from which a common mould could not be removed without violence.†

* Plaster casts are varnished by a mixture of soap and white wax in boiling water. A quarter of an ounce of soap is dissolved in a pint of water, and an equal quantity of wax afterwards incorporated. The cast is dipped in this liquid, and after drying a week, is polished by rubbing with soft linen. The surface produced in this manner approaches to the polish of marble.

When plaster casts are to be exposed to the weather, their durability is greatly increased by saturating them with linseed oil, with which wax or rosin may be combined. When intended to resemble bronze, a soap is used, made of linseed oil and soda, colored by the sulphates of copper and iron. Walls and ceilings are rendered water proof in the same way. See an abstract of a memoir of D'Arcet and Thenard, in Brande's Journal, vol. xxii. 184, and Franklin Journal, ii. 276.

† See a paper by Mr Fox, republished in the Franklin Journal, vol. iii.

Architectural models and other complex pieces of workmanship, are made by casting the constituent parts separately, and afterwards cementing them together. If the form of the parts is complicated, a mould is required which can be taken to pieces to extract the cast. The cementing of the parts is performed by a thin mixture of plaster and water, recently made, and it is necessary that the surfaces to be joined should be thoroughly wet, before the cement is applied to them.

For small and delicate impressions, which are merely in relief, melted sulphur is sometimes used, also a strong solution of isinglass in proof spirit. The latter material has the advantage that it is not brittle when dry, but possesses a consistence like that of horn. Both substances yield very accurate and sharp impressions.

Bronze Casting.—Statues intended to occupy situations in which they may be exposed to violence, are commonly made of bronze. This material resists both mechanical injuries, and decay from the influence of the atmosphere. The moulds in which bronze statues are cast, are made on the pattern, out of plaster and brick dust; the latter material being added to resist the heat of the melted metal. The parts of this mould are covered on their inside with a coating of clay, as thick as the bronze is intended to be. The mould is then closed, and filled on its inside with a nucleus or core of plaster and brick dust, mixed with water. When this is done, the mould is opened, and the clay carefully removed. The mould with its core, are then thoroughly dried, and the core secured in its central position by short bars of bronze which pass into it through the external part of the mould. The whole is then bound with iron hoops, and when placed in a proper situation for casting, the melted bronze is poured in through an aperture left for the purpose. Of course, the bronze fills the same cavity which was previously occupied by the clay, and forms a metallic covering to the core. This is afterwards made smooth by mechanical means.

Practice of Sculpture.—To execute a statue in marble, which shall exactly correspond to a pattern or model, is a work of mechanical, rather than of inventive skill. It is performed by finding, in the block of marble, the exact situation of numerous points corresponding to the chief elevations and cavities in the figure to be imitated, and joining these by the proper curves and surfaces, at the judgment of the eye. These points are found, by measuring the height, depth, and lateral deviation of the corresponding points in the model; after which, those in the block are found by similar measurements. Sometimes the points are ascertained, by placing the model horizontally under a frame, and suspending a plumb-line successively from different parts of the frame, till it reaches the parts of the figure beneath it. Sometimes an instrument is used consisting of a moveable point, attached by various joints to an upright post, so that it may be carried to any part of the statue, and indicate the relative position of that part in regard to the post. Machines have also been contrived for cutting any required figure from a block, the cutting instrument being directed by a guage which rests upon the model in another part of the machine.

Marble is wrought to the rough outline of the statue, by the chisel and hammer, aided by the occasional use of drills and other perforating tools. It is then smoothed with rasps and files, and when required, is polished with pumice stone and putty. The hair of statues is always finished with the chisel; and for this object, very sharp instruments with different points and edges are necessary. The ancient sculptors appear to have relied almost wholly upon the chisel, and to have used that instrument with great boldness and freedom, such as could have been justified only by consummate skill in the art. The moderns, on the contrary, approach the surface of the statue with great caution, and employ safer means for giving the last finish. Some of the most celebrated antique statues, such as the Laocoon, the Apollo Belvidere, and Venus de Medicis, are thought to have been finished with the chisel alone.

Materials.—Although marble has been the common material of sculpture, both in ancient and modern times, yet other substances have been occasionally made subjects of the chisel. Statues of porphyry, granite, serpentine, and alabaster, are found among the remains of antiquity. Other materials of a less durable kind, were also employed. Some of the principal works of Phidias were made of ivory and gold, particularly his colossal statues of Jupiter Olympius, and Minerva, at Athens.

Objects of Sculpture.—In sculpture, as in the other imitative arts, two ends propose themselves to the skill of the artist. One consists in the imitation of a particular object, in which case the art of the sculptor can be expected only to equal, but not to surpass, his original. The other consists in new combinations of excellence, and in the invention of forms and expressions, which are not known to exist together in nature, but are embodied in the imagination of the artist. Beauty in objects thus conceived, constitutes the *beau idéal* in art, to attain which, has ever been the ambition of cultivators of the fine arts. In statuary, the specimens which have descended to us from the ancient Greeks, are by universal consent admitted to be the most perfect designs of beauty, and furnish the common models for study and imitation, at the present, as in all former ages.

Gem Engraving.—The art of cutting precious stones, is more properly a species of sculpture, than of engraving. The hardness of these stones renders it impossible to operate on them by the strongest steel instruments. They are therefore wrought in a slow manner, by grinding them away upon the surface of a wheel, commonly made of metal, and covered with the grit, or fine powder of some hard substance. The diamond can only be ground, or cut, with its own dust. Rubies, agates, emeralds, &c., are cut and polished with emery or tripoli, in fine powder. Lapidaries make use of small wheels, balls, and drills, of various forms, made of iron, or copper, which revolve with great rapidity, and act upon the stone through the medium of the pulverized material on their surface. They also use wires covered with emery, for the purpose of sawing plates.

The imitative designs, which are cut upon hard stones, are chiefly of two kinds. The first of these are *cameos*, which are little bas-reliefs or figures, raised above the surface. They are commonly made from stones, the strata of which are of different colors, so that the raised figure is of a different color from the ground to which it is attached. Varieties of agate, carnelian, onyx, &c., are made use of for this purpose. Sometimes several successive strata of different colors, are so wrought as to produce the appearance of painting. A cheaper kind of cameos are made from marine shells. These having lime for their basis, may be scratched with steel, or corroded with acids. *Intaglios* are the second kind of engraved gems. They differ from cameos in having the figure cut into, or below, the surface, so that they serve as seals to produce impressions in relief upon soft substances.

Mosaic.—Mosaics are imitations of paintings made by combining together an infinite number of minute stones of different colors, and cementing them on a plane surface. In the most costly mosaics, precious stones have been cut, and arranged to produce this effect. But in common works of this art, enamels of different colors, manufactured for the purpose, are the material employed. The enamel is first formed into sticks, from the ends of which, pieces of the requisite size are cut or broken off. These are confined in their proper places upon a plate of metal or stone, by a cement made of quicklime, pulverized lime-stone, and linseed oil. After the whole has adhered, it is allowed to dry two months, and is then polished with a flat stone and emery.* *Inlaid works* of agate, and other costly stones, are executed on the same principle as mosaic; except that the stones are larger, and cut to the shape of different parts of the object to be represented; whereas in mosaic, the pieces are of the same size and shape. The *opus reticulatum* of the an-

* One of the largest mosaics which has been executed, is a copy of Leonardo da Vinci's celebrated picture of the last supper. It measures 24 feet by 12, and employed eight or ten artists for eight years. It was executed under the direction of Raffaelli, at Milan, by order of the French government. *Cadell.*

cients, with which columns and walls were sometimes incrusted, is found to consist of small stones, of a pyramidal form, the apex of which is imbedded in mortar, while the base, which is polished, forms the outer surface.

Scagliola.—This name is given at Rome, to a sort of artificial inlaid work, composed of plaster, but resembling stone. For works of this kind, gypsum, dried and powdered, is mixed with a solution of glue, and spread on a tablet for the ground of the picture. Cavities of the form intended in the design, are then made in it with an engraving tool. These are successively filled up with portions of plaster of different colors, so managed as to produce the effect of painting. In this way buildings, and various natural objects are represented. The surace is finely polished, by rubbing it with different powders, and, where the ground is white, with rushes.

WINCKELMANN, *Histoire de l'Art chez les Anciens*, 3 vols. 4to. tr. 1802; —MILLIN, *Dictionnaire des Beaux Arts*, 3 vols. 8vo. 1806;—FLAXMAN'S Lectures on Scuplture, large 8vo. 1829;—REES' Cyclopædia;—Works of VASARI;—QUATREMERE DE QUINCY—CICOGNARA—VISCONTI, &c.; —Travels, and Works of CLARKE—EUSTACE—CADELL—DODWELL—STUART—ELGIN, &c. &c.

CHAPTER VII.

OF ARCHITECTURE AND BUILDING.

Architecture.—Architecture, in its most general sense, is the art of erecting buildings, of any kind. In modern use, this name is sometimes restricted to the external forms, or styles, of building, in which sense, architecture is one of the fine arts. It appears to have been among the earliest inventions, and its works have been commonly regulated by some principle of hereditary imitation. Whatever rude structure the climate and materials of any country have obliged its early inhabitants to adopt for their temporary shelter, the same structure, with all its prominent features, has been afterwards kept up by their refined and opulent posterity. Thus, the Egyptian style of building has its origin in the *cavern* and *mound*;* the Chinese architecture is modelled from the *tent*; the Grecian, is derived from the wooden *cabin*, and the Gothic, from the *bower* of trees.

Elements.—The essential elementary parts of a building, are those which contribute to its support, inclosure, and covering. Of these, the most important are the foundation, the column, the wall, the lintel, the arch, the vault, the dome, and the roof.

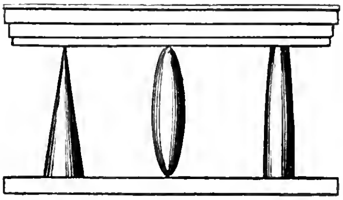
Foundations.—In laying the foundation of any building, it is necessary to dig to a certain depth in the earth, to secure a solid basis, below the reach of frost and common accidents. The most solid basis is rock, or gravel which has not been moved. Next to these, are clay and sand, provided no other excavations have been made in the immediate neighbourhood.

* Wilkins' Vitruvius, p. xvii.

From this basis, a stone wall is carried up to the surface of the ground, and constitutes the foundation. Where it is intended that the superstructure shall press unequally, as at its piers, chimnies, or columns, it is sometimes of use to occupy the space between the points of pressure, by an inverted arch. This distributes the pressure equally, and prevents the foundation from springing between the different points. In loose or muddy situations, it is always unsafe to build, unless we can reach the solid bottom below. In salt marshes and flats, this is done by depositing timbers, or driving wooden piles, into the earth, and raising walls upon them. The preservative quality of the salt, will keep these timbers unimpaired for a great length of time, and makes the foundation equally secure with one of brick or stone.

Column.—The simplest member in any building, though by no means an essential one to all, is the *column*, or *pillar.* This is a perpendicular part, commonly of equal breadth and thickness, not intended for the purpose of inclosure, but simply for the support of some part of the superstructure. The principal force which a column has to resist, is that of perpendicular pressure. In its shape, the shaft of a column should not be exactly cylindrical; but since the lower part must support the weight of the superior part, in addition to the weight which presses equally on the whole column, the thickness should gradually decrease from bottom to top. The outline of columns, should be a little curved, so as to represent a portion of a very long spheroid, or paraboloid, rather than of a cone. This figure is the joint result of two calculations, independent of beauty of appearance. One of these is, that the form best adapted for stability of base, is that of a cone. The other is, that the figure which would be of equal strength throughout for supporting a superincumbent weight, would be generated by the revolution of two parabolas round the axis of the column. the vertices of the curves being at its extremities.*

* See Tredgold's Principles of Carpentry, p. 50.



1 2 3

In the accompanying wood cut, No. 1 is the figure having the greatest stability of base; 2, the figure which is of equal strength throughout for resisting vertical pressure; and 3, the intermediate, or common form of the column, a little more curved than is usual in practice, and having its top truncated, to give stability to the entablature.

The swell of the shafts of columns, was called the *entasis*, by the ancients. It has been lately found,* that the columns of the Parthenon, at Athens, which have been commonly supposed straight, deviate about an inch from a straight line, and that their greatest swell is at about one third of their height.

Columns in the antique orders are usually made to diminish one sixth, or one seventh, of their diameter, and sometimes even one fourth. The Gothic pillar is commonly of equal thickness throughout.

Wall.—The *wall*, another elementary part of a building, may be considered as the lateral continuation of a column, answering the purpose both of inclosure and support. A wall must diminish as it rises, for the same reasons, and in the same proportion, as the column. It must diminish still more rapidly if it extends through several stories, supporting weights at different heights. A wall, to possess the greatest strength, must also consist of pieces, the upper and lower surfaces of which are horizontal and regular, not rounded nor oblique. The walls of most of the ancient structures, which have stood to the present time, are constructed in this manner, and fre-

* By Messrs Allason and Cockerel. See Brande's Journal, vol. x. p. 204.

quently have their stones bound together with bolts and cramps of iron. The same method is adopted in such modern structures as are intended to possess great strength and durability; and in some cases the stones are even dovetailed together, as in the light houses at Eddystone, and Bell Rock. But many of our modern stone walls, for the sake of cheapness, have only one face of the stones squared, the inner half of the wall being completed with brick; so that they can in reality be considered only as brick walls faced with stone. Such walls are said to be liable to become convex outwardly, from the difference in the shrinking of the cement.

Rubble walls are made of rough, irregular stones laid in mortar. The stones should be broken, if possible, so as to produce horizontal surfaces. The *coffer* walls of the ancient Romans were made by inclosing successive portions of the intended wall in a box, and filling it with stones, sand, and mortar, promiscuously. This kind of structure must have been extremely insecure. The Pantheon, and various other Roman buildings, are surrounded with a double brick wall, having its vacancy filled up with loose bricks and cement. The whole has gradually consolidated into a mass of great firmness. The *reticulated* walls of the Romans, having bricks with oblique surfaces, would at the present day be thought highly unphilosophical. Indeed they could not long have stood, had it not been for the great strength of their cement.

Modern brick walls are laid with great precision, and depend for firmness more upon their position than upon the strength of their cement. The bricks being laid in horizontal courses, and continually overlaying each other, or *breaking joints*, the whole mass is strongly interwoven, and bound together. Wooden walls, composed of timbers covered with boards, are a common, but more perishable kind. They require to be constantly covered with a coating of a foreign substance, as paint or plaster, to preserve them from spontaneous decomposition.

In some parts of France, and elsewhere, a kind of wall is made of earth, rendered compact by ramming it in moulds or cases. This method is called building in *Pisé*, and is much more durable than the nature of the material would lead us to suppose.

Walls of all kinds are greatly strengthened by angles and curves, also by projections, such as pilasters, chimnies, and buttresses. These projections serve to increase the breadth of the foundation, and are always to be made use of in large buildings, and in walls of considerable length.

Lintel.—The lintel, or beam, extends in a right line over a vacant space, from one column or wall to another. The strength of the lintel will be greater in proportion as its transverse vertical diameter exceeds the horizontal, the strength being always as the square of the depth. [See page 47.] The *floor* is the lateral continuation or connexion of beams by means of a covering of boards.

Arch.—The arch is a transverse member of a building answering the same purpose as the lintel, but vastly exceeding it in strength. The arch, unlike the lintel, may consist of any number of constituent pieces, without impairing its strength. It is, however, necessary that all the pieces should possess a uniform shape, the shape of a portion of a wedge; and that the joints, formed by the contact of their surfaces, should point towards a common centre. In this case, no one portion of the arch can be displaced or forced inward; and the arch cannot be broken by any force which is not sufficient to crush the materials of which it is made. In arches made of common bricks, the sides of which are parallel, any *one* of the bricks might be forced inward, were it not for the adhesion of the cement. Any *two* of the bricks, however, constitute a wedge, by the disposition of their mortar, and cannot collectively be forced inward. An arch of the proper form, when complete, is rendered stronger, instead of weaker, by the pressure of a considerable weight, provided this pressure be uniform. [Pl. I. Fig. *k*.] While building, however, it requires to be supported by a centring of the shape of its internal surface, until it is complete.

The upper stone of an arch is called the *key-stone*, but is not more essential than any other.

In regard to the shape of the arch, its most simple form is that of the semi-circle. [Pl. 1. Fig. *k*.] It is, however, very frequently a smaller arc of a circle, and still more frequently a portion of an ellipse. The simplest theory of an arch supporting itself only, is that of Dr Hooke. The arch, when it has only its own weight to bear, may be considered as the inversion of a chain, suspended at each end. The chain hangs in such a form, that the weight of each link or portion is held in equilibrum by the result of two forces acting at its extremities; and these forces, or tensions, are produced, the one by the weight of the portion of the chain below the link, the other by the same weight increased by that of the link itself, both of them acting originally in a vertical direction. Now, supposing the chain inverted, so as to constitute an arch of the same form and weight, the relative situations of the forces will be the same, only they will act in contrary directions, so that they are compounded in a similar manner, and balance each other on the same conditions. The arch thus formed, is denominated a *catenary* arch. [Pl. I. Fig. *l*.] In common cases it differs but little from a circular arch of the extent of about one third of a whole circle, and rising from the abutments with an obliquity of about 30 degrees from a perpendicular.

But though the catenary arch is the best form for supporting its own weight, and also all additional weight which presses in a vertical direction, it is not the best form to resist lateral pressure, or pressure like that of fluids, acting equally in all directions. Thus the arches of bridges and similar structures, when covered with loose stones and earth, are pressed sideways, as well as vertically, in the same manner as if they supported a weight of fluid. In this case, it is necessary that the arch should arise more perpendicularly from the abutment, and that its general figure should be that of the longitudinal segment of an ellipse. [Pl. 1. Fig. *m*.] In small arches in common buildings, where the disturbing force is not great, it is of little consequence what is the shape of the curve. The outlines may even be perfectly straight, as in the tier of bricks which we frequently see over a window. This is, strictly speaking, a real arch, provided the surfaces of the bricks tend towards a common centre. [Pl. 1. Fig. *s*.] It is the weakest kind of arch, and a part of it is necessarily superfluous, since no greater portion can act in supporting a weight above it, than can be included between two curved or arched lines.

Besides the arches already mentioned, various others are in use. The *acute* or *lancet* arch, [Pl. I. Fig. *o*] much used in Gothic architecture, is described usually from two centres outside the arch. It is a strong arch for supporting vertical pressure. The *rampant* arch [Fig. *n*] is one, in which the two ends spring from unequal heights. The *horse shoe* or *Moorish* arch [Fig. *p* and *q*] is described from one or more centres placed above the base line. In this arch, the lower parts are in danger of being forced inward. The *ogee* arch [Fig. *r*] is concavo-convex, and therefore fit only for ornament.

In describing arches, the upper surface is called the *extrados*, and the inner, the *intrados*. The *springing* lines are those where the intrados meets the abutments, or supporting walls. The *span* is the distance from one springing line to the other. The wedge-shaped stones which form an arch, are sometimes called *voussoirs*, the uppermost being the keystone. [Pl. I. Fig. *k*.] The part of a pier from which an arch springs, is called the *impost*, and the curve formed by the upper side of the voussoirs, the *archivolt*.

Abutments.—It is necessary that the walls, abutments, and piers, on which arches are supported, should be so firm as to resist the lateral *thrust*, as well as vertical pressure, of the arch. It will at once be seen that the lateral or sideway pressure of an arch is very considerable, when we recollect that every stone, or portion of the arch, is a wedge, a part of whose force acts to separate the abutments. For want of attention to this circumstance, important mistakes have been committed, the strength of buildings materially impaired, and their ruin accelerated. In some cases, the want of lateral firmness in the walls, is compensated by a bar of iron stretched across the span of the arch and connecting the abutments, like the tie beam of a roof. This is the case in the cathedral of Milan, and some other Gothic buildings.*

Arcade.—In an arcade, or continuation of arches, it is only necessary that the outer supports of the terminal arches should be strong enough to resist horizontal pressure. In the intermediate arches, the lateral force of each arch is counteracted by the opposing lateral force of the one contiguous to it. In bridges, however, where individual arches are liable to be destroyed by accident, it is desirable, that each of the piers should possess sufficient horizontal strength, to resist the lateral pressure of the adjoining arches.

Vault.—The vault is the lateral continuation of an arch, serving to cover an area, or passage, and bearing the same relation to the arch, that the wall does to the column. A simple vault is constructed on the principles of the arch, and distributes its pressure equally along the walls, or abutments. A complex or *groined* vault is made by two vaults intersecting each other; in which case, the pressure is thown upon springing points, and is greatly increased at those points. The groined vault is common in Gothic architecture. [Pl. VI. Fig. 6.]

Dome.—The dome, sometimes called *cupola*, is a concave covering to a building, or part of it, and may be either a segment of a sphere, of a spheroid, or of any similar figure. When built of stone, it is a very strong kind of structure, even more so than the arch, since the tendency of each part to fall, is counteracted, not only by those above and below it, but also by those on each side. It is only necessary that the constituent pieces should have a common form, and that this form should be somewhat like the frustrum of a pyramid, so that

* Cadell's Journey through Carniola and Italy, vol. ii. p. 77.

when placed in its situation, its four angles may point toward the centre, or axis, of the dome. During the erection of a dome, it is not necessary that it should be supported by a centring, until complete, as is done in the arch. Each circle of stones, when laid, is capable of supporting itself, without aid from those above it. It follows, that the dome may be left open at top, without a key-stone, and yet be perfectly secure, in this respect, being the reverse of the arch. The dome of the Pantheon, at Rome, has been always open at top, and yet has stood unimpaired for nearly 2000 years. The upper circle of stones, though apparently the weakest, is nevertheless often made to support the additional weight of a lantern or tower above it. In several of the largest cathedrals, there are two domes, one within the other, which contribute their joint support to the lantern which rests upon the top. In these buildings, the dome rests upon a circular wall, which is supported in its turn by arches upon massive pillars or piers. This construction is called building upon *pendentives*, and gives open space and room for passage, beneath the dome.

The remarks which have been made in regard to the abutments of the arch, apply equally to the walls immediately supporting a dome. They must be of sufficient thickness and solidity to resist the lateral pressure of the dome, which is very great. The walls of the Roman Pantheon are of great depth and solidity. In order that a dome in itself should be perfectly secure, its lower parts must not be too nearly vertical, since in this case, they partake of the nature of perpendicular walls, and are acted upon by the spreading force of the parts above them. The dome of St Paul's church, in London, and some others of similar construction, are bound with chains or hoops of iron, to prevent them from spreading at bottom. Domes which are made of wood, depend in part for their strength, on their internal carpentry. The Halle du Bled, in Paris, had, originally, a wooden dome more than 200 feet in diameter, and only one foot in thickness. This has since been replaced by a dome of iron.

Plate I.—In the first plate is given a comparative view in outline of some of the most remarkable domes in ancient and modern buildings, together with the edifices to which they belong, likewise various other structures reduced to the same scale.

The highest dome, [No. 3] is that of St Peter's church, at Rome, generally considered the most splendid building in the world, and one of the largest in size. This edifice was a century in building, from about 1510 to 1610. It was begun by Bramante, and finished by Michael Angelo and Vignola. The dome is of an ellipsoidal form, solid at bottom, but divided into two thin, concentric domes at top, between which is the stair leading to the lantern. The whole height from the ground to the cross at top, is about 470 feet. The base of the dome rests upon arches, supported by massive stone piers. Within the last century, some fissures of dangerous appearance were discovered in this dome; to remedy which, it was surrounded with iron chains by the artist Zabaglia.

The next dome in height, [No. 4] is that of the church of St Maria del Fiore, at Florence. Its vertical section is an elongated ellipsoid, its horizontal section octagonal. This church is about 380 feet high, and was built between 1298 and 1472. The dome was erected by Bruneleschi, one of the earliest revivers of antique architecture.

St Paul's cathedral, London, [No. 5] was erected by Sir Christopher Wren, between 1685 and 1710. It has two domes at different heights, the inner being made of brick, and the outer of wood. Between the two, is a hollow, truncated cone of brick work, which furnishes the support of the lantern at top. The outline of the dome is somewhat more than a semicircle, and is prevented from spreading at bottom, by a strong iron hoop.

The church of St Genevieve, in Paris, [No. 6] which, during the absence of the Bourbon family, was called the Pantheon, was begun by Soufflot, in 1757. This edifice has been threatened with ruin, in consequence of the piers, which support the dome, being made too small for the nature of the material, and the superincumbent weight. It became necessary to replace a part of the stones which were crushed, and to increase the amount of support, to obtain present security.

The Mosque of St Sophia, at Constantinople, [No. 7] presents a specimen of the kind of dome used by the ancients, which was more flat than any of the preceding examples, and was usually a small segment of a sphere. This edifice was erected during the reign of Justinian, in the sixth century. Owing to the want of sufficient solidity in the supporting wall, the dome fell down at two successive times, and the architect was under the necessity of filling up the subjacent arcades, and of building large buttresses on the outside of the wall, to resist the pressure, and give to the dome eventual stability. The span of this dome is 112 feet.

The Pantheon, at Rome, [No. 8] is probably the oldest dome now standing, and is one of the best constructed. Its outer and inner surfaces are of different curvatures, so that the thickness increases downward, the inner surface being a hemisphere. The walls of this edifice are of great solidity, and to this circumstance the security of the superstructure is in part owing. This dome is open at the top. It was built by Agrippa, in the reign of Augustus Cæsar. A more perfect view of the Pantheon is given in Plate V.

The outline of St Mark's church, at Venice, which has several domes; that of the front of the Parthenon, at Athens, which shows the lowness of the Grecian pediment; that of the restored temple of Vesta, at Tivoli, and lastly that of the small Ionic temple which stood upon the Ilissus, are added merely to give an idea of their comparative size. The column erected to the memory of the emperor Trajan, also one of the obelisks brought from Egypt by the ancient Romans, are introduced upon the same scale.

No. 1, in the same plate, represents the outline of the largest of the Egyptian Pyramids, respecting the dimensions of which, travellers vary greatly in their accounts. One of the more moderate of their estimates is here taken, which makes the height a little less than 500 feet.

No. 2, shows the length and height of the Coliseum, at Rome, a vast elliptical amphitheatre, which 15,000 men were occupied ten years in completing. It was built in the reign of Vespasian and Titus, and its walls are standing at the present day.

No. 15, represents the celebrated leaning tower of Pisa. The several stories of this structure are supported by arcades upon columns, in the Greco-gothic style. The height of the whole is 180 feet. This tower leans over about 14 feet from a perpendicular. The view here taken of it, does not represent its greatest inclination. Whether the obliquity was the effect of design, or of the settling of the foundation on one side, is a point upon which writers are not agreed. It was built in the twelfth century.

No. 16, is the steeple of the Gothic Cathedral, at Strasburg. It is among the highest steeples in Europe, and is introduced to show its comparative elevation. No. 17, is the centre steeple of the *Duomo* or Cathedral of Milan, about 350 feet high. This edifice is of white marble. Its general character is Gothic, intermixed with details in the later Roman style.

The proportions of most of the foregoing buildings are taken from Durand, who has reduced them to a scale. The same scale applies to the other architectural plates in this volume, with the exception of perspective representations, in which more than one side is seen.

The outlines of several American edifices, reduced to the same scale, are added in this plate, for the convenience of comparison. No. 18, is that of the Capitol, at Washington, built of freestone, the length of which is 350 feet, the height of the front 70 feet, and the height of the centre dome 148 feet. No. 19, is the City Hall, at New York, built chiefly of marble; its length 220 feet, and the height of the statue at top, 120 feet. No. 20, is the State House, in Boston, 173 feet in length, built of brick, and painted. No. 21, is the Bank of the United

States, at Philadelphia, a marble building, having its front 86 feet wide, copied in most respects from the Parthenon at Athens. No. 22, the monument erected at Baltimore, in commemoration of the battle and victory at that place. Height about 55 feet.

Roof.—The *roof* is the most common and cheap method of covering buildings, to protect them from rain and other effects of the weather. It is sometimes flat, but more frequently oblique in its shape. The flat or platform roof is the least advantageous for shedding rain, and is seldom used in northern countries. The *pent* roof, consisting of two oblique sides meeting at top, is the most common form [Pl. I. Fig. *w*.] These roofs are made steepest in cold climates, where they are liable to be loaded with snow. Where the four sides of the roof are all oblique, it is denominated a *hipped* roof, [Fig. *x*] and where there are two portions to the roof, of different obliquity, it is a *curb*, or *mansard* roof. [Fig. *y*.] In modern times, roofs are made almost exclusively of wood, though frequently covered with incombustible materials. The internal structure or carpentry of roofs, is a subject of considerable mechanical contrivance. The roof is supported by *rafters*, which abut on the walls on each side, like the extremities of an arch. If no other timbers existed, except the rafters, they would exert a strong lateral pressure on the walls, tending to separate and overthrow them.* To counteract this lateral force, a *tie beam*, as it is called, extends across, receiving the ends of the rafters, and protecting the wall from their horizontal thrust. To prevent the tie beam from *sagging*, or bending downward with its own weight, a *king post* is erected from this

* The largest roof that has hitherto been built, is supposed to have been that of the riding house, at Moscow. Its span was 235 feet, and the slope of the roof, about 19 degrees. The principal support of this immense truss, consisted in an arch of timber in three thicknesses, indented together, and strapped and bolted with iron. The principal rafters and tie beams, were supported by several vertical pieces, notched to this arch, and the whole stiffened by diagonal braces. *Tredgold's Carpentry*, p. 87.

beam, to the upper angle of the rafters, serving to connect the whole, and to suspend the weight of the beam. This is called *trussing*. *Queen posts* are sometimes added, parallel to the king post, in large roofs, also various other connecting timbers. In Gothic buildings, where the vaults do not admit of the use of a tie beam, the rafters are prevented from spreading, as in an arch, by the strength of the buttresses.

In comparing the lateral pressure of a high roof, with that of a low one, the length of the tie beam being the same, it will be seen that a high roof, from its containing most materials, may produce the greatest pressure, as far as weight is concerned. On the other hand, if the weight of both be equal, then the low roof will exert the greater pressure, and this will increase in proportion to the distance of the point at which perpendiculars drawn from the end of each rafter, would meet.

In roofs, as well as in wooden domes, and bridges, the materials are subjected to an internal strain, to resist which, the cohesive strength of the material is relied on. On this account, beams should, when possible, be of one piece. Where this cannot be effected, two or more beams are connected together by *splicing*. Spliced beams are never so strong as whole ones, yet they may be made to approach the same strength, by affixing lateral pieces, or by making the ends overlay each other, and connecting them with bolts and straps of iron. The tendency to separate is also resisted, by letting the two pieces into each other, by the process called *scarfing*. *Mortises*, intended to *truss* or suspend one piece by another, should be formed upon similar principles.

Roofs in this country, after being boarded, receive a secondary covering of shingles. When intended to be incombustible, they are covered with slates or earthen tiles, or with sheets of lead, copper, or tinned iron. Slates are preferable to tiles, being lighter, and absorbing less moisture. Metallic sheets are chiefly used for flat roofs, wooden domes, and curved and angular surfaces, which require a flexible material to cover them, or have not a sufficient pitch to shed the rain from slates or shingles. Various artificial compositions are occasionally used to cover roofs, the most common of which are mixtures of tar with lime, and sometimes with sand and gravel.

Styles of Building.—The architecture of different countries has been characterized by peculiarities in external form, and in modes of construction. These peculiarities, among ancient nations, were so distinct, that their structures may be identified even in the state of ruins; and the origin and era of each may be conjectured with tolerable accuracy. Before we proceed to describe architectural objects, it is necessary to explain certain terms, which are used to denote their different constituent portions. The architectural *orders* will be spoken of under the head of the Grecian and Roman styles, but their component parts ought previously to be understood.

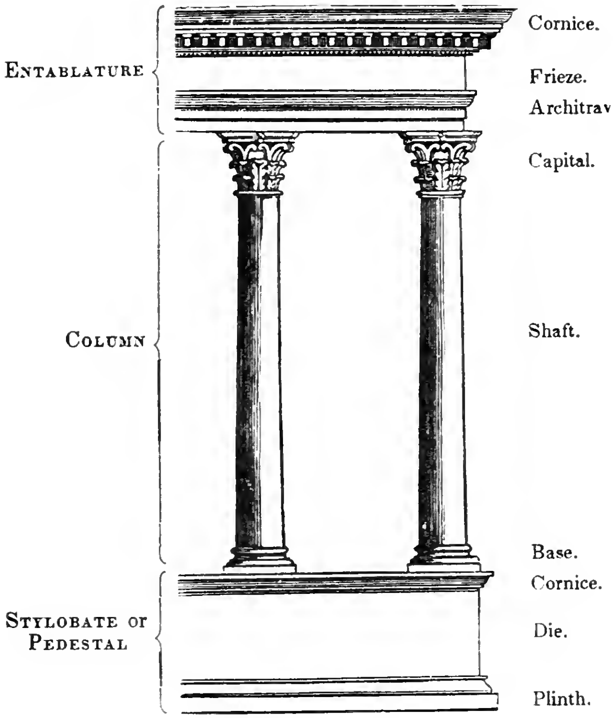
Definitions.—The front or *façade* of a building, made after the ancient models, or any portion of it, may present three parts, occupying different heights.

The *pedestal* is the lower part, usually supporting a column. The single pedestal is wanting in most antique structures, and its place supplied by a *stylobate*. The stylobate is either a platform with steps, or a continuous pedestal, supporting a row of columns. The lower part of a finished pedestal is called the *plinth*,* the middle part is the *die*, and the upper part the *cornice* of the pedestal, or *surbase*.

The *column*, is the middle part, situated upon the pedestal or stylobate. It is commonly detached from the wall, but is sometimes buried in it for half its diameter, and is then said to be *engaged*. *Pilasters* are square or flat columns, attached to walls. The lower part of a column, when distinct, is called the *base*; the middle, or longest part, is the *shaft*, and the upper, or ornamented part, is the *capital*. The height of columns is measured in diameters of the column itself, taken always at the base.

* The name plinth, in its general sense, is applied to any square projecting basis, such as those at the bottom of walls, and under the base of columns.

The *entablature*, is the horizontal, continuous portion, which rests upon the top of a row of columns. The lower part of the entablature is called the *architrave*, or *epistylium*. The middle part is the *frieze*, which, from its usually containing sculpture, was called *zophorus* by the ancients. The upper, or projecting part, is the *cornice*.



A *pediment*, is the triangular face, produced by the extremity of a roof. The middle, or flat portion, inclosed by the cornice of the pediment, is called the *tympanum*. Pedestals for statues, erected on the summit and extremities of a pediment, are called *acroteria* [Pl. V. Fig. 2.] An *attic*, is an upper part of a building, terminated at top by a horizontal line, instead of a pediment.

The different *mouldings* in architecture are described from their sections, or from the profile which they present, when cut across. Of these the *torus* is a convex moulding, the section of which is a semicircle or nearly so [Pl. I. Fig. *a.*] The *astragal*, is like the torus, but smaller [Fig. *b.*] The *ovolo* is convex, but its outline is only the quarter of a circle [Fig. *c.*] The *echinus* resembles the ovolo, but its outline is spiral, not circular [Fig. *d.*] The *scotia* is a deep, concave moulding [Fig. *e.*] The *cavetto* is also concave, and occupying but a quarter of a circle [Fig. *f.*] The *cymatium* is an undulated moulding, of which the upper part is concave, and the lower convex [Fig. *g.*] The *ogee* or *talon*, is an inverted cymatium [Fig. *h.*] The *fillet* is a small square or flat moulding [Fig. *i.*] *

Measures.—In architectural measurement, a *diameter* means the width of a column at the base. A *module* is half a diameter. A *minute* is a sixtieth part of a diameter.

Drawings.—In representing edifices by drawings, architects make use of the *plan*, *elevation*, *section*, and *perspective.* The *plan* is a map, or design, of a horizontal surface, showing the ichnographic projection, or ground work, with the relative position of walls, columns, doors, &c.† The *elevation* is the orthographic projection of a front, or vertical surface; this being represented, not as it is actually seen in perspective, but as it would appear if seen from an infinite distance. The *section* shows the interior of a building, supposing the part in front of an intersecting plane, to be removed. The *perspective* shows the building as it actually appears to the eye, subject to the laws of scenographic perspective. The three former are used by architects, for purposes of admeasurement, the latter is used also by painters, and is capable of bringing more than one side into the same view, as the eye actually perceives them.

* By a singular mixture of derivations, the Greek, Latin, Italian, French, and English languages are laid under contribution for the technical terms of Architecture.

† See various plans of temples on pages 137, 138.

Restorations.—As the most approved features in modern architecture are derived from buildings which are more or less ancient, and as many of these buildings are now in too dilapidated a state to be easily copied, recourse is had to such imitative restorations in drawings and models, as can be made out from the fragments and ruins which remain. In consequence of the known simplicity and regularity of most antique edifices, the task of restoration is less difficult than might be supposed. The ground work, which is commonly extant, shows the length and breadth of the building, with the position of its walls, doors, and columns. A single column, whether standing or falling, and a fragment of the entablature, furnish data from which the remainder of the colonnade, and the height of the main body, can be made out. A single stone from the cornice of the pediment, is often sufficient to give the angle of inclination, and consequently the height of the roof. In this way, beautiful restorations are obtained of structures, when in so ruinous a state, as scarcely to have left one stone upon another.

EGYPTIAN STYLE.

In ancient Egypt, a style of building prevailed, more massive and substantial than any which has succeeded it. The elementary features of Egyptian architecture, were chiefly as follows. 1. Their walls were of great thickness, and sloping on the outside. This feature is supposed to have been derived from the mud walls, mounds, and caverns of their ancestors. 2. The roofs and covered ways were flat, or without pediments, and composed of blocks of stone, reaching from one wall or column to another. The principle of the arch, although known to them, was seldom, if ever, employed by them. 3. Their columns were numerous, close, short, and very large, being sometimes 10 or 12 feet in diameter. They were generally without bases, and had a great variety of capitals, from a simple square block, ornamented with hieroglyphics, or faces, to an elaborate composition of palm leaves not unlike the Corinthian capital. 4. They used a sort of concave entablature, or cornice, composed of vertical flutings, or leaves, and a winged globe in the centre. 5. Pyramids, well known for their prodigious size, and obelisks composed of a single stone, often exceeding 70 feet in height, are structures peculiarly Egyptian. 6. Statues of enormous size, sphinxes carved in stone, and sculptures in outline of fabulous deities and animals, with innumerable hieroglyphics, are the decorative objects which belong to this style of architecture.

For Egyptian specimens, see Pl. I. Fig. 1.; Pl. VI. Fig. 1, and Pl. VII. Fig. 1, 2, and 3.

The architecture of the ancient Hindoos, appears to have been derived from the same original ideas as the Egyptian. The most remarkable relics of this people, are their subterraneous temples, of vast size and elaborate workmanship, carved out of the solid rock, at Elephanta, Ellora, and Salsette. One of their columns is shown in Plate VII. Fig. 4.

THE CHINESE STYLE.

The ancient Tartars, and wandering shepherds of Asia, appear to have lived from time immemorial in *tents*, a kind of habitation adapted to their erratic life. The Chinese have made the tent the elementary feature of their architecture, and of their style any one may form an idea, by inspecting the figures which are depicted upon common china ware. Chinese roofs are concave on the upper side, as if made of canvass instead of wood. A Chinese portico, is not unlike the awnings spread over our shop windows in summer time. The *verandah*, sometimes copied in dwelling houses here, is a structure of this sort. The Chinese towers and pagodas, have concave roofs, like awnings, projecting over their several stories. The lightness of the style used by the Chinese, leads them to build with wood, sometimes with brick, and seldom with stone [Pl. VI. Fig. 2, and VII. Fig. 18.]

THE GRECIAN STYLE.

Grecian architecture, from which have been derived the most splendid structures of later ages, has its origin in the wooden hut or cabin, formed of posts set in the earth, and covered with transverse poles and rafters. Its beginnings were very simple, being little more than imitations, in stone, of the original posts and beams. By degrees these were modified and decorated, so as to give rise to the distinction of what are now called the *orders* of architecture.

Orders of Architecture.—By the architectural orders, are understood certain modes of proportioning and decorating the column and its entablature. They were in use during the best days of Greece and Rome, for a period of six or seven centuries. They were lost sight of in the dark ages, and again revived by the Italians at the time of the restoration of letters. The Greeks had three orders, called the *Doric*, *Ionic*, and *Corinthian*. These were adopted and modified by the Romans, who also added two others, called the *Tuscan* and *Composite.*

Doric Order.—The Doric is the earliest and most massive order of the Greeks. It is known by its large columns with plain capitals; its *triglyphs* resembling the ends of beams, and its *mutules* corresponding to those of rafters. The column, in the examples at Athens, is about six diameters in height. In the older examples, as those at Pæstum, it is but four or five. The shaft had no base, but stood directly on the stylobate. It had 20 flutings, which were superficial, and separated by angular edges. The perpendicular outline was nearly straight. The Doric capital was plain, being formed of a few *annulets* or rings, a large *echinus*, and a flat stone at top called the *abacus*. The architrave was plain; the frieze was intersected by oblong projections called *triglyphs*, divided into three parts by vertical furrows, and ornamented beneath, by *guttæ* or drops. The spaces between the triglyphs were called *metopes*, and commonly contained sculptures. The sculptures representing Centaurs and Lapithæ, carried by Lord Elgin to London, were metopes of the Parthenon, or temple of Minerva, at Athens. The cornice of the Doric order consisted of a few large mouldings, having on their under side a series of square, sloping projections, resembling the ends of rafters, and called *mutules*. These were placed over both triglyphs and metopes, and were ornamented, on their under side, with circular *guttæ*. The best specimens of the Doric order, are found in the Parthenon, the Propylæa, and the Temple of Theseus, at Athens [Pl. VI. Fig. 7. Pl. IV. Fig. 1, 2, 3, 4, 5, and 6.]

Ionic Order.—The Ionic is a lighter order than the Doric, its column being eight or nine diameters in height. It had a base often composed of a torus, a scotia, and a second torus, with intervening fillets. This is called the *Attic* base [Pl. VII. Fig. 9.] Others were used in different parts of Greece. The shaft had 24, or more, flutings, which were narrow, as deep as a semicircle, and separated by a fillet or square edge. The capital of this order consisted of two parallel double scrolls, called *volutes*, occupying opposite sides, and supporting an abacus, which was nearly square, but moulded at its edges. These volutes have been considered as copied from ringlets of hair, or perhaps from the horns of Jupiter Ammon. When a column made the angle of an edifice, its volutes were placed, not upon opposite, but on contiguous sides; each fronting outward. In this case the volutes interfered with each other at the corner, and were obliged to assume a diagonal direction. The Ionic entablature consisted of an architrave and frieze, which were continuous or unbroken, and a cornice of various successive mouldings, at the lower part of which was often a row of *dentels* or square teeth. The examples at Athens, of the Ionic order, are the temple of Erectheus, and the temple on the Ilissus, which was standing in Stuart's time 70 years since, but is now extinct [Pl. VII. Fig. 9. Pl. IV. Fig. 8, 9, 10, and 11.]

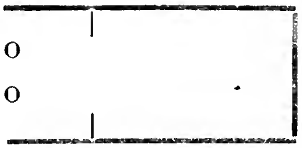
Corinthian Order.—The Corinthian was the lightest and most decorated of the Grecian orders. Its base resembled that of the Ionic, but was more complicated. The shaft was often ten diameters in height, and was fluted like the Ionic. The capital was shaped like an inverted bell, and covered on the outside with two rows of leaves of the plant acanthus,* above which were eight pairs of small volutes. Its abacus was moulded and concave on its sides, and truncated at the corners, with a flower on the centre of each side. The entablature of the Corinthian order, resembled that of the Ionic, but was more complicated and ornamented, and had, under the cornice, a row of large oblong projections, bearing a leaf or scroll on their under side, and called *modillions*. No vestiges of this order are now found in the remains of Corinth, and the most legitimate example at Athens, is in the choragic monument of Lysicrates. The Corinthian order was much employed in the subsequent structures of Rome, and its colonies [Pl. VII. Fig. 10. Pl. V. Fig. 1, 2, 3, &c.]

Caryatides.—The Greeks sometimes departed so far from the strict use of the orders, as to introduce statues, in the place of columns, to support the entablature. Statues of slaves, heroes, and gods, appear to have been employed occasionally for this purpose. The principal specimen of this kind of architecture, which remains, is in a portico, called Pandroseum, attached to the temple of Erectheus, at Athens, in which statues of Carian females, called *Caryatides*, are substituted for columns [Pl. IV. Fig. 9.] One of these statues has been carried to London.

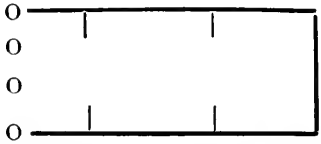
Grecian Temple.—The most remarkable public edifices of the Greeks, were their temples. These being intended as places of resort for the priests, rather than for the convening of assemblies within, were in general obscurely lighted. Their form was commonly that of an oblong square, having a colonnade without, and a walled *cell* within. The cell, was usually

* The origin of the Corinthian capital has been ascribed to the sculptor Callimachus, who is said to have copied it from a basket accidentally enveloped in leaves of acanthus. A more probable supposition traces its origin to some of the Egyptian capitals, which it certainly resembles.

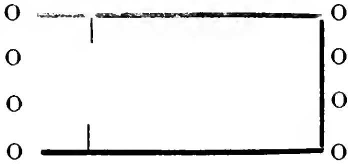
without windows, receiving its light only from a door at the end, and sometimes from an opening in the roof. The part of the colonnade which formed the front portico, was called the *pronaos*, and that which formed the back part, the *posticus*. The colonnade was subject to great variety in the number and disposition of its columns, from which Vitruvius has described seven different species of temples. These were, 1. The temple with *antæ*. In this the front was composed of pilasters, called antæ, on the sides, and two columns in the middle.



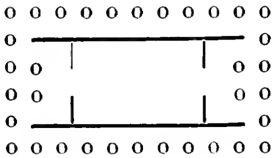
2. The *Prostyle*. This had a row of columns at one end only.



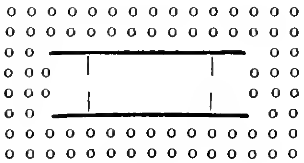
3. The *Amphiprostyle*, having a row of columns at each end.



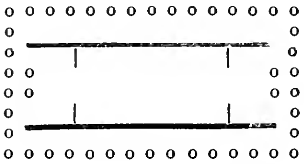
4. The *Peripteral* temple. This was surrounded by a single row of columns, having six in front, and in rear, and eleven, counting the angular columns, on each side.



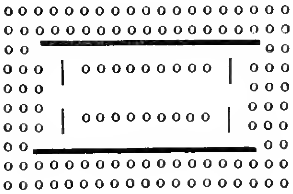
5. The *Dipteral*, with a double row of columns all round the cell, the front consisting of eight.



6. The *Pseudo-dipteral* differs from the dipteral, in having a single row of columns on the sides, at the same distance from the cell, as if the temple had been dipteral.



7. The *Hypæthral* temple had the centre of its roof open to the sky. It was colonnaded without, like the dipteral, but had ten columns in front. It had also an internal colonnade, called *peristyle*, on both sides of the open space, and composed of two stories or colonnades, one above the other.



Temples, especially small ones, were sometimes made of a circular form. When these were wholly open, or without a cell, they were called *Monopteral* temples. When there was a circular cell within the colonnade, they were called *Peripteral.**

Grecian Theatre.—The theatre of the Greeks, which was afterwards copied by the Romans, was built in the form of a horse shoe, being semicircular on one side, and square on the other. The semicircular part, which contained the audience, was filled with concentric seats, ascending from the centre, to the outside. In the middle, or bottom, was a semicircular floor called the *orchestra*. The opposite, or square part, contained the actors. Within this was erected, in front of the audience, a wall ornamented with columns and sculpture, called the *scena*. The stage, or floor, between this part and the orchestra, was called the *proscenium*. Upon this floor was often erected a moveable wooden stage, called, by the Romans, *pulpitum*. The ancient theatre was open to the sky, but a temporary awning was erected to shelter the audience from the sun and rain.

Remarks.—Grecian architecture is considered to have been in its greatest perfection in the age of Pericles and Phidias. The sculpture of this period, is admitted to have been superior to that of any other age; and although architecture is a more arbitrary art, than sculpture, yet it is natural to conclude, that the state of things which gave birth to excellence in the one, must have produced a corresponding power of conceiving sublimity and beauty in the other. Grecian architecture was, in general, distinguished by simplicity of structure, fewness of parts, absence of arches, lowness of pediments and roofs, and by decorative curves, the outline of which was a spiral line, or conic section, and not a circular arc, as afterwards adopted by the Romans.

* The *intercolumniation*, or distance between the columns, according to Vitruvius, was differently arranged under the following names. In the *pycnostyle*, the columns were a diameter and a half apart. In the *systyle* they were two diameters apart. In the *diastyle*, three. In the *arœostyle*, more than three. In the *eustyle*, two and a quarter.

Plate IV.—This plate is intended to give a view, upon the same scale as Pl. 1, of various examples of Grecian architecture, the remains of which are extant at the present day. The limits of the plate permit only the front elevation to be given, which, in the oblong Grecian temples, was the end of the building.

No. 1, represents the principal temple at Pæstum, in Italy. At this place are now standing, the walls and colonnades of three temples, built in the ancient Doric style, and undoubtedly erected by a Grecian colony in that country. The characters of this early Doric, are short and heavy columns, much diminished upwards, large capitals, and a massive entablature, nearly half as high as the columns. The outline of the columns in this building is straight, or without entasis. The temple appears to have been hypæthral, though the number of columns is less than in the rule prescribed by Vitruvius.

No. 2, is the Temple of Concord, commonly so called, at Agrigentum, now Girgenti, in Sicily. It is erected in the massive style of the older Doric, on a stylobate of four steps, and, with the exception of the roof, is in a state of good preservation at the present day. Other Doric ruins are found in the same place, also at Segesta, Selinus, and other parts of Scicily. Views of these structures are given in Wilkins' *Magna Græcia.*

No. 3, is the Temple of Theseus, at Athens, situated in the lower part of that city, some way from the Acropolis. It is the most perfectly preserved of any of the Athenian edifices, its columns and walls having suffered scarce any dilapidation. At the top of its stone platform, or stylobate, it measures 104 feet in length, by 45 in breadth, and has six columns on each front, with thirteen on each side, counting those at the angles. The temple of Theseus was erected by Cimon, the son of Miltiades, about 450 years before Christ. The sculptures upon the frieze of this building, are supposed by Stuart, and others, to refer to the exploits of Theseus, but according to Mr Wilkins,* they represent the labors of Hercules.

* Topography and buildings of Athens, 8vo. 1816.

No. 4, is the Propylæa, at Athens, a structure of much beauty, which commanded the entrance to the Acropolis, or citadel. Besides a portico of six Doric columns on each front, it had an Ionic colonnade within, and a separate quadrangular building attached to each side. Before the entrance, are two large pedestals, supposed to have supported equestrian statues. The Propylæa were ascended by steps at different stages, and had also an inclined plane for carriages. This building was erected in the time of Pericles, and is now in a ruinous state, a great portion of what remains being hidden by the walls of the Turks. No. 5, is a transverse section of the Propylæa, made at right angles with the former view, and showing the different ascents.

No. 6, is the façade of the Parthenon, or temple of Minerva, situated on the summit of the Acropolis, at Athens. This building is now considered the best model for the Doric order, and no edifice, ancient or modern, commands such general applause at the present day. It was built by the architect Ictinus, during the administration of Pericles, about 440 years before Christ. Its decorative sculptures are supposed to have been executed under the direction of Phidias. The Platform or stylobate, consists of three steps, the uppermost of which is 227 feet in length, and 101 in breadth. The number of columns is eight in the portico of each front, and seventeen on each flank, besides which there is an inner row of six columns at each end of the cell. The proportional height of the columns is five diameters and 33 minutes, and they diminish thirteen minutes in diameter, from bottom to top. The sculptures on the frieze represent the combats of the Centaurs and Lapithæ. Those on the eastern pediment, represented the fabulous birth of Minerva; and those on the western, the contests between that goddess and Neptune, for the right of presiding over the city. When Athens was visited by Wheler, in 1676, the Parthenon remained entire, with the exception of its roof. But during the siege of the city by the Venetians, in 1687, a shell which exploded in the midst of the cell, destroyed the whole central part of the wall, together with nineteen of the columns. Most of the sculpture of both pediments has also disappeared.

No. 7, is the choragic monument of Thrasyllus, situated without the Acropolis, and constituting the front of a grotto. It is not, strictly speaking, of any architectural order, but departs from the Doric, in having a row of circular wreaths, instead of triglyphs, and a continuous row of guttæ at the bottom of the frieze.

No. 8, is the small Ionic amphiprostyle temple on the banks of the Ilissus, which was standing in Stuart's time, but has now wholly disappeared. The delineations obtained from this building by Stuart, have since furnished the most popular models of the Ionic order.

No. 9, is the Erectheum, an Ionic building, much admired, in the Acropolis, at Athens. It comprises two temples, one dedicated to Minerva Polias, the other to the nymph Pandrosus. The smaller portico of the Pandroseum, is remarkable for a row of Caryatides, or female statues, which perform the office of columns in supporting the entablature.* No. 10, is an Ionic capital from the temple on the Ilissus. Those of the temple of Minerva Polias were similar in the general form of the volutes, but had also an ornamented neck above the flutings.

No. 11, represents the façade of the Temple of Apollo Didymæus, near Miletus. It was among the most celebrated Grecian structures. It was termed by Strabo, the greatest of all temples, and was ranked by Vitruvius, with that of Diana, at Ephesus. Although few of its columns are now standing, the ruins give evidence of its original size and magnificence. It appears to have been a dipteral temple, surrounded with a double row of columns, triple in front, and in all 112. Views

* One of these statues was carried off by Lord Elgin, and is placed with other Athenian marbles in the British Museum. Stuart makes this building to consist of three temples, viz. those of Erectheus, Minerva Polias, and Pandrosus. Mr Wilkins divides it into two.

of this building are given in the Ionian Antiquities, and in the *Voyage Pittoresque* of Choiseul Gouffier.

No. 12, is the choragic monument of Lysicrates, at Athens, sometimes improperly called the Lantern of Demosthenes. This elegant little structure has a circular ornamented roof of one stone, and six Corinthian columns engaged in a circular wall, the whole supported on a square basis. It is now half inclosed in a modern convent.

No. 13, is the octagon tower, at Athens, commonly called the *Tower of the winds*, from the emblematic sculptures on its sides. Its sides are marked with lines for indicating the hour of the day by the shadows of gnomons.

ROMAN STYLE.

Roman architecture had its origin in copies of the Greek models. All the Grecian orders were introduced into Rome, and variously modified. Their number was augmented by the addition of two new orders, the Tuscan and the Composite.

Tuscan Order.—This order, derived from the ancient Etruscans, is not unlike the Doric deprived of its triglyphs and mutules. It had a simple base containing one torus. Its column was seven diameters in height, with an astragal below the capital. Its entablature, somewhat like the Ionic, consisted of plain, running surfaces. There is no vestige of this order among ancient ruins, and the modern examples of it are taken from the descriptions of Vitruvius [Pl. VII. Fig. 6].

Roman Doric.—The Romans modified the Doric order by increasing the height of its column to eight diameters. Instead of the echinus which formed the Grecian capital, they employed the ovolo, with an astragal and neck below it. They placed triglyphs over the centre of columns, not at the corners, and used horizontal mutules, or introduced foreign ornaments in their stead. The Theatre of Marcellus has examples of the Roman Doric [Pl. VII. Fig. 8].

Roman Ionic.—The Romans diminished the size of the volutes in the Ionic order. They also introduced a kind of Ionic capital in which there were four pairs of diagonal volutes, instead of two pairs of parallel ones. This they usually added to parts of some other capital, but at the present day it is often used alone, under the name of *modern* Ionic.

Composite Order.—This fifth order was made by the Romans out of the Corinthian, simply by combining its capital with that of the diagonal, or modern Ionic [Pl. VII. Fig. 11.] Its best example is found in the arch of Titus. The favorite order, however, in Rome and its colonies, was the Corinthian, and it is this order which prevails among the ruins, not only of Rome, but of Nismes, Pola, Palmyra, and Balbec.

Roman Structures.—The temples of the Romans, sometimes resembled those of the Greeks, but often differed from them. The *Pantheon*, which is the most perfectly preserved temple of the Augustan age, is a circular building, lighted only from an aperture in the dome, and having a Corinthian portico in front. The *amphitheatre* differed from the theatre, in being a complete circular, or rather elliptical building, filled on all sides with ascending seats for spectators, and leaving only the central space, called the *arena*, for the combatants and public shows. The Coliseum is a stupendous structure of this kind. The *aqueducts* were stone canals, supported on massive arcades, and conveying large streams of water, for the supply of cities. The *triumphal arches* were commonly solid oblong structures, ornamented with sculptures, and open with lofty arches for passengers below [Pl. VI. Fig. 8.] The *Basilica* of the Romans, was a Hall of Justice, used also as an exchange, or place of meeting for merchants. It was lined on the inside with colonnades of two stories, or with two tiers of columns one over the other. The earliest christian churches at Rome, were sometimes called basilicæ, from their possessing an internal colonnade. The monumental *pillars*, were towers in the shape of a column on a pedestal, bearing a statue on the summit, which was approached by a spiral staircase within. Sometimes, however, the column was solid. The *Thermæ*, or baths, were vast structures, in which multitudes of people could bathe at once. They were supplied with warm and cold water, fitted up with numerous rooms for purposes of exercise and recreation.

Remarks.—In several particulars, the Roman copies differed from the Greek models, on which they were founded. The stylobate or substructure, among the Greeks, was usually a plain succession of platforms, constituting an equal access of steps, to all sides of the building. Among the Romans, it became an elevated structure, like a continued pedestal, accessible by steps only at one end. The spiral curve of the Greeks, was exchanged for the geometrical circular arc, as exemplified in the substitution of the ovolo for the echinus in the Doric capital. The changes in the orders, have been already mentioned. After the period of Hadrian, Roman architecture is considered to have been on the decline. Among the marks of a deteriorated style introduced in the later periods, were columns with pedestals, columns supporting arches, convex friezes, entablatures squared so as to represent the continuation of the columns, pedestals for statues projecting from the sides of columns, niches covered with little pediments, &c. See Plates VI. and VII.

Plate V.—In this plate is represented a series of buildings in the Roman style, reduced to a scale, after Durand. They are all of the Corinthian order. No. 1, is the Pantheon, already mentioned, of which the portico is of stone, while the body, or circular part covered by the dome, is of brick. The occurrence in this building, of two pediments, one above the other, is considered a defect, and probably indicates that the parts of the edifice were erected at different times. The entablature consists only of a cornice. In most other respects, the symmetry of this building is much admired.

No. 2, is the temple of Antoninus and Faustina, at Rome. The walls and columns are raised upon an elevated stylobate, and are approached by steps in front only, differing in this respect from the Grecian temples, which were accessible on all sides.

No. 3, is the *Maison carree* at Nismes, in France. It is pseudo-peripteral, having its columns engaged in the wall, with the exception of ten, which form the portico in front. It has been lately discovered that this building, which remains in excellent preservation, was erected to the memory of Caius and Lucius Cæsar, sons of Agrippa, and grandsons of Augustus.*

No. 4, is the circular, peripteral temple of Vesta, at Rome. The temple of Vesta, at Tivoli, outlined in Plate I, differs from this, in having a raised stylobate. The dome, in both these buildings, is an imaginary restoration, made after the rules of Vitruvius. Messrs Taylor and Cresy have given to the temple at Tivoli, a conical roof, like that of the monument of Lysicrates.

No. 5, is a temple at Pola, in Istria, dedicated to Rome and Augustus. At this place are many interesting antiquities, among which are an amphitheatre and triumphal arch.

No. 6, is the structure commonly called the Arch of Theseus, at Athens. It was erected probably by the Roman emperor Hadrian, to divide the new city from the old, and bears an inscription on each side, indicating that on one side is seen the city of Theseus, and on the other the city of Hadrian.

No. 7, is a sepulchre at Mylassa, in Asia Minor, apparently of Roman origin, and described in the Ionian antiquities. Its angular pillars are square, but the intermediate columns have a form very unusual in ancient or modern architecture, being compressed, so that a section of the shaft represents an ellipse. They are fluted for half their length.

No. 8, is the triumphal arch of Constantine, at Rome, which, with the exception of a part of its sculptures, is entire at the present day. This arch was built after the arts had begun to

* The origin and date of this beautiful temple were unknown, until an artist, named Seguier, made out the inscription on the frieze, by connecting together the holes in which the nails were driven, that formerly confined bronze letters upon the wall.

decline, and is constructed chiefly of materials taken from the arch of Trajan, erected two centuries before. Its columns stand upon separate, projecting pedestals, and have a part of the entablature squared upon the top of each.

No. 9, is the external portico of the Temple of the Sun, at Palmyra. The ruins of this city exceed in extent and magnificence anything else which remains of antiquity in Europe, or Asia. It is built in the Corinthian order, and in the later style of Roman architecture, characterized by niches in the walls at different heights containing statues, by numerous small pediments and entablatures, also in some cases by statues supported on brackets, or pedestals projecting from the sides of columns. In this portico, an example occurs of double columns, a feature rarely met with, in antique architecture, but sometimes used by the moderns, upon an extensive scale.*

No. 10, is the circular temple at Balbec, a place distinguished by the magnificence and colossal size of its ruins. This temple is singular in the form of its outline, which is circular, with large concave recesses between all the columns, as shown more distinctly in the ground plan, No. 11, of the same building. In other respects it partakes of the later Roman style.

No. 12, is the octagonal temple of Jupiter, forming part of the palace erected by the Roman emperor Diocletian, at Salona, now Spalatro, in Dalmatia, where its extensive ruins are still extant.

GRECO-GOTHIC STYLE.

After the dismemberment of the Roman empire, the arts degenerated so far, that a custom became prevalent of erecting new buildings with the fragments of old ones, which were dilapidated and torn down for the purpose. This gave rise to an irregular style of building, which continued to be imitated, es-

* To the regular duplicature of columns introduced in the colonnade of the Louvre, in Paris, Perrault has given the name of *aræo-systyle*. See note p. 139.

pecially in Italy, during the dark ages. It consisted of Grecian and Roman details, combined under new forms, and piled up into structures wholly unlike the antique originals. Hence the names *Greco-gothic* and *Romanesque* architecture have been given to it. It frequently contained arches upon columns, forming successive arcades, which were accumulated above each other to a great height. The effect was sometimes imposing. The Cathedral and Leaning Tower, at Pisa, and the Church of St Mark, at Venice, are cited as the best specimens of this style [Pl. I. Fig. 15. and Pl. VII. Fig. 13.] The Saxon architecture, used anciently in England, has some things in common with this style [Pl. VII. Fig. 14.]

SARACENIC STYLE.

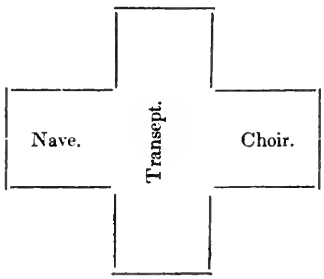
The edifices erected by the Moors and Saracens in Spain, Egypt, and Turkey, are distinguished, among other things, by a peculiar form of the arch. This is a curve, constituting more than half of a circle, or ellipse. This construction of this arch, is unphilosophical, and comparatively insecure. A similar peculiarity exists in the domes of the oriental Mosques, which are sometimes large segments of a sphere, appearing as if inflated; and at other times concavo-convex in their outline, as in the mosque of Achmet. The *minaret* is a tall, slender tower, peculiar to Turkish architecture. A peculiar flowery decoration, called *arabesque*, is common in the Moorish buildings of Europe, and Africa [Pl. VI. Fig. 3.—Pl. VII. Fig. 16. Pl. I. Fig. *p* and *q*.]

GOTHIC STYLE.

The Goths, who plundered Rome, had nothing to do with the invention of Gothic architecture. The name was introduced by Sir Christopher Wren, and others, as a term of reproach, to stigmatize the edifices of the middle ages, which departed from the purity of the antique models. The term was, at first, very extensive in its application, but it is now confined chiefly, to what may be called the modern Gothic,—the style of building cathedrals, churches, abbeys, &c. which was introduced in England six or eight centuries ago, and adopted, nearly at the same time, in France, Germany, and other parts of Europe. The Gothic style is peculiar and strongly marked. Its principle seems to have originated in the imitation of groves, and bowers, under which the Druids performed their sacred rites. Its characteristics, at sight, are, its pointed arches, its pinnacles and spires, its large buttresses, clustered pillars, vaulted roofs, profusion of ornaments, and the general predominance of the perpendicular over the horizontal.

Although the Gothic style of building was originated at a period, when the arts were less successfully cultivated than they were in the time of the Greeks; it has nevertheless given rise to some of the most lofty, the most highly decorated, and the most imposing structures now in existence.

Definitions.—As the common place for the display of Gothic architecture, has been in ecclesiastical edifices, it is necessary to understand the usual plan and construction of these buildings. A church or cathedral is commonly built in the form of a cross, having a tower, lantern, or spire, erected at the place of intersection. The part of the cross, situated toward the west, is called the *nave*. The opposite or eastern part is called the *choir*, and within this is the *chancel*. The transverse portion, forming the arms of the cross, is called the *transept*.



Any high building erected above the roof, is called a *steeple;* if square topped, it is a *tower;* if long and acute, a *spire*, and if short and light, a *lantern*. Towers of great height, in proportion to their diameter, are called *turrets*. The walls of Gothic churches, are supported on the outside, by lateral projections, extending from top to bottom, at the corners, and between the windows. These are called *buttresses*, and they are rendered necessary to prevent the walls from spreading under the enormous weight of the roofs [Pl. VI. Figs. 4, and 5.] On the tops of the buttresses, and elsewhere, are slender pyramidal structures, or spires, called *pinnacles*. These are ornamented on their sides, with rows of projections, appearing like leaves or buds, which are named *crockets*. The summit, or upper edge of a wall, if straight, is called a *parapet;* if indented, a *battlement*. Gothic windows were commonly crowned with an acute arch. They were long and narrow, or if wide, were divided into perpendicular lights by *mullions*. The lateral spaces on the upper and outer side of the arch, are called *spandrells;* and the ornaments in the top, collectively taken, are the *tracery*. An *oriel*, or *bay window*, is a projecting window. A *wheel*, or *rose window*, is large and circular. A *corbel*, is a bracket or short projection from a wall, serving to sustain a statue, or the springing of an arch.

Gothic *pillars* or columns, are usually clustered, appearing as if a number were bound together. The single shafts thus connected, are called *boltels*. They are confined chiefly to the inside of buildings, and never support anything like an entablature. Their use is to aid in sustaining the vaults under the roof, which rest upon them at springing points [Pl. VI. Fig. 6.] Gothic vaults intersect each other, forming angles called *groins*. The parts which are thrown out of the perpendicular, to assist in forming them, are the *pendentives*. The ornamented edge of the groined vault, extending diagonally, like an arch, from one support to another, is called the *ogyve*. The gothic term *gable*, indicates the erect end of a roof, and answers to the Grecian pediment, but is more acute.

The Gothic style of building is more imposing, and more difficult to execute, than the Grecian. This is because the weight of its vaults and roofs is upheld at a great height, by supporters acting at single points, and apparently but barely sufficient to effect their object. Great mechanical skill is necessary, in balancing and sustaining the pressures; and architects at the present day, find it difficult to accomplish what was achieved by the builders of the middle ages.

Plate VI.—No. 1, is the front of an ancient Egyptian temple, at Essenay. It has the sloping walls, concave entablature, crowded columns, and hieroglyphic sculptures, peculiar to the edifices of that country. The roof is flat, and supported on twentyfour columns inside.—No. 2, represents an octagonal pagoda, at Sinkicien, in China. It gives an example of the curved Chinese roof, formed in imitation of the tent.—No. 3, the Mosque of Achmet, at Constantinople, built in 1610. It has a central dome, surrounded by four half domes, which cover vast recesses resembling niches. Its court is surrounded by a sort of cloister, covered by numerous small cupolas, and having tall minarets at the angles and sides.—No. 4, is a perspective view of York Cathedral, one of the most admired specimens of Gothic architecture. It is built in the form of a cross, and has three towers, of which the two front ones are surmounted by pinnacles, and the central one by battlements. It was built between the years 1171 and 1426.—No. 5, is a Gothic exterior, from the wall of Westminster Abbey, showing the buttresses, which support the walls, also the short pinnacles and battlements. The slanting braces at top are called *flying buttresses.*—No. 6, is a Gothic interior, from the nave of York Cathedral. It shows the clustered pillars, pointed arches, groined vaulting, and tracery, which belong to the Gothic style.

Plate VII.—In this plate is presented a series of columns, with some of their entablatures, arches, &c., illustrative of the styles of building which have prevailed in different epochs, and countries. The three first figures are those of Egyptian columns, all serving to show the massiveness of structure which prevailed in the buildings of that nation. A great variety of these columns exist at the present day in Upper Egypt, particularly at Karnac and Luxor, the remains of ancient Thebes. No. 1, is from a tomb of Silsilis, and has an outline which is common among the Egyptian ruins.—No. 2, likewise a common form, has a capital composed of faces.—No. 3, is a column from Komonbu. The idea of the Corinthian capital, seems to have been borrowed from Egyptian specimens of this kind. The column No. 4, is from the great cave at Elephanta, near Bombay, one of the wonderful subterranean structures, excavated by the ancient inhabitants of Hindostan out of solid rock. No. 5, is a column from the ruins of Persepolis. At this place, which contains the most remarkable relics of the ancient arts of Persia, the style of architecture partakes of the Egyptian and Hindoo characteristics, the columns, however, being more slender.—No. 6, represents the Tuscan order, used by the ancient inhabitants of Etruria.—No. 7, is the Grecian Doric, of the age of Pericles, at which time it is considered to have been in greatest perfection.—No. 8, is the Roman Doric, represented with a base, after the restorations of the moderns.—No. 9, is the Grecian Ionic. The base represented in this figure, and the next, is called the *Attic base.*—No. 10, the Corinthian order.—No. 11, the Composite order, in which the volutes are larger than in the Corinthian. The modern Ionic is taken from the upper part of this capital. The frieze is represented as convex, a feature which is considered peculiar to the later or declining period of Roman architecture.—No. 12, is a combination of the column with a pedestal, and a squared portion of the entablature, usually attached to the main edifice, by one side. This peculiarity was introduced after the arts had begun to decline, and appears in many of the later Roman edifices. It has been absurdly imitated in more modern times, by making a squared entablature to constitute a portion of the column, and placing another entablature above it.—No. 13, shows a mode of building with arches between the columns and the entablature. It is taken from the remains of Diocletian's palace at Spalatro, and seems to have given rise to the Greco-gothic style.—No. 14, which also exhibits arches upon columns, is a specimen of Saxon architecture from the Cathedral at Ely.—No. 15, is a twisted column from a cloister belonging to St Paul's church, without the walls, at Rome, rebuilt about the year 800. Columns of this sort occur in various Italian structures, but it is difficult to conceive of a form more at variance with architectural fitness or security.—No. 16, Moorish double columns, arches, and arabesques, from the Alhambra, at Grenada. In the same building, the true Saracenic or horse-shoe arch, also occurs.—No. 17, a Gothic pillar from Salisbury Cathedral. Other Gothic forms are seen in Plate VI. Fig. 6.—No. 18, a Chinese column from the viceroy's palace, at Canton.—No. 19, section of a reeded Egyptian column.—No. 20, section of a fluted Doric column.—No. 21, section of a fluted Ionic column.—No's 22, 23, and 24, sections of different Gothic columns.

Application.—In edifices erected at the present day, the Grecian and Gothic outlines are commonly employed, to the exclusion of the rest. In choosing between them, the fancy of the builder, more than any positive rule of fitness, must direct the decision. Modern dwelling houses have necessarily a style of their own, as far as stories and apartments, and windows and chimnies, can give them one. No more of the styles of former ages can be applied to them, than what may be called the unessential and decorative parts. In general, the Grecian style, from its right angles and straight entablatures, is more convenient and fits better with the distribution of our common edifices, than the pointed and irregular Gothic. The expense also is generally less, especially if anything like thorough and genuine Gothic is attempted; a thing, however, rarely undertaken as yet, in this country. But the occasional introduction of the Gothic outline, and the partial employment of its ornaments, has undoubtedly an agreeable effect, both in public and private

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edifices; and we are indebted to it, among other things, for the spire, a structure exclusively Gothic, which, though often misplaced, has become an object of general approbation, and a pleasing landmark to our cities and villages.

Wilkins' Translation of Vitruvius, 4to. 1817;—Elmes' Lectures on Architecture, 8vo. 1823;—Stuart's Antiquities of Athens, 4 vols. fol. 1762, &c.;—Antiquities of Ionia, by the Dilettanti Society, 2 vols. fol. 1817-21;—Antiquities of Attica, by the same, fol. 1817;—Wilkins' Magna Græcia, fol. 1807;—Desgodetz's Buildings of Rome, 2 vols. fol. tra. 1771;—Taylor and Cresys' Antiquities of Rome, 2 vols. fol. 1821-2;—Durand, *Recueil des Edifices*, oblong fol. 1801;—Pugins' Specimens of Gothic Architecture, 2 vols. 4to. 1823;—Brittons' Architectural Antiquities of Great Britain, 4 vols. 4to. 1815, &c.;—Tredgold's Elements of Carpentry, 4to. 1821;—Nicholsons' Architectural Dictionary, 3 vols. 4to. 1821.

CHAPTER VIII.

ARTS OF HEATING AND VENTILATION.

In cold and temperate climates, a large portion of human labor is devoted to procure and sustain such a degree of heat, as is necessary to a comfortable existence. The means of effecting this object, as far as the economy of fires and dwelling houses is concerned, will be considered in the present chapter. To procure heat, to distribute it, to retain it, and to obviate its inconveniences by ventilation, are the principal objects that present themselves in a survey of the subject.

PRODUCTION OF HEAT.

Fuel.—Heat is artificially obtained for common purposes, by the combustion of fuel. Fuel may be usefully considered with regard to its compactness or weight, its quantity of combustible matter, and its quantity of water.

Weight of Fuel.—In regard to the first consideration, if other things be equal, the more compact and heavy any fuel is, the more difficult it is to kindle, but the more permanent will it be found when once on fire. Coal, for example, is a compact fuel, when compared with light dry wood. Coal cannot so well be kindled by a small blaze, nor by a very small quantity of other combustible matter on fire, because its density renders it a rapid conductor, and it carries off the heat of the kindling substance, so as to extinguish it, before it is itself raised to the temperature necessary for its combustion. But if the heat of other fuel be applied to it in sufficient quantity, and long enough, to ignite it, it then produces a powerful fire, and a much more durable one than lighter fuel. Light fuel, on the other hand, being a slow conductor of heat, kindles easily; and, from the admixture of atmospheric air in its pores and crevices, burns out rapidly, producing a comparatively temporary though often a strong heat.

Combustible matter of Fuel.—The quantity of combustible matter of fuel, if the weight and other circumstances be equal, may be learnt from the ashes, or residuum, left after the combustion. For example, good Newcastle coal contains a greater portion of combustible matter than Nova Scotia coal, and leaves behind a smaller amount of earthy and incombustible substance. The heating power, and consequent value, of different kinds of fuel, is affected by this circumstance, though by no means dependent on it. The fitness of fuel for various purposes, is furthermore affected by the facility, with which it gives off a part of its combustible matter in the form of vapor, or gas; which, being burnt in that state, produces *flame.** For example, the bituminous coals abound in volatile matter, which, when ignited, supports a powerful blaze. On the other hand, the Lehigh and Rhode Island coals are destitute of bitumen, and yield but little flame. It is from similar causes, that dry pine wood produces a powerful blaze, while its charcoal yields comparatively little. A blaze is of great service, where heat is required to be applied to an extensive surface, as in reverberating furnaces, ovens, glass houses, &c. But when an equable, condensed, or lasting fire is wanted, the more solid fuels, which blaze less, are to be preferred.

Water in Fuel.—The quantity of watery fluid contained in fuel, greatly affects the amount of heat it produces, much more, indeed, than is commonly admitted in practice. It is a well known law of chemistry, that the evaporation of liquids, or their conversion into steam, consumes, and renders latent, a great amount of caloric. When green wood, or wet coal, are added to the fire, they abstract from it by degrees, a sufficient part of its heat, to convert their own sap or moisture into steam,

* See Chapter IX. Art. *Flame.*

before they are capable of being burnt. And as long as any considerable part of this fluid remains unevaporated, the combustion goes on slowly, the fire is dull, and the heat feeble. Green wood commonly contains a third, or more, of its weight of watery fluid, the quantity varying according to the greater or less porosity of different trees. Nothing is further from true economy than to burn green wood, or wet coal, on the supposition that because they are more durable, they will in the end prove more cheap. It is true, their consumption is less rapid; but to produce a given amount of heat, a far greater amount of fuel must be consumed. Wood that is dried under cover is better than wood dried in the open air, being more free from decomposition.

Not only the production of steam, but likewise the formation of different gases, which are evolved during combustion, affect the usefulness of fuel, according to their quantity and capacity for heat. It is difficult, however, to estimate with accuracy the amount of their practical effect.

Charcoal.—Charcoal is prepared from wood, and *coke* in a similar manner from pitcoal; by raising those substances to a high temperature, sufficient to deprive them of their moisture and volatile matter. When intended for chemical uses, charcoal is made by exposing wood to heat in iron cylinders, or other close vessels. But for the common purposes of fuel, it is made by a sort of smothered combustion, in which masses of wood, when set on fire, are covered with earth, so as nearly to exclude the atmospheric air. This exclusion of air prevents the wood from being consumed, while the red heat, which is kept up for some time, dissipates the moisture from its pores. Charcoal is generated in a small way, every night, in fires which are raked up; the brands and half burnt coals, are kept from consuming, by the partial exclusion of the air, while the light ashes, being a slow conductor of caloric, prevent them from cooling below a red heat. Charcoal, when newly made from the heavier kinds of wood, such as oak and walnut, is a powerful, and for some purposes, an economical kind of fuel.

Coke, a kind of fuel used for certain purposes in England, is charred pitcoal. It produces a strong and steady heat, but does not blaze. Large quantities of coke are formed in the manufactories of coal gas.

COMMUNICATION OF HEAT.

Radiated and conducted Heat.—Caloric, or heat, is communicated to apartments, by fires kept in them, in two ways. A part of it is radiated, the rest is conducted. The first portion passes through the air with great velocity, in diverging rays. The second, penetrates slowly through the densest bodies, whether transparent, or opaque. In a fire place or open stove, the heat which is felt by holding the hand before the fire, is radiated caloric. That which is felt by placing the hand on the iron or bricks, is conducted caloric. To enjoy the full effect of radiated caloric, we must be in presence or sight of the radiating object. To receive conducted heat, we must be in contact with the substance which imparts it. Since, however, we cannot remain in contact with the fire itself, we derive our conducted heat from the air, a fluid, which constantly touches, and envelopes our persons; and which, when heated in itself, becomes a source of warmth to us. The object of the various contrivances, known under the names of stoves and fire places, is to enable us to use fire with safety, and to obtain from it a due supply of radiated caloric, and heated air.

In common cases, radiant heat is more agreeable, than conducted heat, when we wish to obtain a sudden warmth; since its degree may be increased at pleasure, by altering our proximity to the fire; the effect of the radiation being inversely proportionate to the square of the distance. But as only one half of the recipient body can be warmed at a time by radiation, no person surrounded by a cold atmosphere, can be made uniformly warm, by the radiated heat of a fire. It is only when the surrounding atmospheric air has become warm, that we obtain all the advantage which fire is capable of affording.

Fire in the open Air.—The simplest, and least effectual mode, by which heat can be obtained, is from a fire in the open air. The hunter, or backwoodsman, when he encamps for the night, builds a fire of logs, and lays down to sleep, with his feet extended towards it. In this situation he can enjoy only a small portion of the radiated heat of the fire, this heat being thrown off equally in all other directions. Of the conducted heat he obtains none; for the air which surrounds the fire having nothing to confine it, ascends by its diminished specific gravity, as fast as it is warmed, and its place is immediately supplied by strata of colder air from beneath. Hence a current of cold air will take place from the atmosphere on all sides, towards the fire, so that the person who derives warmth from the fire on one side, will on the other be exposed to additional cold. The first step towards remedying this inconvenience, is to build up a barrier, or imperfect wall, on the outside of the place occupied by the tenant. This will intercept the current of cold air, and oblige it to approach the fire by other directions, at the same time that it will gradually become heated itself, and radiate back a portion of its warmth. The next improvement consists in extending the wall, so as completely to surround the fire, thus obliging the air to approach it from above, or from doors and avenues purposely left for its entrance. This is, in fact, the commencement of a dwelling house. A roof with an aperture for the escape of the smoke, is a further improvement on the plan, and lastly the introduction of a chimney, at once renders the mansion convenient and tenantable.*

Fire places.—Chimnies from their usual situation in regard to rooms, and also for the sake of a more perfect draught, have an opening on one side of their base, to which we give the name of fire place. The fire place in former times was an oblong or cubical cavity, having its sides nearly at right angles with the back. In a cavity of this description, the greater part of

* See Sylvester's account of the Derbyshire Infirmary.

the heat generated by the fire, was totally lost to the apartment, nearly all the conducted heat being carried, with the air, up the chimney; while of the radiated heat, but a small part could directly enter the room, viz. the part radiated from the front of the fire; the heat of the other sides being chiefly thrown into the hearth, back, and sides, or up the chimney. In the old fire places, the inconvenience was still further augmented by increasing their dimensions to an enormous size, so that seats or benches could be placed on each side, on the inside of the jambs. The consequence was, that a prodigious current of air was constantly carried up the chimney, and the seats, on the inside of the fire place, became the only comfortable ones in the room.

Admission of cold Air.—It is obvious, that in apartments with open fire places, the air must be continually shifting, and that cold air must enter at the crevices of the doors and windows, to supply the place of that which maintains the combustion, or escapes up the chimney. In moderate weather this change of air is an advantage, since it freshens and ventilates the room, the air of which would otherwise become close and impure. In moderate weather also, the radiant heat is adequate to warm the walls of the room, which in their turn become sources of radiant heat, and likewise contribute to warm the air by their contact. But in very cold weather, it is nearly or quite impossible to render a large apartment warm by means of a common open fire place; for, in proportion to the briskness of the fire itself, will be the rapidity with which the cold air presses into the room, and a person near the hearth feels perhaps as much cold on one side of his body, as heat on the other.

Open Fires.—The cheerful sight of an open fire, to which habit and association have attached us, has created a strong and almost general preference to the open fire place over the close stove, and a desire, by remedying its defects, to make it more effectual and useful. Of various philosophers who have exercised their ingenuity on this subject, the two who appear to have labored with most success, are our countrymen, Dr Franklin, and Count Rumford.

Franklin Stove.—Dr Franklin, whose writings on the economy of fire contain the basis of many of the improvements which have since been introduced, invented an apparatus of cast-iron, to which he gave the name of the *Pennsylvania Fire Place*, but which is now often known by the name of *Franklin Stove.* This fire place, when executed agreeably to the author's instructions, is one of the most effective and economical modes in which an open fire can be managed. By means of a narrow and circuitous smoke flue, which is surrounded and intersected with air passages, a great part of the heat of the fire is retained in the room, and at the same time a current of fresh air, warmed by the fire place, is introduced into the apartment. In Plate VIII. Fig. 1. is seen a section of the Pennsylvania fire place. A, is the place of the fuel and fire; B C D, the smoke flue, passing first upward, then downward to the floor, and escaping by the chimney D, next the wall, K. E H, is the air chamber into which the air is admitted from without the house through the passage I. After being heated, it is discharged into the apartment by lateral openings at the top G.*

Fire places which stand out into the room, also fire places with hollow backs or pipes for hot air, are to be viewed, in most instances, as simplifications only, of Franklin's plan.

Rumford Fire Place.—Count Rumford's fire place forms a pleasant and effectual mode of economizing the heat of an open fire, besides which, its cheapness and simplicity give it the advantage over more complicated plans, and have occasion-

* Most of the articles now sold as Franklin stoves, are very different from the original Pennsylvania fire place. If any defect existed in the plan of the inventor, it was in the small quantity of air admitted through a circuitous and obstructed channel, and in the bad character of the material, cast-iron being liable to warp and crack, if exposed to great heat and cold on opposite sides.

The first person who suggested the introduction of heated air, through hollow passages, appears to have been M. Gauger, in a work entitled *La Mechanique de Feu*, published in 1709.

ed its very general introduction. The peculiarities of this fire place consist, 1st, in an advanced back, which brings the fire nearer into the room, and at the same time by narrowing the throat of the chimney diminishes the current of air which escapes through it ; 2dly, in the oblique sides or covings of the fire place, which are enabled, when heated, to radiate their warmth into the room. Count Rumford recommends that the angle, made by the sides with the back, should be one of 135 degrees. He also advises that the color of the covings should be white, this color being best adapted for radiation.

Double Fire Place.—For parlors, and common apartments, no contrivance appears so pleasant and effectual, as the double fire place, which has of late years been extensively introduced in this city and vicinity. It is a modification of Franklin's plan, and is made from any common fire place, by inserting within it another fire place made of soapstone, leaving an empty space, of about an inch in depth, between the two, so that when finished, the back and sides may be hollow. This hollow space does not communicate with the fire, but has two openings, one at bottom, communicating with the external atmosphere by a perforation in the wall, or by a tin pipe laid in the floor ; the other, opening into the apartment, at a point higher than the fire place, and commonly at the side of the chimney. In this fire place, an open fire, of wood or coal, may be used with the full advantage, ever obtained, of its radiant heat. A large part of the conducted heat is also saved, since the air which enters from without, becomes heated in the hollow space, and ascends by it, in consequence of its diminished specific gravity, entering the room in a strong warm current. This air serves the purpose of ventilation ; it supersedes the entrance of cold air through the crevices and keyholes, and is also a preventive against smoking. The circumstances to be attended to in the construction, are as follows. 1. The openings for the air should be large, in common cases from four to seven inches in diameter, since it is better to introduce a large quantity of air moderately warmed, than a small quantity made very hot. More heat will in this case be conducted from the stone, and the unpleasant effects of *burnt air* will be avoided. 2. The openings into the room should be made, when practicable, at least a foot higher than the top of the fire place, for when they are on a level with it, or lower, the warm air is liable to be drawn up the chimney, and the main object defeated. But if the opening is above the fire place, then the warm air will ascend and be diffused through the upper parts of the room, till the whole is gradually warmed. 3. The cold air should be taken from without the house, and not from an entry or cellar, because changing the air of those places in winter, is apt to reduce them to a freezing temperature. The external opening should be guarded with a wire net, to exclude leaves and light substances; and the internal, should be commanded by a shutter, to regulate the heat. For safety, it is best, though not always necessary, that the hot air passage should not be in contact with the wood work of the house. 4. Good soapstone is the best material for these fire places, and with careful use will last many years. See *Soapstone*. For wood fires, the stone should be an inch and a half thick, and for coal fires, two or three inches.

In Plate VIII. Fig. 2, is a section of a double fire place. A, is the place of the fire; H, the soapstone back; B, the throat; C, the chimney; E, the external opening; D G G, the hollow, or passage for heated air; M, a pipe for conveying the hot air to N, a lateral opening into the room; P, the mantel piece. A soapstone fire place may be rendered very effectual, by causing it to project a little into the room, and by adding an air box to the top, as seen in Pl. VIII. Figs. 3 and 4. In the section, Fig. 3, A, is the fire; B B, the smoke passage; C c c, the air passage; D, a box for heated air covering the fire place, and communicating with the hollow back c c, by a side passage at the dotted lines; E, a side opening for discharging the hot air into the room; G, the mantle piece. In fire places of cheap construction, a simple hollow back, made by one slab of soapstone, with openings as have been described, will contribute much to increase the warmth of the room.

Coal Grate.—When coals are used for fuel, it is necessary, on account of their small size, to confine them together with a grate. As they contain more combustible matter, in the same space, than wood, and produce a greater degree of heat, a much smaller fire place answers for them. A very small throat also in the chimney, is sufficient to carry off the smoke from a common coal grate. With this exception, it has the same characteristics as a common fire place.

Anthracite Grate.—Grates for burning anthracite, require more perpendicular height than others, and should be of such a proportionate depth as will keep the coal together, and not offer too great a surface to the atmosphere. In extremely cold weather, it is observed that the front surface of anthracite grows black and burns feebly in an open grate, while it does not in a furnace or stove. In this case, the cold air conducts off the heat of the surface faster than the combustion renews it; and if the amount of surface be too great in proportion for that of the solid contents, the fire will go out. Anthracite grates are usually provided with a very narrow throat, to carry off the gases which result from the combustion; there being no visible smoke. The throat, however, should always be large enough to transmit the smoke of any other fuel; for otherwise, a part of the carbonic acid which is formed, will escape into the room, and contaminate the atmosphere, in the same way as burning charcoal. See Chap. I. art. *Anthracite.*

Burns' Grate.—Mr Burns, of Glasgow, has made an alteration in the coal grate, by introducing the external air through an opening immediately under the grate. This air supplies the fuel with oxygen, and furnishes most of the current which passes up the chimney. The air of the room of course remains comparatively stationary, and is sooner heated. This plan, when combined with the double fire place, already mentioned, [Pl. VIII. Figs. 3 and 4] is a powerful mode of obtaining heat. A moveable stone screen should be placed in front of the ash pit, to prevent the ashes from being blown into the room. The external opening which admits the air, should not be near any wood work, as sometimes the current is reversed by winds, and sparks and smoke are driven out at the opening.

Building a Fire.—In building and maintaining an open fire, whether of wood or coal, certain circumstances deserve attention, in the common fire places. It is advantageous to make the perpendicular height of the fuel as great as is consistent with safety. A stratum of coals, or ignited wood, will radiate more heat into the lower part of the room, if placed vertically, than if laid horizontally. Fuel, for economy, should be so subdivided, as to be easy of ignition, and so placed as to give free access for the air to its different surfaces. In this way the smoke is more likely to be burnt. To secure the greatest effect of radiation, the combustion should be kept, as much as possible, to the front surface. In kindling a fire, the live coals should be kept together, and placed near the bottom. A blower, added to a common grate, converts it, for the time being, into a wind furnace.

Furnaces.—The object of the furnaces used by artists and manufacturers, is the reverse of that intended to be produced by stoves and fire places; furnaces being required to produce an intense heat, and to confine it to a limited space. Hence furnaces and their chimneys are surrounded with nonconductors, that they may expend as little of their heat as possible, on the air and surrounding objects. They are commonly made of fire-proof bricks, and when small, are inclosed in iron. Their most simple form is that of an upright, hollow cylinder, with a grate at bottom. *Air* or *wind furnaces* have their combustion supported by a draught of air, which ascends rapidly because it is strongly heated and rarified. *Blast furnaces* have the air driven through their fuel with bellows. *Reverberating furnaces* are provided with a concave covering, which reverberates, or throws back the flame, upon the substances to be heated or melted. There are some cases in which furnaces are used for warming dwelling houses, particularly when fuel is used which requires strong ignition, such as the Anthracites.

Stoves.—Stoves differ from fire places by inclosing the fire so as to exclude it from sight, the heat being given out through the material of which the stove is composed. The common Holland stove, of which we have an almost infinite variety of modifications, is an iron box of an oblong square form, intended to stand in the middle of a room. The air is admitted to the fire through a small opening in the door, and the smoke passes off through a narrow funnel. The advantages of this stove are—1. That being insulated and detached from the walls of the room, a greater part of the heat produced by the combustion is saved. The radiated heat being thrown into the walls of the stove, they become hot, and in their turn radiate heat on all sides to the room. The conducted heat is also received by successive portions of the air of the room which pass in contact with the stove. 2. The air being made, as in furnaces, to pass through the fuel, a very small supply is sufficient to keep up the combustion, so that little need be taken out of the room. 3. The smoke being confined by the cavity of the stove, cannot easily escape into the room, and may be made to pass off by a small funnel, which, if sufficiently thin and circuitous, may cause the smoke to part with a great portion of its heat, before it leaves the apartment. These circumstances render the Holland stove one of the most powerful means we can employ for keeping up a regular and effectual heat, with a small expense of fuel.

The disadvantages of these stoves are, that houses containing them are never well ventilated, but that the same air remains stagnant in a room for a great length of time. Hence it necessarily becomes impure by the breath of persons who remain in it, and by the burning of dust and other substances which settle on the heated iron of the stove. A dryness of the air is also produced, which is oppressive to most persons, so that it often becomes necessary to place an open vessel of water on the stove, the evaporation of which, may supply moisture to the atmosphere. Where rooms are kept very warm by stoves, it is found advantageous even to cause the water to boil, in order to insure a sufficient supply of vapor. Stoves are very useful in large rooms, which are frequented occasionally, but not inhabited constantly; as halls, churches, &c. But for common rooms, which are occupied at all times, they are objectionable, for the reasons which have been stated.

Russian Stove.—In cold countries, where it is desirable to obtain a comfortable warmth, even at the sacrifice of other conveniences, various modifications of the common stoves have been introduced, to render them more powerful, and their heat more effectual. The Swedish and Russian stoves are small furnaces, with a very circuitous smoke flue. In principle, they resemble a common stove, with a funnel bent round and round, until it has performed a great number of turns or revolutions before it enters the chimney. It differs, however, in being wholly enclosed in a large box of stone or brick work, which is intersected with air pipes. In operation, it communicates heat more slowly, being longer in becoming hot, and also slower in becoming cold, than the common stove. Russian stoves are usually provided with a damper, or valve, at top, which is used to close the funnel or passage, when the smoke has ceased to ascend. Its operation, however, is highly pernicious, since burning coals when they have ceased to smoke, always give out carbonic acid in large quantities, which, if it does not escape up chimney, must deteriorate the air of the apartment, and render it unsafe.

Cockle.—The name of cockle is given to an upper part of a stove or furnace, resembling an inverted vessel. A large cockle saves much heat, since its extensive surface conveys the heat from the flame and smoke, and communicates it to the atmosphere. In some stoves, the cockle is filled with a chequer work of bricks, among which the smoke and flame circulate. After becoming once heated, these bricks are slow in cooling, and continue to yield warmth to the apartment, like the Russian stoves, for some time after the fire is extinguished.

Cellar Stoves and Air Flues.—Such is the tendency of heated or rarified air to ascend, that buildings may be effectually warmed by air flues communicating with stoves in the cellar, or any part of the building below that to be warmed. A large suite of apartments may be sufficiently heated in this way by a single stove. The stove for this purpose should be large and of a kind best adapted to communicate heat. It should be entirely enclosed in a detached brick chamber, the wall of which should be double, that it may be a better non-conducter of heat. The space between the brick chamber and stove should not exceed an inch. In the apparatus of the Derbyshire and Wakefield Infirmaries, which has been imitated in this country, the whole of the air is repeatedly conducted by numerous pipes within half an inch of the stove and its cockle. For the supply of fuel, the same door which opens into the chamber, should open also into the stove, that there may never be any communication with the air of the cellar. A current of external air should be brought down by a separate passage, and delivered under the stove. A part of this air is admitted to supply the combustion; the rest passes upward in the cavity between the hot stove and the wall of the brick chamber, and after becoming thoroughly heated, is conducted through passages in which its levity causes it to ascend, and be delivered into any apartment of the house. Different branches being established from the main pipe, and commanded by valves or shutters, the hot air can be distributed at pleasure, to any one or more rooms at a time. This plan is very useful in large buildings, such as manufactories, hospitals, &c. on account of the facility with which the same stove may be made to warm the whole, or any part of them. The advantage of a long vertical draught enables us to establish a more forcible current of warm air. See page 175. The rooms, while they are heated, are also ventilated; for the air which is continually brought in by the warm pipes, displaces that which was previously in the room, and the air blows out at the crevices and key-holes, instead of blowing in, as it does in rooms with common fire places.

Heating by Steam.—Steam is found to be a useful medium for communicating heat to large buildings. It has the advantage that it conveys heat in any direction, horizontally, upward, or downward, and to the most remote apartments of the largest buildings. In green-houses it has been made to yield a sufficient supply of heat, at the distance of 800 feet from the boiler in which it is produced.* When steam of low pressure is employed, the heat never exceeds 212 degrees of Fahrenheit, so that the air in contact with the apparatus, is never contaminated by the burning of dust.

In constructions for heating by steam, a strong boiler is made use of, provided with a safety valve, and the other appendages common to the boilers of steam engines. From this boiler a steam pipe is carried in any required direction, and distributes branches to the different apartments which are to be warmed. Whenever the water in the boiler is heated to the point of ebullition, steam passes into the pipes, and drives out the atmospheric air through valves provided for the purpose. As long as the surface of the pipes remains of a less heat than 212 degrees, a part of the steam continually condenses, and is immediately succeeded by fresh steam from the boiler. In the act of condensing, it gives out its latent heat to the material of which the pipe is made, and this material, in turn, imparts it to the air of the room. In this manner the steam will continue to be condensed, and to give out heat, as long as the air of the room is at any point below 212 degrees. By the condensation, a quantity of water is constantly formed, which, for economy of heat, is returned by a separate pipe, while it is yet warm, to the boiler. Inverted syphons containing water, are used to prevent the air and steam from communicating. If the steam pipes are made of thin or weak materials, it is necessary to provide them with safety valves opening inward; otherwise they would be crushed by the pressure of the atmosphere, when the fire is extinguished

* At Messrs Loddiges, at Hackney. Tredgold, on Warming, &c. p. 19.

In calculating the effect of this method, it has been ascertained that under favorable circumstances, one cubic foot of boiler will heat about 2000 cubic feet of space in a cotton mill, where the required temperature is from 70 to 80 degrees of Fahrenheit.* And if we allow 25 cubic feet of a boiler for one horse's power, in a steam engine supplied by it, it will follow, that such a boiler is adequate to warm 50,000 cubic feet of space for every horse's power. It is said also that every square foot of surface in a steam pipe, will warm 200 cubic feet of space. These calculations, however, do not apply to buildings unfavorably arranged, nor to very cold weather. The pipes, employed to distribute the steam, should be made of materials which cool most rapidly. Iron, of which the surface is tarnished with rust, is found to exceed tinned iron, in the rapidity of cooling, in the proportion of about 18 to 10.† Room must be allowed for the expansion of the pipes, which in cast-iron may be taken at a tenth of an inch for every ten feet in length. In cotton and calico manufactories, steam is found very advantageous in drying cloths quickly and well.

In comparing the effect of steam heat, with that of smoke flues, different representations have been made by writers on the subject. Mr Tredgold observes that 'he must be a novice in the science of heat, who cannot produce nearly the same effect by the one as by the other, all other circumstances being the same.' The steam apparatus, however, requires more careful management, and does not admit of neglect. Although easily kept in order by a skilful attendant, yet it cannot, in common cases, be entrusted to ordinary or careless persons.

RETENTION OF HEAT.

Causes of Loss.—However advantageously heat may be produced and distributed, it will fail in producing its desired effect, unless suitable provision is made for retaining it, where

* Buchanan on Heat and Fuel, p. 160.   † Tredgold, p. 58.

it is wanted. Heat constantly tends to an equilibrium, and, unless this tendency be retarded, dwelling houses and their apartments will cool, as fast as they are warmed. The chief causes which operate to cool apartments, are—1. The escape of the warm air upward, through crevices, apertures, and chimnies. 2. The power of conducting and of radiating heat, which all substances possess in a greater or less degree, and by which the internal heat of houses is gradually conveyed to the external atmosphere. To obviate the first of these causes, apartments should be made as tight as possible; and to prevent the second, at least in part, their walls should be made thick, and of materials which are slow conductors of heat.

Crevices.—As crevices in rooms commonly occur from the shrinking of their materials, care should be taken to employ, in building, wood which is thoroughly seasoned, and which is known to be permanent in its dimensions. Of the kinds of wood employed for doors and windows, mahogany is the most permanent, and next to this is pine. Oak, and some other hard woods, are very liable to shrink and crack.

Chimnies.—Chimnies occasion less expenditure of warm air from rooms, than their size would lead us to expect, because they open at the bottom, or near the floor. If, therefore, the room be tight, and the chimney cold, the warm air, while at rest, will be retained in the upper portion of the room, or that which is above the fire place, as effectually as in a gasometer. But if a chimney is heated, and a current thus established through it, it may then drain off the air of the apartment; and hence the foundation for the common belief that a room becomes colder in the night, for having had a fire in the day. The warm air may be retained, if the throat of the fire place be closed with a damper.

Entries and Skylights.—Entries, as they are commonly constructed, extending from the bottom of a house to the top, have a bad influence on the retention of heat. The evil is increased, when they are surmounted with a skylight, the panes of which are arranged like tiles, and not air tight. Such entries are difficult to warm, and serve to drain off the warm air of apartments, whenever the communicating doors are left open; and to transmit it to the roof.* To prevent this effect, entries should be commanded with doors in different stories; and skylights should be made sufficiently erect, to have their sashes complete, or else a tight horizontal window should be added underneath the skylight.

Windows.—The heat conducted off by the external atmosphere, passes, most readily, through the windows, since, the walls of houses, especially when thick, are slow in conducting caloric, while a pane of glass interposes but a slight barrier against its escape. On this account, the unnecessary multiplication of windows should be avoided. In cold climates, a great advantage is obtained from using double windows in winter, which, by confining between them a stratum of air, interpose a powerful nonconductor between the room and the atmosphere. To secure the full benefit of the double window, it should be made as tight as possible, so that the included stratum of air may not easily change; otherwise the expected benefit will not be obtained.

VENTILATION.

Objects.—If the only object of human habitations were to procure heat, it would be best obtained by keeping the air in a state of stagnation, and employing those means to create warmth, which are attended with the least circulation, or change. But since the air of inhabited rooms would become in time unfit for respiration, it is necessary that it should be removed, as fast as deteriorated, and be replaced by fresh air from abroad.

Rooms which are heated with stoves are never well ventilated. Those heated by common fire places, are ventilated, at

* The opposite currents in an open door, by which cold air enters at bottom, and warm air escapes at top, may be made obvious, in the familiar experiment of holding a lighted candle at the bottom and top of the door. In one case the flame will point into the room, and in the other out of it.

the expense of losing much of their warmth by the admission of cold air. Those heated by the double fire place [p. 162,] are sufficiently ventilated, with air at an agreeable temperature. Rooms heated by steam are not at all ventilated, unless it be by additional arrangements. Those warmed by hot air flues are apparently well ventilated, yet in hospitals and crowded buildings, it is sometimes necessary to add fire places, or other openings, for discharging the air.

Ventilators.—The principal gases, which it is the object of ventilation to remove, are carbonic acid and nitrogen; these being produced in excess by the process of respiration, by the combustion of lamps, and by fires with an imperfect draught. The specific gravity of carbonic acid is greater than that of common air. That of nitrogen is somewhat less. These gases when evolved, are at an higher temperature than the surrounding air, and are mixed with steam; therefore, while rarefied by heat, they ascend to the top of the apartment. On this account the *ventilators* intended to discharge them, are made to consist of openings, commanded by shutters, at the upper part of the room. In rooms which are liable to be crowded with people, these ventilators have a good effect, especially in warm weather, and the larger they are, the greater is the advantage derived from them. In cold weather, however, they have the disadvantage that they discharge the pure heated air, in common with the noxious vapors, and thus defeat our efforts to obtain warmth. In common dwelling houses, no more ventilation is necessary, than can be obtained from doors, open fire places, and windows which open at top as well as at bottom.

Culverts.—In the Derbyshire Infirmary an ingenious mode of ventilation is adopted, by means of an empty culvert, or subterranean passage; one end of which opens into the building, while the other end is provided with a turncap, presenting its open mouth to the wind. The air, in passing this culvert, partakes of the temperature of the earth, and is thus warmed in winter, and cooled in summer. The effect, however, is obviously of a limited kind, since the continual transmission of air must bring the surface of the culvert to a temperature approaching that of the surface of the ground.

Smoky Rooms.—Under the head of ventilation may be placed the art of remedying smoky apartments. Smoke is a heterogeneous vapor, composed of the gases which result from combustion, together with a quantity of opaque matter, which escapes from the fuel without being burnt. Smoke is specifically heavier than the atmosphere, and always descends after it is cooled, as may be seen by observing the current of smoke from a chimney in a cold morning. At the time however of its disengagement from the fire, it is rarefied by heat, and will always ascend through a chimney properly constructed, if it is not prevented by some opposing influence. The causes which produce smoky apartments are principally the following.

Damp Chimnies.—When a fire is first made in a chimney which has not been used for many months, it is apt to smoke. This is because the chimney is cold, and the column of air which it contains is not lighter than the surrounding atmosphere. The difficulty of remedying this evil is greater, if the bricks have absorbed much moisture, or the chimney be new; as in this case the chimney will not be well heated, till the moisture is evaporated. To expedite the drying and heating of the chimney, a window should be kept open on the side against which the wind blows, and the communication with the rest of the house, at the same time, closed. This will mechanically assist the smoke and hot air in ascending the chimney.

Large Fire Places.—If a fire place be made too high, it will be liable to smoke; for, since the throat of the chimney takes in air from all directions, if the fire be too remote from this point, its smoke will be less likely to find its proper way. On the other hand, the lower the mantel piece is brought, the nearer will the fire place approach to the character of a wind furnace. In like manner, if the throat of the fire place be too large, the air of the room, as well as that of the fire, will pass freely up the chimney, and thus the whole included air being colder, its current will be more sluggish. The advanced back of the Rumford fire place, by contracting the throat, remedies this difficulty; and at the same time presents a mechanical obstacle against sudden counter currents.

Close Rooms.—Closeness of a room is a cause of its being smoky. If the walls, doors, and windows, are air tight, or nearly so, the outer air cannot enter to take the place of that which passes up the chimney. The current of heated air and smoke will therefore be interrupted, and expand into the room. In most rooms it happens that the crevices occasioned by the shrinking of the wood, or by the want of exactness in finishing, admit air enough, and more than enough, to supply the chimney. In new apartments, however, where all the joinings have been made with great accuracy, it has been found necessary to make perforations in the walls, to admit air sufficient to keep up a current. These should always be made behind the back of the fire place, when possible, for reasons already explained.

Contiguous Doors.—The doors of a room, if placed very near a fire place, or on the same side of the room with it, are apt to occasion a smoke, as often as they are opened. The gust of air which enters at an open door so situated, blows across the chimney. A part of it ascends the flue, while the rest extends into the room, carrying with it a part of the smoke.

Short Chimnies.—The longer a chimney is, the more perfect is its draught, since the upward tendency is proportionate to the difference of weight between the column of air included in the chimney, and a similar column of external air. Short chimnies or flues are liable to smoke from the heated passage not being long enough to establish a strong current. The fire places in upper stories are more apt to smoke than those in the lower apartments. In low houses, outhouses, &c., the chimney should always be carried to the greatest practicable height. Two flues in the same chimney or stack should not communicate at any point short of the top.

Opposite Fire Places.—When two chimnies exist in different parts of the same room, or in rooms which communicate by doors, it is difficult to kindle a fire in one, while the other is burning, especially if the room be tight; because in this case the fire which is first established, feeds itself by a current brought down the vacant chimney. After both fires are kindled, it is necessary to keep up a certain equilibrium between them, otherwise the stronger will overpower the latter, and draw down its smoke into the room. If doors or windows be opened, the evil is obviated. If the fires are in different rooms, the communicating doors between them should be shut.

Neighbouring Eminences.—The vicinity of elevated objects, such as hills, precipices, or very high buildings, is productive of smoky rooms to houses in their neighbourhood. When the wind blows in a direction from the elevated object to the house, it falls down in an oblique direction upon the roof; a part of it enters the chimney, and beats down the smoke, by overpowering its current. On the other hand, when the wind sets towards the hill or elevated object, its passage becomes obstructed, and it presses in every direction to escape; and while its upper portions pass off by the top of the opposing body, the lower portions press downward through any passages which may afford them an escape. Chimnies in houses thus situated should be carried up to a great height, so as, if possible, to overtop the eminence, their sides being secured by iron braces.

Turncap, &c.—In many instances, a turncap, which is a curved tube regulated by a weathercock, so as always to turn its mouth in a direction from the wind, will prevent smoking, in the case last stated. The turncap offers, also, a security against the influence of strong winds, which in common cases and in houses most favorably situated, often invert the course of the smoke by the strong pressure they exert on the tops of chimnies, and by impinging against their inner side. In like manner, the *pots*, which are frusta of cones or pyramids, placed on the tops of chimnies, assist the escape of smoke, by causing the wind to glance upward from their sides.

Contiguous Flues.—When two chimnies are contiguous to each other, or in the same stack, one is frequently liable to smoke, when the other contains a fire, from a variety of circumstances. Not only the effect of high winds, but also any circumstance, which tends to produce an inverted current, may bring down the smoke from one chimney into the apartment which contains the other. To prevent this evil, the fire places should be furnished with dampers which can be closed when the flue is not in use.

Burning of Smoke.—This subject has excited great attention, owing to the nuisance produced by smoke in large cities and manufacturing towns, chiefly where coal is burnt. In an economical view it deserves attention, since it renders the same fuel more effective. Several methods of getting rid of smoke have been proposed and executed with some success. The first mode is to cause the smoke to pass through a portion of fuel which is perfectly ignited and does not smoke, and which, if accurately managed, burns it up. This has been effected by an inverted draught, in a syphon chimney, and also by a revolving grate, which places the ignited fuel between the fresh fuel and the chimney. Another mode is to mix a current of fresh air with the smoke, which causes it to burn upon passing in contact with a clear fire. A third method which has been adopted for disposing of smoke, consists in building chimnies of an extraordinary height, so that most of the smoke may be deposited in soot upon their sides. It has also been proposed to build circuitous chimnies, in one part of which the smoke should pursue a descending course, and that in this part a shower of water should be kept up, to precipitate the denser particles of the smoke. The expense of this method will probably prevent its use, unless in some cases to get rid of dangerous metallic fumes in manufactories.

Franklin's Works;—Rumford's Works;—Tredgold, on Warming and Ventilating Buildings, 8vo. 1824;—Buchanan, on the Economy of Fuel and Management of Heat, 8vo. 1810;—Sylvester's Philosophy of Domestic Economy, and account of the Derbyshire Infirmary, 4to.;—Account of the Wakefield Asylum, fol.;—Brande's Quarterly Journal, No's 22, 24, 27, 37, &c.

CHAPTER IX.

ARTS OF ILLUMINATION.

Flame.—Artificial light is obtained for common purposes, by the combustion of substances, which afford a permanent and luminous flame. All flames are not equally luminous. Those substances which, during combustion, produce chiefly gaseous or volatile matter, emit from their flame a very feeble light, as is seen in burning hydrogen, or sulphur. Those, on the other hand, which produce particles of solid matter during their combustion, yield a whiter flame, and a greater illumination. Sir Humphrey Davy is of opinion that the brilliancy of the flames, used for illumination, is owing to the decomposition of the gaseous matter towards the interior of the flame, by which solid charcoal is produced, and strongly ignited, before it is burnt. In a conical flame, like that of a candle, the combustion takes place most rapidly toward the surface, where the inflammable gas mixes with the atmospheric air. At the centre of the base, there is a darker portion, which consists of the matter, which is volatilized, but not yet fully on fire. In the interior, or most luminous part, the solid particles are brought to a white heat, just before they are burnt. The degree of their ignition is very powerful, since it is found that the flame of a common candle is hot enough to melt a small filament of platinum.

Support of Flame.—That a flame may burn steadily, and produce a uniform light, it is necessary that the supply of combustible matter should be constant and uniform. For this purpose the combustible must be in a liquid, or gaseous state, when it approaches the flame, so that it may flow in an uninterrupted current. This current is commonly sustained either by capillary attraction, or by mechanical pressure, operating on the reservoir which contains the combustible.

Torches and Candles.—The rudest material used for affording light, is the torch, composed of the resinous part of wood of the pine or fir. In such torches, the turpentine, or melted resin, oozes out through the pores of the wood, and is gradually burnt, the wood interposing a vehicle, which regulates the supply, and prevents it from being consumed at once; thus sustaining a dull and irregular light, with much smoke, for some time. A common candle is an improvement upon this natural mechanism. It consists, as is well known, of a fusible solid, as tallow, wax, or spermaceti, formed into a cylinder, having a wick of cotton, or some other porous substance, for its axis. As the tallow melts by the radiated heat of the flame, it is carried upward by the capillary attraction of the wick, and is converted into vapor as fast as it reaches the surface. The end of the wick, although it is blackened by the heat, is prevented from consuming, merely because it is surrounded by inflammable vapor, so that the oxygen of the atmosphere has no access to it. If the wick be turned to one side, so as to project from the blaze into the atmospheric air, it is immediately burnt off. Tallow being more fusible than wax, requires to be burnt with a larger wick. The reason why this wick requires continual snuffing is, that if it is suffered to became long, it divides the blaze, and intercepts a part of the light; it also cools the flame by its radiation, obstructs the combustion, and thus causes the escape of smoke and the deposition of charcoal. Wax and spermaceti, being less fusible, may be burnt with a smaller wick, which, if made sufficiently slender, bends out of the flame and burns off, so as not to requirer snuffing.

Lamps.—When the combustible used is fluid at common temperatures, a vessel is necessary to contain this fluid and supply it to the flame. In this country, and in England, whale oil is the principal fluid which is burnt in lamps.* In France

* The oil which is extracted in cold weather, and called *winter strained oil*, remains fluid at low temperatures. The summer strained oil is liable to con-

and the south of Europe, the oil of poppies, of nuts, rape seed, and the inferior kinds of olive oil, are used for this purpose. The volatile oils are but seldom burnt, since they exhale a strong odor, and throw off soot during their combustion. They are also liable to take fire over their whole surface, unless guarded with great care. Naptha, however, as it is found native, or as it is distilled from pitcoal, is used for supplying street lamps in some of the cities of Europe.

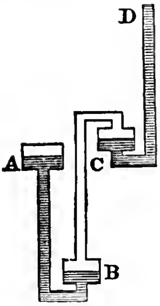
Reservoirs.—As the flame of a lamp is intended to consume no more oil than is attracted upward by the capillary action of the wick, it is necessary that a sufficient body of oil should be so placed, as to keep its surface permanently at a small distance below the level of the flame. The Greeks and Romans employed lamps of various forms, having the wick projecting from a sort of beak at the side, nearly on a level with the surface of the oil. A similar plan is now practised in our street lamps. At the present day, portable lamps of small size, are made with a central wick, having the reservoir of oil immediately below the flame. These reservoirs, if small, require frequent filling, and if large, cast an inconvenient shadow. All closed lamps require a minute hole for the admission of air, otherwise the pressure of the atmosphere will prevent the oil from ascending the wick. If this hole be obstructed, the oil will also sometimes overflow, from the expansion of the confined air, when heated.

Astral Lamp.—With a view to get rid of the effect of shadow, various contrivances have been introduced, in which the reservoir is placed at a distance from the flame. In the Astral and Sinumbral lamps, the principle of which was invented by Count Rumford, the oil is contained in a large horizontal ring, having a burner at the centre, communicating with the ring by two or more tubes placed like rays. The ring is placed a little below the level of the flame, and from its

geal in winter. To obviate this inconvenience, lamps have been contrived for melting the summer oil by the heat of the blaze. This is done either by placing the reservoir of oil immediately over the blaze, or by conducting the heat by a metallic bar, which extends from the flame into the reservoir.

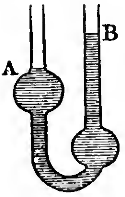
large surface affords a supply of oil for many hours. A small aperture is left for the admission or escape of air, in the upper part of the ring. When these lamps overflow, it is usually because the ring is not kept perfectly horizontal, or else because the air hole is obstructed, a circumstance which may even happen from filling the lamp too high with oil.

Hydrostatic Lamps.—In several cases, the laws of hydrostatics have been applied to raise oil to the flame from a reservoir placed so far below the wick as to be out of the reach of its effective capillary attraction. One of these hydrostatic lamps is constructed on the principle of Hero's fountain. It is composed of three vessels or cavities, occupying different heights, and communicating by tubes or syphons. One portion of oil, by descending gradually from the middle vessel A, to the lower vessel B, causes another portion of oil to ascend from the upper vessel C, to the flame at D, the hydrostatic equilibrium being kept up by the intervention of the column of air B C.



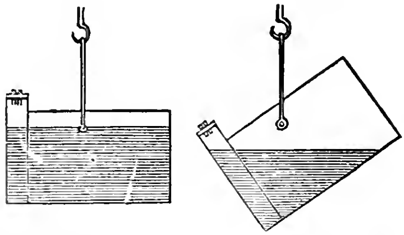
The lamps of Girard de Marselle, and of King, are on this principle, though the form of their apparatus is that of a cylinder, with internal tubes opening into different cavities.

Other hydrostatic lamps are constructed, so as to contain, in one part, a column of some fluid, the specific gravity of which is considerably greater than that of oil; such, for example, as water saturated with salt. This fluid acts in such a manner as to raise the oil, by its greater weight. Thus if an inverted syphon contain oil in one part, and salt water in another, the surfaces of the two fluids will stand at different heights, inversely proportionate to their specific gravities. In the diagram, A represents the surface of the heavier fluid, and B, that of the oil. The bulbs serve as reservoirs to prolong the action. Mr Kiers' lamp is constructed on this principle. Those of Barton and Edelkrantz depend on the same princi-



ple; but in their construction, an open tube of oil is made to float in an upright vessel containing a heavier fluid, which in some cases is salt water, in others mercury. As the oil consumes, the tube, with the wick and light, descend in the supporting fluid, and follow the surface of the oil, as it lowers.

Automaton Lamp.—The automaton lamp of Porter, is a simple and effectual contrivance for keeping the surface of the oil near the level of the blaze. It consists of an oblong tin box, having the wick tubes at one end, this end being thus rendered heavier than the other. The box is suspended on pivots, placed a little out of the centre, and toward the tubes, so that when the lamp is full of oil, the box will hang level. As the oil burns out, however, the end containing the tubes will preponderate, so as to keep the flame always near the surface of the oil. The annexed figures show the position of the lamp when full, and when half exhausted. This lamp is of cheap construction, and is said to be extensively used in cotton mills and other manufactories in the north of England.



Mechanical Lamps.—Some lamps are manufactured in France, in which the oil is raised from a large reservoir below, to a small one near the flame, by means of a pump. This in some instances is worked by hand, and in others is carried by clock work, the motion being derived from a spring, which is wound up as often as necessary.

Fountain Lamp.—The most common mode of disposing of the oil in large lamps, is to place the reservoir above the level of the flame, so that the burner, or part containing the wick, may be supplied in small quantities, as fast as its oil is consumed. These reservoirs are constructed on the principle of the bird fountain. They are open at bottom, but the oil is kept from running out at once, by the pressure of the atmosphere. The reservoir commonly terminates in a neck at bottom, with an opening on one side. This neck is immersed beyond the opening, in a small cavity, which contains oil nearly on a level with the burners, and communicates with them by tubes. So long as the whole of the opening is immersed, no oil can descend from the reservoir, because no air can enter to take its place. But whenever the oil in the lower cavity is consumed so far as to sink below the upper edge of the opening, a bubble of air will enter the neck and ascend into the reservoir; at the same time displacing an equal bulk of oil, which descends to feed the lamp. For convenience, the opening is commanded by a sliding valve, and when the reservoir is to be filled, it is unscrewed from the lamp, inverted, and the oil poured in at the neck. When these lamps overflow, it is commonly owing to an increase in the heat of the room, which causes the air in the upper part of the reservoir to expand, and drive out a portion of oil. As it is not easy to prevent this occurrence, lamps are usually provided with receptacles at bottom, to receive the waste oil which runs over at the wick.

Argand Lamp.—This name is applied, after one of the inventors, to all lamps with hollow or circular wicks; and of course, most of the lamps already described, may be also Argand lamps, if furnished with a circular burner. The intention of the Argand burner, is to furnish a more rapid supply of air to the flame, and to afford this air to the centre, as well as the outside of the flame. It is constructed by forming a hollow cylindrical cavity, which receives oil from the main body of the lamp, and at the same time transmits air through its axis, or central hollow. In this cavity is placed a circular wick, attached at bottom to a moveable ring. This ring is capable of being elevated or depressed, by means of a rack and pinion, or more commonly by a screw; so that the height of the wick may be varied to regulate the size of the flame. On the outside is placed a glass chimney, which is capable of transmitting a current of air, on the same principles as a common smoke flue. When this lamp is lighted, the combustion is vivid, and the light intense, owing to the free and rapid supply of air. The flame does not waver, and the smoke is wholly consumed. The brilliancy of the light is still further increased, if the air be made to impinge laterally against the flame. This is done either by contracting the glass chimney near the blaze, so as to direct the air inwards, or by placing a metallic button over the blaze, so as to spread the internal current outward.

Reflectors.—For obvious reasons, a lamp yields most available light, when it is placed in the centre of a room or space to be illuminated. In this situation, if a reflecting surface be brought near to it, this surface by its reflection will increase the amount of light in one direction, at the expense of intercepting it in another, so that the total advantage is not increased by the reflector. But when a lamp is placed near a wall, so that a part of its rays are wasted by falling immediately upon the wall, in this case if a polished surface be placed behind the flame, it reflects back most of the rays, which would otherwise be lost upon the nonreflecting wall; and thus it increases the effect of the light. The familiar fact that rooms with light colored walls are most easily lighted, is owing to the greater reflective power which such walls possess, when compared with darker surfaces.

Hanging of Pictures.—As the surface of varnished paintings has a considerable reflecting power, it happens that when the spectator stands in the way of the reflected light, his eye is dazzled, and rendered incapable of distinctly perceiving the picture. Paintings, therefore, should not be hung opposite to lights, nor in any situation in which a line drawn from the place intended for spectators will make the same angle with the surface of the picture, as a line drawn from a window or other illuminating point; the angle of reflection being always equal to the angle of incidence. As a general rule, a picture will be in a bad light with regard to a spectator, whenever the image of a window could be seen by him in a looking-glass occupying the same place as the picture.

Transparency of Flame.—If two lamps be placed by the side of each other, the flame of the one, when clear of smoke, does not intercept the light of the other, and casts little or no shadow. Count Rumford found that the brilliancy of flame is, in some high ratio, proportionate to its elevation of temperature. If several concentric circular wicks, or several parallel flat wicks, be burnt near together, they produce more light, in consequence of the accumulation of heat, than they would do if burnt separately.

Glass Shades.—To relieve the eye from the glare of light, produced by bright lamps, shades of roughened glass are frequently used. A rough surface upon glass may be produced by grinding it with sand or emery, by corroding it with fluoric acid, or by covering it with powdered glass and exposing it to heat till the particles adhere. Glass shades have the effect to disperse the rays of light, by the numerous reflections and refractions which they occasion; till at length the light issues from all parts of their surface, and it appears as if the glass itself were the luminous body.

Sinumbral Lamp.—The reservoir of the sinumbral lamp is constructed on the same general principles with that of the astral. The ring, however, which holds the oil, is so formed as to oppose the smallest diameter of its section to the rays of light. A large shade of ground glass is used, which nearly incloses the light, and by the different refractions and reflections given to the rays by the ground glass, they escape in all directions, so that there is no perceptible shadow at a small distance from the ring. Reflectors are sometimes added, when it is desired to throw the principal mass of light in one direction.

Measurement of Light.—The following method of measuring the comparative illuminating power of different lights, is founded on the law, that the amount of rays thrown on a given surface, is inversely as the square of the distance of the illuminating body. Place two lights, which are to be compared with each other, at the distance of a few feet, or yards, from a screen of white paper, or a white wall. On holding a small card near the wall, two shadows will be projected on it, the darker one by the interception of the brighter light, and the fainter shadow by the interception of the duller light. Bring the fainter light nearer to the card, or remove the brighter light farther from it, till both shadows acquire the same intensity, which the eye can judge of with great precision, particularly from the conterminous shadows at the angles. Measure now the distances of the two lights from the wall or screen, and the squares of these distances will give the ratio of illumination. Thus if an argand flame and a candle stand at the distances of ten feet and four feet respectively, when their shadows are equally deep we have the square of ten and the square of four, or 100 and 16, as their relative quantities of light. In this experiment the spectator should be equidistant from each shadow.

Gas Lights.—In the flame of a common lamp or candle, the combustible matter is not burnt until it has first been converted into vapor, or inflammable gas. This gaseous matter is burnt as fast as it is generated, in consequence of being brought immediately in contact with the atmospheric air, and set on fire by the same heat which produces it. It is found, however, if certain combustibles be exposed to heat, and if the inflammable gas, which they yield, be kept separate from the atmospheric air, that this gas may be conveyed in pipes to any distance, and burnt for light in any place where a stream of it is discharged into the atmosphere. In this way various combustibles may be used which are not capable of being burnt in lamps, and a brilliant and economical light obtained from them. The materials chiefly employed for this purpose, are *pitcoal*, and animal *oil*. Various other substances are capable of supporting gas lights, such as bitumen, rosin, oleaginous vegetable seeds,* other oily or resinous bodies, and even wood, and turf.

* Professor Olmstead has found that cotton seed produces gas of a superior kind for purposes of illumination. See his account of this article in Silliman's Journal, vol. viii. p. 294, and x. 363.

The inflammable gas, which is procured from all these substances is chiefly carburetted hydrogen. Of this, two kinds are known, the first sometimes called olefiant gas, and the other subcarburetted hydrogen. Mr Brande, however, considers the last species as merely a mixture of the first with hydrogen. The fitness of a mixed gas for purposes of illumination, is dependent on the quantity of carburetted hydrogen which it contains, other things being equal.

Coal Gas.—The use of coal gas for puposes of illumination, appears to have been first introduced by Mr Murdoch, in 1792, although its power of affording a luminous flame was known much earlier. It is found that the bituminous coals, and particularly cannel coal, afford the most and the best illuminating gas. Some of the Anthracites, according to Professor Silliman, afford as much gas as Liverpool coal, but it burns with a feeble flame, and is unfit for the purposes of illumination.

In the manufacture of coal gas, the coal is placed in iron retorts, which are subjected to a strong heat in a furnace. The gas is thus driven off, mixed with the vapor of tar, oil, and ammoniacal water, and in this state is conducted by pipes first into a horizontal trunk of cast-iron, called the hydraulic main, and from thence into a condensing apparatus, surrounded with cold water, where the vapors of the tar, oil, and water, are condensed and fall down, while the gaseous product is conveyed along, containing several impure gases, such as sulphuretted hydrogen, and carbonic acid.

In order to separate the carburetted hydrogen from these impurities, various contrivances have been adopted. The usual method of purifying coal gas, is to make it pass through a mixture of lime and water, called *Cream of Lime*, which absorbs or combines with the contaminating gases. For this purpose, a considerable number of purifiers are erected, and the lime and water are kept in a state of constant agitation, either by a steam engine, or by one or two men, till the gas is rendered sufficiently pure. Sometimes the purification is effected by causing the gas to pass in contact with solid lime, newly slaked; and sometimes by passing it through retorts containing clippings of iron made red hot. When thus purified, the gas is conveyed by a pipe to the gasometer.

The *Gasometer*, is a large inverted vessel, made of malleable iron, or copper, either of a cylindrical or rectangular form, and suspended over a reservoir of water of a little larger size, by means of counter-weights. The gas is introduced by pipes ascending from the bottom of the reservoir, and rising a little above the surface of the water. While the gasometer is filling with gas, it gradually rises out of the water, until it is filled, after which no more gas is admitted, and its contents are ready to be distributed through the pipes by which it is to be conveyed to the place intended to be illuminated by burning it. As the gas is forced out by the weight of the gasometer, and is burned, the gasometer descends gradually in the water, till the whole of its contents are expelled, when it is again filled by the same process as before.

The gas being thus ready for use, must be carried off by pipes, the diameter of which is proportional to the degree of light required. It has been found that a pipe one inch in diameter, will, under a pressure of a column of water from five eighths to three fourths of an inch, supply gas equal to 100 candles; and if there was no friction, or mechanical impediment, the number of candles would be found for other diameters of pipe, by multiplying the square of the diameter of the pipe in inches by 100. The friction, however, or obstruction, diminishes so rapidly with the diameter of the pipe, that the number of candles is always greater than this rule gives. Thus a pipe three inches in diameter will supply light equal to 1000 candles—a pipe four inches, 2000—a pipe six inches, 5000—and a pipe ten inches, about 14,000.*

When the gas is to be burned in rooms, shops, or streets, it is allowed to escape through small circular apertures of from one fortieth to one sixtieth of an inch in diameter, which may

* Brewster's edition of Ferguson's Mechanics, vol. ii. p. 273.

be arranged in various ornamental ways, or disposed in a circle, like an argand burner, with a current of air running between them. The lights thus produced are equal, steady, and of the most brilliant kind. When the supply of gas is cut off, they are instantly extinguished. When it is restored, the invisible current flows out, and may be instantly lighted again by the contact of flame.

Oil Gas.—It has been long known to chemists, that wax, oil, tallow, &c., when passed through ignited tubes, are resolved into combustible gaseous matter, which burns with a bright light. Of late years this gas has been much used for purposes of illumination. Oil gas is considered in many respects superior to coal gas, and free from its inconveniences. The material from which it is produced containing no sulphur or other matter by which coal gas is contaminated, it never produces a suffocating smell in rooms; so that the costly operation of purifying the gas by lime, and other means, is avoided. Nothing is contained in oil gas which can injure the metal of which the conveyance pipes are made.

The oil gas has a further advantage over coal gas, in containing a greater proportion of carburetted hydrogen, so that one cubic foot of oil gas is said to go as far as two or three of coal gas. This circumstance is of impoitance, as it reduces in the same proportion, the size of the gasometers, which are necessary to contain it. Oil gas contains about 75 per cent. of carburetted hydrogen, while purified coal gas but seldom contains more than 40 per cent.

In procuring this gas, a quantity of oil is placed in an air-tight vessel, in such a manner, that it may pass slowly into retorts or iron tubes, which are kept at a moderate red heat. Fragments of coke or brick, are usually enclosed in the tubes. The oil, in its passage through the retorts, is principally decomposed, and converted into gas proper for illumination, carrying with it, however, some oil in the state of vapor. To purify the gas from this oil, which is suspended in it, and which occasions an empyreumatic smell, it is conveyed into wash vessels, where, by bubbling through water, or through fresh oil, it is cooled and rendered fit for use. It then passes by a proper pipe into a gasometer, from which it is suffered to pass off in pipes, in the usual manner, to its places of destination.

The poorest kinds of oil, which are unfit for burning in lamps, produce excellent gas. This is, indeed, the chief source of economy in the process.

According to Mr Brande, a light equal to ten wax candles for one hour, requires for its production, 2600 cubic inches of pure carburetted hydrogen, or olefiant gas, 4875 cubic inches of oil gas, or 13120 cubic inches of coal gas.

Gasmeter.—In dispensing gas for the illumination of particular rooms, it was found necessary to possess some method of measuring the quantity expended in each place. An ingenious instrument, called the gasmeter, has been introduced for this purpose. It consists of a horizontal cylinder partly filled with water, within which another cylinder revolves on an axis, having its interior surface divided into several compartments. These compartments, being successively filled with the gas, as it passes through, rise out of water like inverted buckets of an overshot wheel, and cause the inner cylinder to revolve. The number of revolutions is registered by machinery, and thus the quantity of gas which escapes in a given time is estimated.

Portable Gas Lights.—The magnitude and expense of gas works, prevents the use of them, except in cases where a large number of lights are wanted, within a convenient distance from the gasometer. The gas, however, may be conveyed to any distance, by condensing it in strong vessels of iron or copper, made of a small or portable size. The gas is forced into these vessels by a condensing pump, and when afterwards suffered to escape through a small orifice, is capable of supporting a flame for many hours. The economy, however, of this process has with reason been doubted.

Safety Lamp.—In coal mines an inflammable gas is generated, called *fire damp* by the miners, and composed chiefly of carburetted hydrogen. This gas, when mixed with atmospheric air is liable to take fire from the flame of a lamp or candle, and to explode with great violence. Terrible accidents have happened, and many lives have been destroyed, from these explosions. To prevent such accidents, several troublesome and circuitous modes of obtaining light were resorted to by the miners; such as striking sparks from a wheel, and inclosing a lamp within a tight lantern, which was supplied with air from a bellows. All these are now superseded by the *safety lamp* of Sir Humphrey Davy. This important invention consists simply of a lamp, the flame of which is wholly enclosed in a cylinder of fine wire gauze. Its operation depends on the principle discovered by Sir H. Davy, that explosive mixtures cannot be inflamed through minute apertures in metallic surfaces, or tissues. The wire gauze, being a powerful conductor and radiater of heat, cools a flame which is in contact with it, so as to deprive it of the power of producing an explosion on the other side. If this lamp be immersed in an explosive mixture, the gas will be inflamed, and burn on the inside of the gauze cylinder, but not on the outside. In these cases the flame of the lamp first enlarges, and is then extinguished, the whole of the cage being filled with a lambent blue light. If the supply of gas be withdrawn, this appearance gradually ceases, and the wick becomes rekindled.

Lamp without Flame.—This curious instrument may be made by winding upon the wick of a lamp containing alcohol, a fine wire of platinum, not more than a hundredth part of an inch in thickness. There should be about sixteen spiral turns, one half of which should surround the wick, and the other half rise above it. Having lighted the lamp for an instant, on blowing it out, the wire will become brightly ignited, and will continue to glow as long as any alcohol remains, without the blaze being any more renewed. The principle depends upon the slow combustion which is found to take place in inflammable or explosive mixtures, at a lower temperature than is necessary to produce inflammation. This combustion is not visible, but the heat is nevertheless sufficient to ignite minute solids exposed to its influence. In the lamp which has been described, the explosive mixture is the vapor of alcohol and atmospheric air. But the experiment may be varied, by using ether, camphor, &c., and by substituting platinum leaf for wire.

Modes of procuring Light.—To obtain light and fire, when wanted, in an expeditious manner, various instruments have been introduced, constructed on optical, mechanical, and chemical principles. The methods by which they operate are chiefly the following. 1. By concentration of the solar rays, as in the focus of a common lens, or burning glass. 2. By friction. Dry wood takes fire, if rubbed violently in the manner practised by savages, or if it be held against the surface of a wheel which revolves rapidly. Phosphorus takes fire by very slight friction, and on this account is used in the *phosphoric fire bottles*, the matches of which, after being charged with a minute quantity of phosphorus, take fire by rubbing them on the cork. 3. By percussion. When hard bodies, such as flint and steel, are brought into collision, small particles of ignited matter are struck off in the form of sparks, which are sufficiently hot to set fire to tinder, gunpowder, &c. Common firelocks, tinder-boxes, &c., operate on this principle. 4. By compression. If a piece of tinder is confined in a small cavity at the end of a condensing syringe, it will take fire, if the piston of the syringe be driven down with a stroke, so as suddenly to condense the air. The tinder commonly used for this purpose, is what is called German tinder, made of a fungus that grows on trees, *(Boletus igniarius)* boiled in a solution of nitre and dried. 5. By chemical action. In the *oxymuriatic fire boxes*, the matches are charged with chlorate of potash mixed with sulphur or some other combustible. When these are brought into contact with sulphuric acid, a violent chemical action takes place, and the match takes fire. Homberg's *pyrophorus* takes fire on exposure to the air. It may be made by calcining alum with less than an equal quantity of flour or sugar, until the smoke and flame disappear. It is then kept in close stopped bottles; and if a little of it be shaken out upon any light combustible, as cotton or tow, it causes it to inflame. The *platinum lights* depend on a remarkable property discovered by Dobereiner, in platinum, by which a sponge made of that metal, becomes ignited when exposed to a stream of hydrogen gas.

Accum, on Gas-light, 8vo. 1816;---Peckston, on Gas-lighting;---Rumford's Works;---Nicholson's Philosophical Journal, vol. i. 4to. vol. xiv. 8vo., &c.---Rees' Cyclopedia;—Ure's Chemical Dictionary.

CHAPTER X.

ARTS OF LOCOMOTION.

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 are brought to act against the ground. Sir Everard Home is of opinion that serpents use their ribs in the manner of legs,

* 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.

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, besause 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 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 ex-

* 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.

cepted, 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 centre 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

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

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

* If the plane on which a carriage moves, and the line of draught be both horizontal, the advantage for surmounting an immoveable 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.

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 require this direction. 2. The horse exerts a greater force in proportion as the line of draught passes near the fulcrum, 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

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

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

advantage as far as friction is concerned, when the line of direction makes an angle of about 18½ 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 14 or 15 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 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

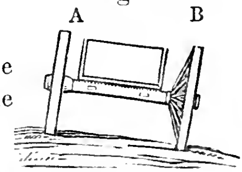
* Treatise on Mechanics, vol. ii. p. 18.

† 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.

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. 1, at the bottom of the 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 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.

Fig. 1.



In the opposite figure, A represents the cylindrical, and B the dished form of the wheel.

* This word, instead of *nave*, is so generally used in this country, that it

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 waggons 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

would be a useless refinement to avoid it. The same is true of the word *factory* for manufactory, and also of many mechanical terms.

* See a paper by Mr Gilbert, in Brande's Journal, vol. 19.

for any difference in the strength or activity of the animals. In Fig. 2, the centre 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 A B assumes the position C D, the foremost horse will have the disadvantage of acting by a lever equal only to E F, while the other horse acts by a lever equal to E C. 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 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. 3, where

Fig. 2.

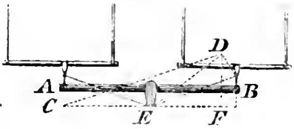
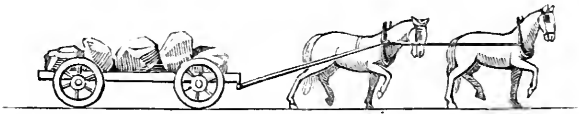


Fig. 3.



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

* 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.

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.*

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 laborious to pass; but in time, the stones become consolidated, and form a mass of great hardness, smoothness, and permanency. The 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.

* 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

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 shallow 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 340 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 inclosure, 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 500 feet, and the distance between the points of support, or centre of the piers, 560 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.

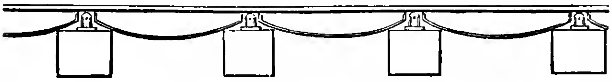
The object of a rail road is to furnish a hard, smooth, and unchanging surface for wheels to run upon. These surfaces, in most cases, consist of parallel rails of iron, raised a little above the general level of the ground, and having a gravelled road between the rails, so that the rail road combines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

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.

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 railways. Of the iron rail road, there are three principal varieties. 1. The Edge rail. 2. The Tram road. 3. The Single rail.

Edge Railway.—In this species, which is now preferred to all others, 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, when made of cast-iron, are commonly 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. 4 represents a side view of a common cast-iron railway. The ends of the rails are received in a piece of cast-iron, called a

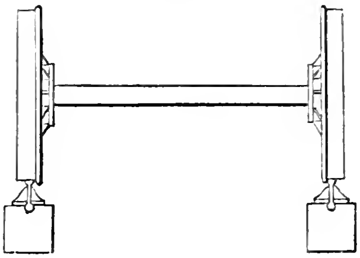
Fig. 4.



chair, and these chairs are affixed to large blocks of stone, with

* Treatise on Rail Roads and Carriages, p. 3.

Fig. 5.



a broad base, called *sleepers*, which are previously placed in the ground upon a proper level. Fig. 5 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 frequently made of wrought-iron with a form nearly similar to that which has been represented. 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 expensive.* Another and a better method has been adopted of laying straight bars of wrought-iron upon tracks of hammered granite. Wrought-iron rails have the advantage of reducing the number of joints, a circumstance which greatly increases the strength as well as smoothness of the road. The comparative durability of wrought, and of cast iron rails, is as yet not fully settled.

In the Liverpool and Manchester rail road, which is thirty three miles in length, the rails are made of wrought-iron, their shape being given them in a rolling-mill, by the method introduced by Mr Birkinshaw. The shape of these rails is somewhat different from the common form, the upper edge being considerably broader than the lower.

Tram Road.—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

* 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 and stone.

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.

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 railway, 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 railway, 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.*

Passings.—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 *sidelings*, for carriages to pass each other at convenient distances. But in both cases the travelling is liable to be retarded by the difficulty which exists, during a great part of the way, for carriages to pass each other when moving in the same direction, those of slow motion obstructing the progress of those which are intended for greater speed. In order to obviate this difficulty, and also to diminish the number of passing places, Mr Tread-

* A railway of this kind was invented, more than twenty years ago, by Henry Sargent, Esq. of Boston.

well proposes * to regulate the times of starting in both directions, and also the velocity of the faster and the slower carriages, by a uniform arrangement, so that they shall always move in concert, and meet at the passing places at stated times, and at no other times or places. By an easy calculation, the more rapid vehicles may be so regulated as to overtake the slower ones exactly at the passing places, and a coach moving at the rate of nine miles an hour, may experience no hindrance from a multitude of waggons moving with a third part of the velocity.

When forks in a rail road occur, at the passing places, or elsewhere, a part of the rails is rendered moveable, so as to direct the wheels upon either track. When the railway 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; but when the single rail crosses a road, a part of it must be made to swing open like a turnpike gate. Railways require to be kept as free as possible from dirt, which greatly increases the resistance. Mr Palmer found upon a tram road, that it required 19 per cent. more power to draw the same carriages when the rails were slightly covered with dust, than when they were swept clean.

Propelling Power.—Horses are extensively employed for drawing loads upon railways, a horse being supposed capable of drawing eight times as much as upon a common road. *Locomotive* steam engines are now much employed upon railways, particularly in England. 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, particularly by Messrs Brathwaite and

* Franklin Journal, vol. iv. p. 278.

Ericsson, in consequence of which they have been enabled to attain the extraordinary speed of thirty miles per hour. (See Steam Engine.)

It has been proposed to place stationary engines at short distances, which should draw carriages forward from one to the other by endless chains, thus saving the transportation of the engines. 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 they may be lifted perpendicularly, by pullies.

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 tracks 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

* 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.

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 insured 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 railways, 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 takes place, is commanded by a *lock*. Locks are tight oblong inclosures 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.

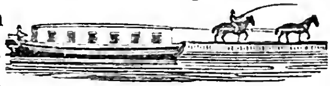
Locks are made of stone or brick, sometimes of wood. The walls are sometimes erected upon an inverted arch, and also upon piles, if the soil is alluvial, or loose. They are laid with hydraulic cement, and rendered impervious to water. The gates are commonly double, resembling folding doors, turning upon *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 pully. 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.*

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 pad-

Fig. 6.



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

dle wheels are 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 50 miles in length, 124 feet in width, at the surface of the water, 36 feet wide at bottom, and about 21 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 120 feet wide at the water surface, and 50 wide at bottom. The depth of water is 20 feet. The distance from sea to sea is about 59 miles, of which 37½ is lake navigation, and 21½ is cut.* The canal of Languedoc, in France, is 64 leagues in length, and connects the Atlantic ocean with the Mediterranean sea. It is 64 feet wide at the surface, and navigable for vessels of 100 tons. The great New York, or Erie Canal, is 360 miles long, and extends from the Hudson River, at Albany, to Lake Erie, at Buffalo. It is 40 feet wide at the surface, 28 feet wide at bottom, and has four feet depth of water.

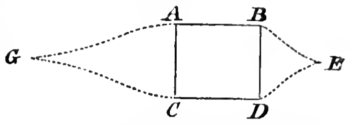
SAILING.

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

* Supplement to the Encyclopedia Britannica, and Edinburgh Encyclopedia.

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 A B C D, in Fig. 7, to move through the 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.

Fig. 7.



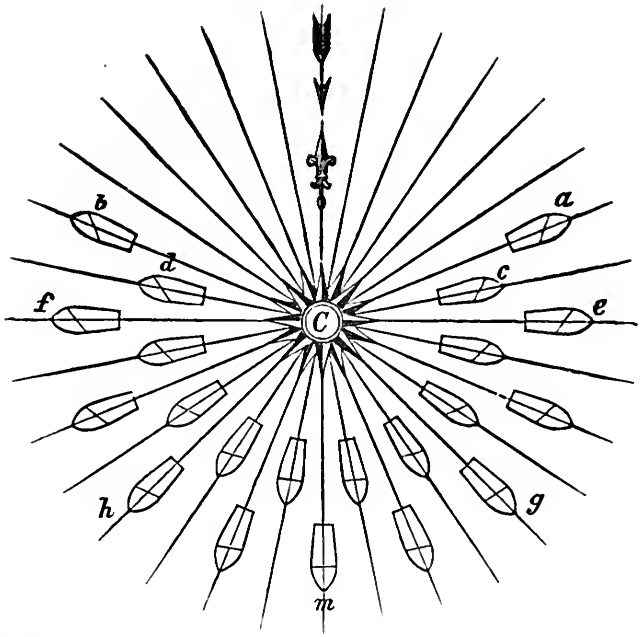
The principal part of the water which is before the moving body, divides and passes off by the sides; but a certain quantity of what is called *dead water*, is pushed along in advance of the moving body, nearly in the same manner as if it were a part of the body itself. The shape of this dead water at 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 B E D. 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 A G C. 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.

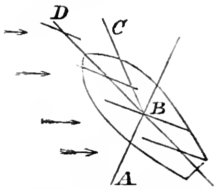
When a ship advances against the wind, and endeavors to proceed in the nearest direction possible to the point of compass from which the wind blows, she is said to be *close hauled*. A large ship will sail against the wind with her keel at an angle of six points, with the direction of the wind, and sloops 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. 8, where the direction of the wind is represented by the

Fig. 8.



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. 8, 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 favorable manner of sailing, because all the sails cooperate 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 A B, in Fig. 9. 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. 9, with the wind blowing in the direction of the arrows, and the sails set as represented, if the vessel were moving in a railway, or unchangeable channel, her course would be B D; but in the water she drifts so much to the leeward, that her real course is B C, and the angle C B D represents the amount of *leeway*.

Fig. 9.



Stability of a Ship.—The masts of a ship, when acted upon by the pressure of the wind against the sails, are so many

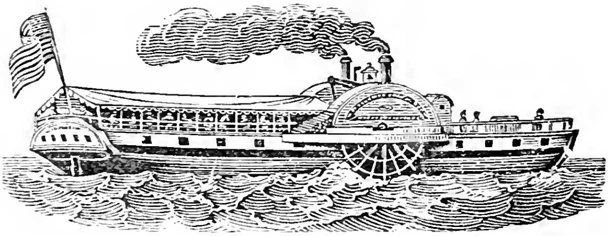
* Robinson's Mechanical Philosophy, vol. iv. p. 620.

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 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 have 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 the annexed figure.

Fig. 10.



The outline of the float-boards, or paddles, is commonly 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.* In Perkins' propelling wheel the paddles are placed obliquely in regard to the axis of the wheel, and the wheel itself is placed obliquely in regard to the keel of the boat. This arrangement 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.

Steam-boats are best adapted to the navigation of rivers and straits, or sounds, where the water is comparatively smooth. They are also used in the open sea; but the violence of the waves renders the action of the paddle wheels irregular, and it is found difficult for them to carry fuel sufficient to supply the engine during long voyages. These obstacles, however, have been in part surmounted, and steam-boats now ply along the coasts both of America and Europe. The steam-ship Savannah crossed the Atlantic, in 1819, and was 21 days from land to land, during 18 of which she was able to use her engine.

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 illustra-

* 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.

ted 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.

Submarine Navigation.—A machine was invented during

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

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 the boat, condensed into a strong copper globe, by which

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

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

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 300 miles; and persons have ascended to the height of 20,000 feet and upwards. The velocity of balloons varies with that of the wind, but has in some instances amounted to the rate of 70 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.

* M. Gay-Lussac, on the 6th of September, 1804, ascended 23,100 feet above Paris. M. Garnerin, September 21st, 1827, passed, in seven hours and a half, from Paris to Mount Tonnere, a distance of 300 miles. This voyago was performed in the night, and during a storm.

Garnerin, and with which he descended from a height of 2000 feet, at Paris, in 1797, was 25 feet in diameter. The parachute was folded up at the beginning of the fall, but soon expanded itself by the resistance of the atmosphere. The only inconvenience which was experienced, arose from a violent oscillating motion.

BREWSTER's Edition of Ferguson's Lectures on Mechanics, &c. 2 vols. 8vo. 1823;—ANSTICE on Wheel Carriages;—EDGEWORTH on Roads and Carriages, 8vo.;—DEPARCIEUX *sur le tirage des chevaux*, in the *Mem. de l'Acad.* Paris, 1760;—YOUNG's Lectures on Natural Philosophy;—McADAM, on roads, 8vo. 1823;—TREDGOLD, on Rail Roads, 8vo. 1825;—WOOD, on Rail Roads, 8vo. 1825;—STRICKLAND's Reports on Canals, Rail Roads, &c., oblong fol. Philad. 1820;—Article Canal, in Rees' Cyclopedia, written by Mr J. Farey;—Articles Navigation Inland, Railway, Bridges, Aeronautics, &c., in the Edinburgh Encyclopedia;—CHAPMAN on Canal Navigation, 4to. 1797;—FULTON on Canal Navigation, 4to. 1796;—SMEATON's Reports, 3 vols. 8vo. 1812; —PRONY, *Architecture Hydraulique*, 2 tom. 4to. 1790;—BELIDOR, *Architecture Hydraulique*, 4 tom. 4to. 1750;—DE CESSART, *Travaux Hydrauliques*, 2 tom. 4to. 1808;—Reports to the House of Commons on Roads, Steam-Boats, &c., 1822, &c.;—Article Seamanship, in the Encyclopedia Britannica, by Prof. Robinson;—DUPIN, *Voyage dans la Grand Bretange*, 6 vols. 8vo. with plates, fol. 1825.

CHAPTER XI.

ELEMENTS OF MACHINERY.

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. 1, they move in the same direction. If the band be crossed, as in Fig. 2, 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.

Fig. 1.

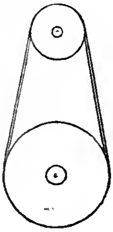
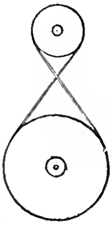
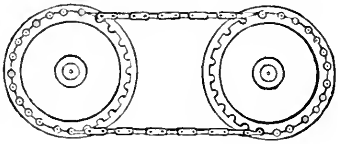


Fig. 2.



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. 3. They are used in locomotive steam engines, chain water wheels, &c.

Fig. 3.

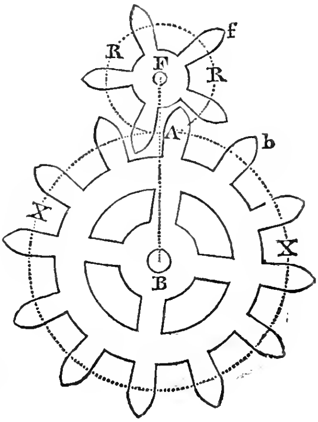


Toothed Wheels.—Toothed wheels afford a more regular and effectual mode of communicating rotary motion than any other kind of connecting mechanism. They move of necessity in opposite directions, and their relative velocity is inversely proportionate to their number of teeth. Thus if a wheel having forty 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.*

* 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.

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 pinion, more commonly, *leaves*. The name of *lanterns* is given to pinions with two heads connected by cylindrical teeth, or *trundles*. In Fig. 4, the line joining 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, F A and B A, which are to each other as the number of leaves in the pinion is to the number of teeth in the wheel; B A is called the *primitive radius* * of the wheel, and F A, the *primitive radius* of the pinion; while the lines or distances F f and B b are called the *true radii*. The circle X A X and R A R are called the *primtive circumferences*, and by workmen, the *pitch lines*.

Fig. 4.



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.

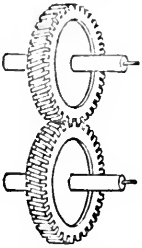
Spiral Gear.—In common cases, the teeth of wheels are cut across the circumference, in a direction parallel to the axis. In the spiral gear, now much used in cotton mills, in this country, the teeth are cut obliquely, so that if continued they would pass round the axis like the threads of a screw. In conse-

&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.

* Called the *proportional radius* by Buchanan.

quence of this disposition, the teeth come in contact only in the line of centres, and thus operate without friction. Fig. 5. The action 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.

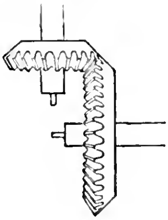
Fig. 5.



The spiral gearing has been applied to clockwork, 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.*

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. 6, and Fig. 12.

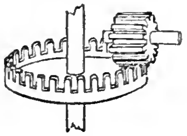
Fig. 6.



* 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.

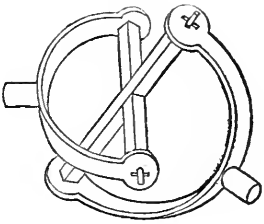
Crown Wheels.—Circular motion is also communicated at right angles, by means of teeth or cogs, situated parallel to the axis of the wheel. Wheels thus formed are denominated *crown* or *contrate* wheels. They act either upon a common pinion, or upon a *lantern*. The crown wheel is represented in Fig. 7. It is less in use than the bevel gear before described, having more friction.

Fig. 7.



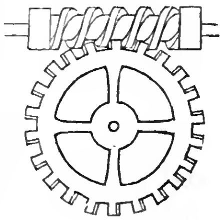
Universal Joint.—The contrivance called Hooke's universal joint, is sometimes used instead of wheels, to communicate circular motion in an oblique direction. It consists of two shafts, or axes, each terminating in a semicircle, and connected together by means of a cross, upon which each semicircle is hinged. Fig. 8. It is 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 40 degrees. By means of a double universal joint, circular motion may be communicated at an angle of from 50 to 90 degrees.

Fig. 8.



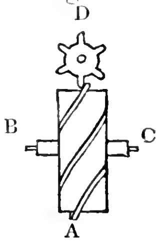
Perpetual Screw.—The perpetual or endless screw, sometimes called *worm* by mechanics, is made use of to convey circular motion from an axle to a toothed wheel, situated in the direction of the same plane with the axle. The relative velocity of a wheel driven by a screw is very slow; for if the screw have only a single thread, the wheel will advance the breadth of one tooth only for each 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. 9. The

Fig. 9.



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. 10. A is a wheel seen edgeways, its axis being B C. Its circumference is furnished with spiral ridges, which, as the wheel turns, cause the pinion D to revolve in the plane of the axis B C.

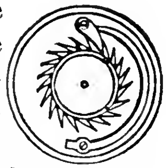
Fig. 10.



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. 11. Ratchet wheels are generally employed to prevent a weight raised by a machine from descending, and to obviate other retrograde movements.

Fig. 11.

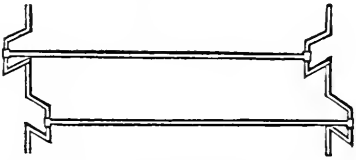


Distant Rotary Motion.—When it is required to transmit circular motion to a distance, for example from one extremity or story of a building to another, various methods are employed. The most common is by band wheels, or drums connected by leather belts of the requisite length. This mode

Fig. 12.

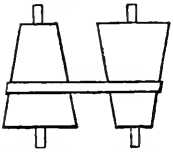
is considered most economical. When a precise velocity is required, a rolling shaft, geared at both ends, as in Fig. 12, is to be preferred. A double crank having its two parts at right angles with each other, and connected with a similar crank by stiff rods or bars, answers the same purpose, Fig. 13. If triple cranks are used, cords will serve instead of bars for connexion, 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.

Fig. 13.



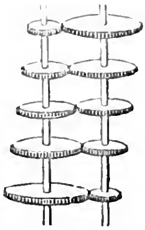
Change of Velocity.—It is sometimes necessary that a machine should be propelled with a velocity which is not equable, but which continually changes in a given ratio. This happens in cotton mills, where it is necessary that the speed of certain parts of the machinery should continually decrease from 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. 14.

Fig. 14.



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 moveable rod, which has a tooth projecting through a longitudinal slit in one side of the axis. This tooth serve to lock any one of the wheels, by entering a notch cut for its reception. Only one

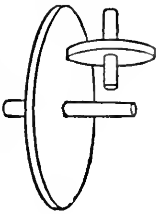
Fig. 15.



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. 15.

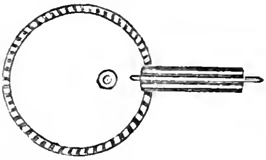
Another mode of changing speed is produced by a large and small wheel placed at right angles with each other, and acting by friction only. The edge of the smaller wheel is kept in close contact with the disc or flat surface of the larger wheel, so that the smaller wheel will revolve faster or slower, according to the distance at which it is kept from the centre of the larger wheel. The distance may be varied at pleasure. Fig. 16.

Fig. 16.



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

Fig. 17.

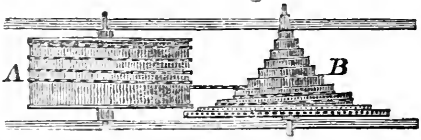


Fusee.—In the preceding arrangements for changing velocity, there is a corresponding change of force, which is in an inverse ratio to the change of velocity. They may therefore be employed for varying force, as well as speed. The fusee of a common watch is a contrivance adapted to this purpose. When a watch is recently wound up, the spring which propels it is

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

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 hyperbola; but the workmen have, in general, no other rule than that of habitual estimation. Fig. 18.

Fig. 18.

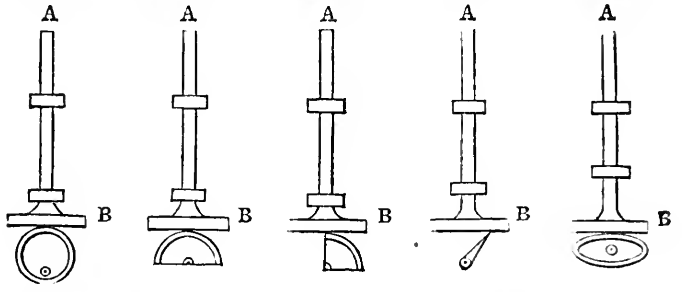


ALTERNATE OR RECIPROCATING MOTION.

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 sawmill. 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 moveable 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. 19, the sliding or reciprocating part, A B, 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. 20, 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. 21, the reciprocating part will remain at rest on the periphery during the first quarter of the revolution; 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. 22, 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. 23, causes two alternate move-

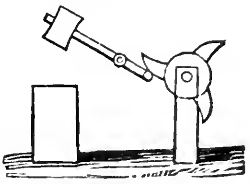
Fig. 19. *Fig.* 20. *Fig.* 21. *Fig.* 22. *Fig.* 23.



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

ments for each revolution; and the triple cam in Fig. 24, applied to a tilt, or trip 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.*

Fig. 24.



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.

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. 25, can only be used upon the end of an axis. The bell crank, Fig. 26, may be used in any part of an axis. The double crank, Fig. 27,

Fig. 25.

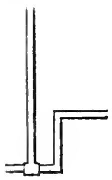


Fig. 26.

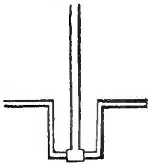
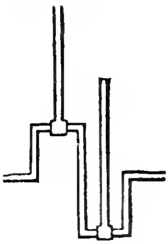


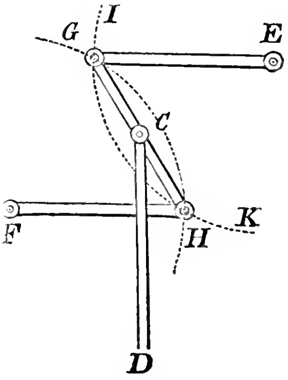
Fig. 27.



* 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.

produces two alternate 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 moveable 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. 28. C D is a rod moving back and forwards in a right line. Every point of junction is a hinge or joint. G E is a rod moveable about E as a centre; and F H a rod of the same length, moveable about F as a centre; these centres being equally distant from the path of C D. G H is a bar connecting these two rods, and having the rod C D attached by a joint to its centre. When the whole is set in motion, the joint G will describe the circular arc I K, and the joint H will describe the circular arc G H, 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 greater 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. 29.

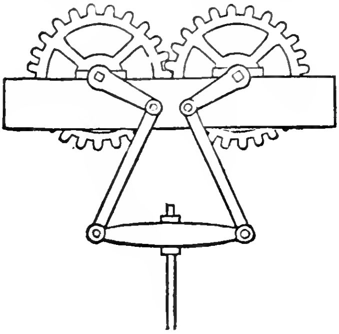
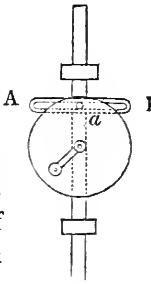


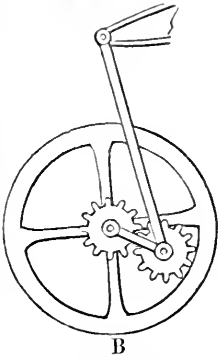
Fig. 30.



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. 30. The end of the crank, seen at *a*, in its revolution traverses the whole length of this groove which is cut in the crossbar A B, while the main bar C D has an alternate motion in the straight path to which it is confined. As the space of ascent or descent of the bar C D 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. 31, a 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.

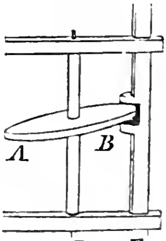
Fig. 31.



The necessity of this wi llbe 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.

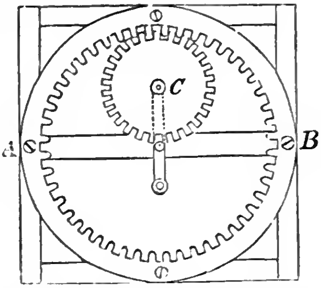
Inclined Wheel.—In Fig. 32, A B is a wheel placed obliquely on its axis C D. The edge, or periphery, of this wheel is received in a notch at B, of a sliding bar E F. As the wheel revolves, the bar E F will move up and down, once during each revolution. This reciprocal motion may be indefinitely varied by bending the edge of the wheel into different curves and angles.

Fig. 32.



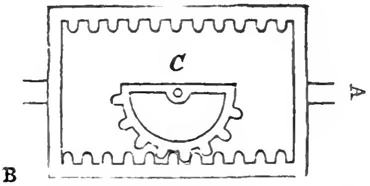
Epicycloidal Wheel.—A very beautiful method of converting circular into alternate motion, or alternate into circular, is shown in Fig. 33. A B is a fixed ring, or wheel, toothed on its inner side. C is a toothed wheel of half the diameter of the ring, revolving about the centre of the ring. While this 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.

Fig. 33.



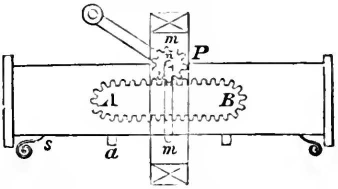
Rack and Segment.—If an alternating motion is required, the velocity of which shall be always equal, a rack is best adapted to produce this effect. In Fig. 34, A B is a parallelogram having a rack on two opposite sides. C is a half wheel toothed on its curved side, and having its centre equally distant 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.

Fig. 34.



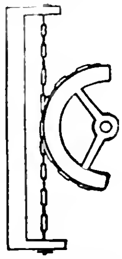
Rack and Pinion.—Another contrivance which renders the change more gradual, is represented in Fig. 35. A B is a double rack, with circular ends fixed to a beam, capable of moving in the direction of its length. The rack is driven by a pinion P, which is capable of moving up and down in a groove *m n*, cut in the cross-piece. When the pinion has moved the rack and beam until it comes to 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 *m n* 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*.

Fig. 35.



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. 36.

Fig. 36.



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. 37, 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. 38, 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. 37.

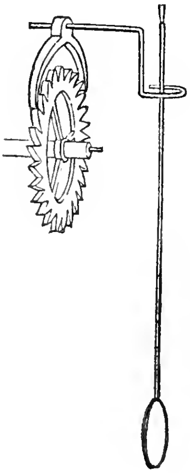
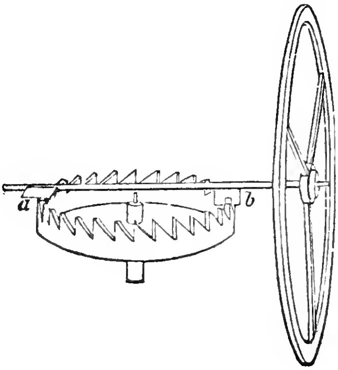


Fig. 38.



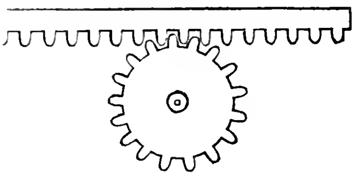
CONTINUED RECTILINEAR MOTION

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. 1. 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. 3, may be substituted.

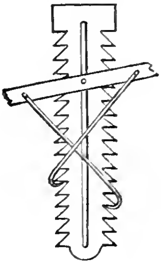
Rack.—If a slow rectilinear motion is required only for limited times, such a mechanism may be used as will permit the moving part to retrace its own path at intervals, and regain its original situation. Fig. 39. A *rack*, which is a straight bar having teeth on one side, will move in this manner if 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.

Fig. 39.



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 moveable 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. 40.

Fig. 40.

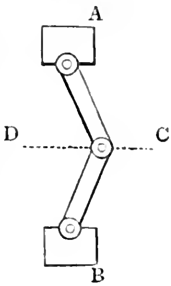


Screw.—A common screw is often made use of to produce rectilinear movements, when the motion is intended to be very slow, or when great power is required.

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, Pl. VIII, or to one at any other angle required. A bent lever like that represented by *y z* in Pl. IX, 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. 41, a moving force applied in the direction C D, acts with great and constantly increasing power to separate the parts A and B.

Fig. 41.



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 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 per-

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

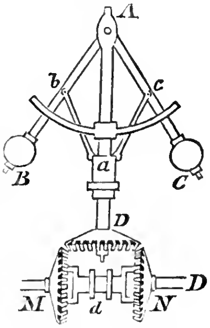
haps the simplest mode of engagement. They consist of two parallel band-wheels on the same axle, one of which is fast, and the other loose, or capable of turning without the axle. The band which communicates the power, is placed upon the loose pulley, when it is desired to stop the machine, and upon 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. 42. A B and A C 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 revolving shaft A D. At *a*, is a collar, or sliding box, connected to the levers by the rods *a b*, and *a c*, with joints at their extremities. It follows that when the weights B and C diverge, the collar *a* will move upward on the shaft A D, and *vice versa*. The governor thus constructed, is attached to some revolving part of the machine. In this state, if it

Fig. 42.



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 is as follows. The lower part of the shaft A D, 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

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

also to vary the distance of the millstones 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 with 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 improvement of the mechanist or engineer more frequently consists in the simplification of his means, than it does in the construction of complex and difficult pieces of workmanship.

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 XII.

OF THE MOVING FORCES USED IN THE ARTS.

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 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

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

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 17. In working at a pump, by 29. In pulling downward, as in the action of ringing a bell, by 39. And in pulling upward from the feet, as in rowing, by 41.*

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 continued. 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* 10 *pounds to the height of* 10 *feet once in a second, and continue this labor for* 10 *hours in the day.*†

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

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

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 197. 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 100, his force at three miles per hour will be 81,—at four miles per hour 64,—at five miles 49,—and at six miles 36. 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 33000 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.

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.

* Treatise on Rail Roads, p. 239.

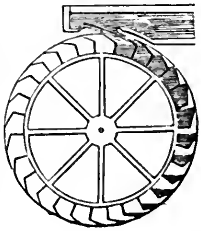
In some ferry boats and machines, horses are placed on a revolving platform, which passes backward under the feet whenever the horse exerts his strength in drawing against a fixed resistance, so that the horse propels the machinery without moving from his place. A horse may act within still narrower 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. 1, it will be seen that the buckets on one side of the wheel are erect, and will consequently become loaded with water; while those on the other

Fig. 1.



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 botton 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. 2, answers this purpose tolerably well, and from its simplicity is the one most commonly used, but it may be improved still farther by giving an additional inclination inward to the outer edge of the bucket, as seen in Fig. 3. 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.†

Fig. 2.

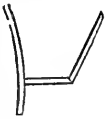
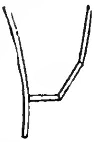


Fig. 3.



In order to prevent the inertia of the water, when it is first

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

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

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. 6. 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. 9.

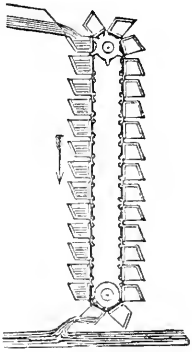
A difficulty often occurs in the entrance of water into the buckets, by the resistance of the air already in the bucket, which causes the water to regurgitate and spill. This evil may be entirely prevented by making the spout considerably narrower than the wheel, so as to leave room for the escape of 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 30 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 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. 4, where too rag 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

Fig. 4.



* Mechanical Philosophy, vol. ii. p. 690.

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.

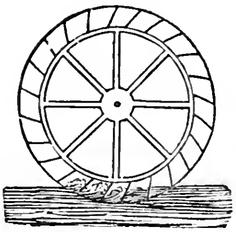
every part of their path the same mechanical effect to turn the wheels, and they do not allow the water to escape till they have reached almost the lowest part of the fall.

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 performance. 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.

Fig 5.



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. 5.

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 48 float-boards produced a greater effect than one with 24, and the latter a greater effect than one with 12. 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 24 in the wheel experimented on.§

* 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.

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 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 20 degrees, so that the lowest float-board shall not be perpendicular, but have its point turned up the stream about 20 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.

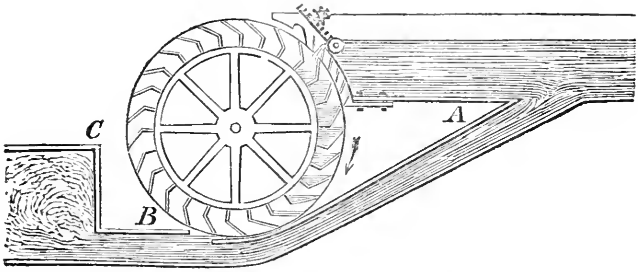
The best way of delivering the water on an undershot wheel in a close mill course, according to Dr Robison, is to let it slide down a very smooth channel without touching the wheel, till it arrives near the bottom, at which place the wheel should be exactly fitted to the course. The floats should be 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 past 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

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

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 Scotland. It consists in a separate passage by which a current of water is taken from the mill-lead, or flume, as at A in Fig. 6, and pass-

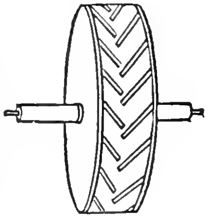
Fig. 6.



es 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.

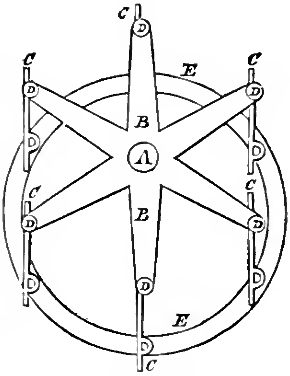
Besant's Wheel.—To diminish the retardation occasioned by back water, Mr Besant has invented a wheel in which the floats are placed obliquely in a double row, as in Fig. 7, where the wheel is represented as seen edgeways. Each pair of floats forms an acute angle, open at its vertex. By this construction 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.

Fig. 7.



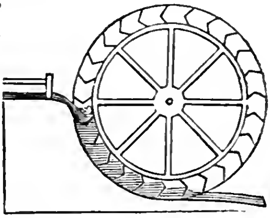
Lambert's Wheel.—As water acts most advantageously upon undershot wheels, when the floats are perpendicular to the surfaces of the stream, it has been attempted in different ways to keep them always in a vertical position. In the method proposed by Mr Lambert, the floats are hung upon hinges or pivots 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. 8, is a view of one side of the wheel with the ring attached. A is the centre of the wheel. B B are spokes or arms of the water wheel C D, C D are the float-boards which are here seen edgeways. E E 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.

Fig. 8.



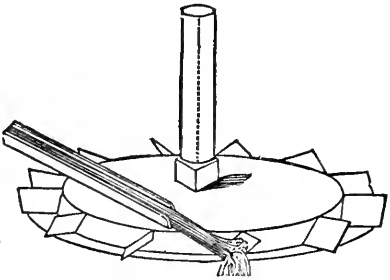
Breast Wheel.—The breast wheel is intermediate between the overshot and undershot wheels, having the water delivered upon it at about half its height, or at the level of its axis. In breast wheels in England, buckets are not commonly employed, but the float-boards are fitted accurately, with as little 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. 9, 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. 9.



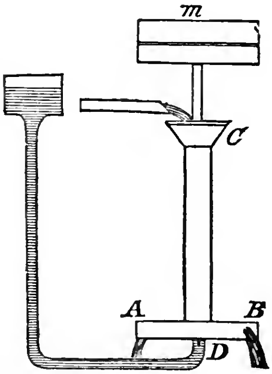
Horizontal Wheel.—A horizontal wheel with oblique floats, sometimes called in this country a *tub wheel*, is turned by a current of water discharged against the floats in the manner represented in Fig. 10. This method is said to be in common use on the continent of Europe, and but seldom employed in England. It is a disadvantageous mode of applying power, and is only recommended in corn-mills by its simplicity, the mill-stones 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.

Fig. 10.



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. 11, where C D is a revolving vertical tube, carrying a mill-stone *m* on the upper part of its axis. At the bottom of this tube is a horizontal tube A B, at the extremities of which are two apertures A and B, opening in opposite directions. A stream of water is introduced from the

Fig. 11.



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*.

In order to understand how this rotary motion is produced, we may suppose the apertures to be shut, and the tube C D 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 C D, and whose base is equal to the area of the apertures. Every part of the tube A B 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 C D, 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 E F D. 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 35½ 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 18 degrees, or less; in other words, that their angle with the axis should be 72 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 por-

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

tion 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 windwheel, to consist of four arms, and that the sails were connected to these arms at one edge, by 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 windwheel, 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 249, 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 windwheel 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 windwheel, or pair of sails, occupying the place of the vane, and situated at right angles with the principal windwheel. 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 wheelwork, they graduallybri ng 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 farther 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 1700 times its original volume,* so that a cubic inch of water furnishes about a cubic foot of steam, at 212 degrees 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 950 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

* 1633 times, according to Gay-Lussac. See Ure's Dictionary, article Caloric.—1711 times, according to Tredgold.

† 950, according to Watt.—967, Ure.

condensing into water, as soon as its temperature is reduced below 212 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 farther increase of temperature, it will continue to expand by the law which governs the increase of all gaseous bodies, and will double its volume once for every 480 degrees of Fahrenheit's thermometer.* And furthermore, if water itself be inclosed 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 212 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 250 degrees, of four atmospheres at 293 degrees, and of eight atmospheres at 344 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.†

* 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 20 atmospheres, is produced by a heat of about 418 degrees Fahrenheit, and one of 50 atmospheres by 510 degrees.

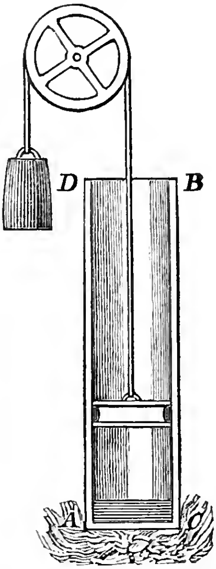
At temperatures below 212 degrees, steam has still a certain elastic force, which discovers itself whenever the pressure of the atmosphere is taken off. Thus its elastic force at 180 degrees is equal to about half an atmosphere; and it has some force at all temperatures above the freezing point.

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 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 moveable part to recede before it, and from this moveable part, motion is communicated to machinery. A hollow cylinder having a moveable 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

* Such was the engine of Branca, in the beginning of the 17th century.

Fig. 12.



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 in the margin. Suppose a cylindric vessel A B C D 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 A C; then as the water becomes converted into steam of slightly greater force than the atmospheric pressure, the piston 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 212 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 weightraised, 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 condense 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

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

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 secondly the *engine* in which it is directed and applied to use.

Boiler.—On account 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 surrounded by

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

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 semicylinder, 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 own fire, water, and steam, is represented in Pl. VIII. Fig. 5. 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, B B B B is the boiler, made of thick sheets or plates of rolled iron strongly rivetted 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 15 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 252. Its use is to regulate the supply of steam by closing the pipe, if the engine goes too fast, or by opening it, if it is too slow. F F 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 H H H H, 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 *a b*. At the other end of this lever is a wire *a c*, 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 *a b*, 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 cannot 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 P P, 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 incumbrance than that which the engine requires; and to prevent this danger, it is inclosed 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 has 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

* See Appendix.

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.

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.

Noncondensing Engine.—The simplest form of the steam engine, is that of the noncondensing, commmonly 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 30 or 40 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 cav-

* In Perkins' 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.

† See Tredgold on the steam engine, p. 181.

ity 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. IX. hereafter to be described. The figure there represented may be considered as a noncondensing 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, 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.

Noncondensing 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 is 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 re-admitted. 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. IX 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 *d d*, 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 Pl. VIII. The appendages represented in Pl. VIII. 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 rivetted together and tightened by hammering. If intended to contain salt water, the boiler is made of copper, to prevent corrosion.

C C C 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 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

G G, 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 *w x* and *y z*, and the connecting rods H *w x y* 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. XI, but has its moveable 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 the lever *r s*, 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, S S, and communicating with the cylinder by the pipe O. It has a valve or cock communicating with the cistern, and moved by the rod *g g*, through which a jet of cold water enters it for the purpose of condensing the steam.

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

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

Q Q 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.

R R 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 S S, 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 expansive.

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 some parts of England and Wales.

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. A valve of this kind is seen at V. in Pl. IX. *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. This is the case with the valve I, in Pl. IX. *Rotary* valves are usually constructed like common stopcocks, 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. See K, in Pl. IX.

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, as the valve *m* Pl. IX.

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 243. Another form is shown in Pl. IX, where the rod *a b* turns upon the joint *a* as a fixed centre, while the rod *c b* 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, 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 244. In some of Murray's engines, the epicycloidal movement was employed. See page 246.* In Maudslay's engine, and some others, instead of a beam, a crosss 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 moveable axis, and in Morey's engine, the cylinder revolves like a fly wheel, the piston being made to act on a fixed crank.

Historical Remarks.—The following are some of the most interesting facts in the history of the Steam Engine.

The ancient Greeks and Romans appear to have been acquainted with the power of steam to produce motion, and invented the eolipile, which was a close vessel containing water, and which gave out a forcible current of steam whenever the water was heated. The force of this current was used by Hero to produce a revolving motion.

The power of confined steam, acting by its pressure, was discovered by the Marquis of Worcester, and an account of its effect published by him in 1663. He produced a steam power sufficient to burst a cannon, and constructed a machine capable of raising water to the height of forty feet. He has not, however, left any drawings or particular description of his machine.

In 1698, a patent was granted to Thomas Savery, for a method of raising water by steam. This apparatus consisted

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

of a boiler, a separate steam vessel, and pipes commanded by valves. The steam from the boiler was first admitted so as to fill the steam vessel. It was then condensed, and the steam vessel filled with water which rose by the atmospheric pressure from the well or mine. The steam was then readmitted, and the water in the vessel was driven upward to the top of the pipes, and discharged.

About the year 1705, Thomas Newcomen, constructed a working steam engine, which has since been called the *atmospheric* engine. It contained a cylinder and piston, and an alternating beam, which was applied to raise water by working a pump. The water was condensed in the cylinder itself, and the valves were moved by hand, until an attendant contrived to make the machine move its own valves, by attaching strings to the working beam.

After this the steam engine continued without any important alteration, for more than half a century, when, about 1769, the discoveries and inventions of James Watt gave a new spring to the energies of this machine, and have more than doubled the power which it formerly possessed. Mr Watt's improvements were numerous and important, but those of greatest value were the following. 1. He introduced the separate condenser. 2. He applied the double action of steam by closing the top of the cylinder, and admitting the steam alternately at each end. 3. He converted to use the expansive power of steam, by cutting off the current before the end of the stroke. Mr Watt also invented the principle of the parallel motion, and applied the governor, to regulate the supply of steam.

In 1802, the first *high pressure* or *noncondensing* engines were constructed by Oliver Evans, in Philadelphia, and in the same year by Trevithick and Vivian, in England. The idea of such an engine had before occurred to Leupold, Watt, and others. The first steam carriage was put in motion on a railway, by Trevithick and Vivian, in 1805.

Steam navigation was suggested in England by Jonathan

Hulls, in 1736. It was first tried in practice by the Marquis de Jouffroy in France, in 1782, and nearly at the same time in America, by James Rumsey of Virginia, and John Fitch of Philadelphia. It was first made practically successful by Robert Fulton, at New York, in 1807. The first steam vessel which crossed the Atlantic, was the American ship Savannah, in 1819.

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 described in the following Chapter, which have been converted 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 noncondensing 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 173 degrees of Fahrenheit, sulphuric ether at 98 degrees, muriatic ether at 51 degrees,* sulphuret of carbon at 116 degrees, and oil gas liquid at 186; 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 212 degrees, has

* Ure's Dictionary.

an elastic force equal to about four atmospheres,* and sulphuric ether of nearly six atmospheres. But these advantages 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

* See Tredgold's tables, Steam Engine, p. 78—81.

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 required 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

* 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.

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 the rate of 24 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;—76 parts of nitre, 15 charcoal, and 9 sulphur, equal to 100. 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 1000 times greater than that of air under the ordinary pressure of the atmosphere. And allowing the pressure of the atmosphere to be 14¾ pounds upon every square inch, the initial force, or pressure, of fired gunpowder will be equal to at least 14,750 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 10,000 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 accelerating 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, *cetærus paribus*, 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 addititional 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.

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

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 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.

SMEATON's Miscellaneous papers, 4to. 1814;—ROBISON's Mechanical Philosophy, vol. 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 XIII.

ARTS OF CONVEYING WATER.

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

* 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 Architecturâ, Lib. viii.

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 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 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

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

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 frustrum 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.

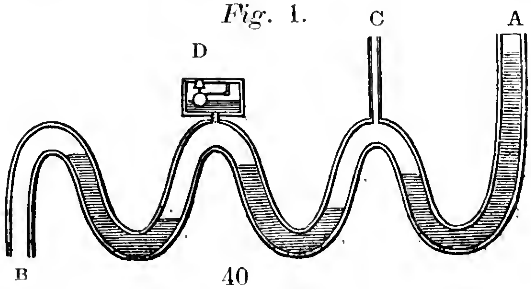
Obstruction of Pipes.—Water pipes are liable to be obstructed, chiefly by the following circumstances. 1. By the freezing of the water in winter, if the pipe has not been laid sufficiently deep. 2. By the deposition of sand and mud in the lower parts of the pipe. To obviate this, the water should pass 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 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

* See Edinburgh Encyclopedia, Art. *Hydrodynamics*, pp. 491, 495.

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. 1, A B repre-

Fig. 1.



sents an undulating pipe, of which 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 34 feet.

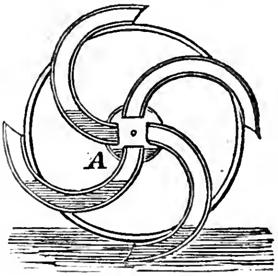
For practical use the longer leg of the syphon is often closed with a stop cock, and the air exhausted from it by a small pump, till the leg is full. The stop cock is then opened, and the fluid immediately flows through the syphon.

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. 2. In the latter case it is necessary that they 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 Virtruvius, which was somewhat similar in its principle to the scoop wheel.

Fig. 2.



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.

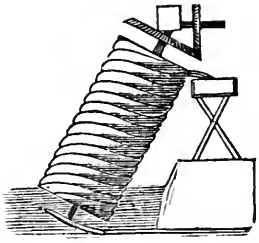
Noria.—The machine used in Spain under the name of noria, consists of revolving buckets like the Persian wheel. But instead of a single wheel, two drums, or trundles, are employed, and the buckets are attached to ropes or chains passing round them. In Spain, earthen pitchers are said to be used, but 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 264, 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 8 or 10 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 mean while 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. 3, but at the same time, in consequence of the revolutions of the screw, it passes continually upward until it is delivered at the highest end.

Fig. 3.

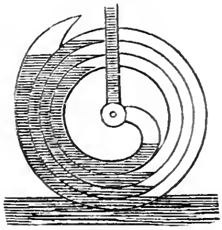


This instrument is sometimes made by fixing a spiral partition round a cylinder, and covering it with an external coating, either of wood or of metal. It should be so placed with respect to the surface of the water, as to fill in each turn one half of a convolution; for when the orifice remains always immersed, its effect is much diminished. It is generally inclined to the horizon in an angle of between 45 and 60 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. 4, or in a cylindrical or conical 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 pos-

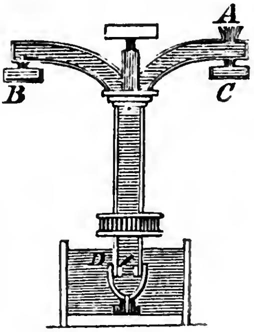
Fig. 4.



sible. 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. 5, a centrifugal pump is represented. The machine is first filled with 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.

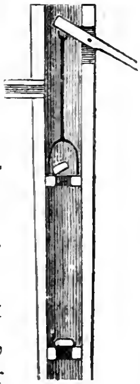
Fig. 5.



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 rotation. In the pumps most commonly used, a cavity is enlarged and contracted by turns, the water being admitted into it through one valve, and discharged through another.

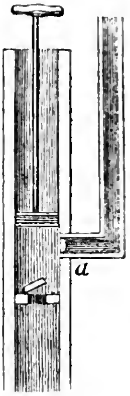
The common *household pump* has otherwise been called the *sucking pump*, from the circumstance that the water is raised in it, by the pressure of the atmosphere. In this country, pumps are made for common use, both in wells, and in ships, by boring logs so as to produce a large hollow, and inserting 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 moveable 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. 6, this pump is represented 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 34 feet below the upper valve, and in practice a much shorter limit is commonly assigned.

Fig. 6.



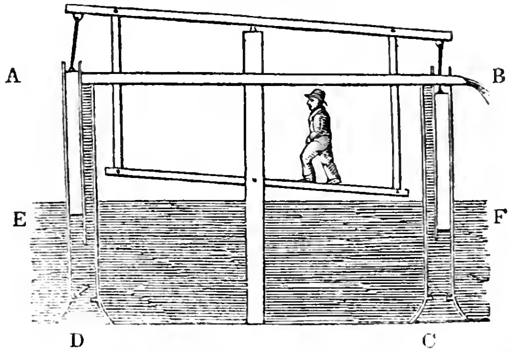
Forcing Pump.—The forcing pump differs from the common sucking pump just described, in having a solid piston without a valve, and the spout, or discharging orifice, placed below the piston. When the piston is raised, the lower valve of the pump rises and admits the water from below, as in the common 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. 7. In a forcing pump the water cannot be brought from a depth of more than 34 feet below the piston, but it can afterwards be sent up to any height desired, in a pipe *a b*, 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.

Fig. 7. b.



Plunger Pump.—A very effectual pump for raising a large quantity of water to a small height, is shown in Fig. 8.

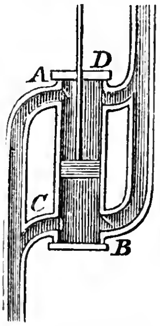
Fig. 8.



It is made by fitting two upright beams or plungers, A and B, of equal thickness throughout, into cavities 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 30 pounds, has been able to raise 580 pounds of water every minute, to a height of 11½ 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 11 pounds raised through 10 feet in a second, instead of 10 pounds, which is a fair estimate of the usual force of a man, without any deduction for friction.

Delahire's Pump.—A pump, partaking of the nature of a forcing and a sucking pump, is sometimes called a *mixed* pump. In Delahire's pump, which is of this kind, and shown in Fig. 9, the same piston is made to serve 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.

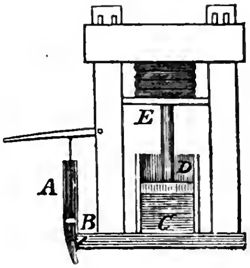
Fig. 9.



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 reinvented 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. 10, the water is forced by the pump A through the 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.

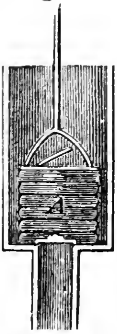
Fig. 10.



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 moveable 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. 11, A 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.

Fig. 11.



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. 12, and the water may be forced 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. 12.

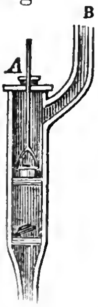
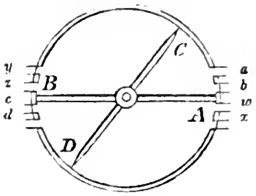


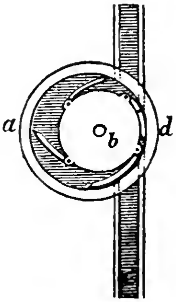
Fig. 13.



Rolling Pump.—A pump of this kind is formed by a barrel, or hollow cylinder, shown in section in Fig. 13, having two partitions. One of these, A B, is fixed, and the other, C D, is composed of two wings, or valves, capable of an alternate motion about the axis of the cylinder. When the partition C D 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 C D 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.

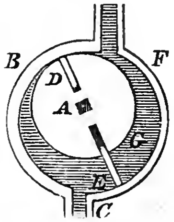
Fig. 14.



Eccentric Pump.—The eccentric pump, a section of which is shown at Fig. 14, consists of a hollow cylinder *a d*, 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. 15.



Another form of an eccentric pump, is seen in Fig. 15. The roller, or solid cylinder, A, revolving within the reservoir, or hollow cylinder, B F, carries with it the slider, D E, 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.

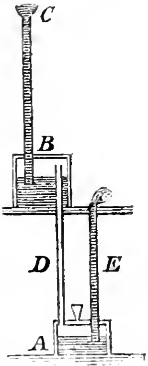
Arrangement of Pipes.—The pipes, through which water is raised, by pumps of any kind, ought to be as short and as straight as possible. Thus, if we have to raise water to a height of 20 feet, and to carry it to a horizontal distance of 100, by means of a forcing pump, it will be more advantageous to raise it first vertically into a cistern 20 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.

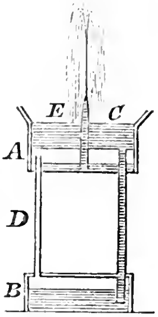
Schemnitz Vessels, or Hungarian Machine.—The mediation of a portion of air, is employed for raising water, not only in the spiral pump, but also in the air vessels of Schemnitz, in the manner shown in Fig. 16. A column of water, descending through a pipe C, into a closed reservoir B, containing air, 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 34 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.

Fig. 16.



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

Fig. 17.



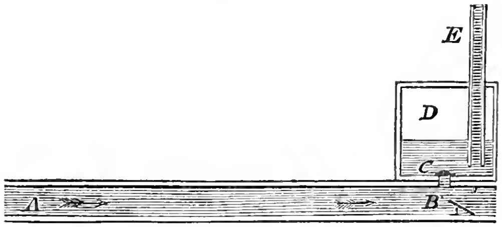
project it upwards in the form of a jet, as in Fig. 17. The first reservoir C of the fountain is lower than the orifice of the jet. A pipe descends from it to the air vessel, B, which is at some distance below, and the pressure of the air is communicated, by an ascending tube, D, to a third cavity, A, 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 181.

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. 18 represents this machine. When the water in the

Fig. 18.



pipe A B has acquired sufficient velocity, it raises the valve B, which immediately stops its further passage. The momentum which the water has acquired will then 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 9 inches in diameter, to the height of sixty feet, and the fall of the returning water produces a concussion sufficient to shake the ground.

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

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 33 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 66 feet, and would throw it to nearly the same height 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 moveable 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 with much velocity, they are capable of throwing the water to a still higher level.

ROBISON's Mechanical Philosophy, Articles Theory of Rivers, Water Works, &c.;—GREGORY's Mechanics, vol. i.;—YOUNG's Natural Philosophy, vol. i.;—BOSSUT *Traité Theoretique et Experimental d' Hydrodynamique*, 1771, &c.;—DU BUAT *Traité d' Hydraulique, et Pyrodynamique*, 1786, &c.;—VENTURI, *Réecherches Experimentales sur les Fluides*, 1797;—REES' Cyclopedia, article Water;—Edinburgh Encyclopedia, article Hydrodynamics;—And the Hydraulic Works of MARIOTTE, GUGLIELMINI, MICHELOTTI, D. and J. BERNOULLI, D'ALEMBERT, FONTANA, M. YOUNG, PRONY, VINCE, JUAN, EYTELWEIN, &c.

CHAPTER XIV.

ARTS OF DIVIDING AND UNITING SOLID BODIES.

Cohesion.—THE attraction of cohesion, which retains together the particles of solid bodies, is the foundation of their strength. It exists in all solids, though in different degrees; and requires, before it can be overcome, the application of force or of art, adapted to the strength and character of the particular body. In some substances, cohesion, when once overcome, cannot be reproduced in its original state. In others it may be restored by the intervention of fluidity, and in all, its effects may be imitated by mechanical arrangements. The various modes by which bodies may be divided, or united, have an important agency in mechanical constructions, and other processes of art.

MODES OF DIVISION.

Fracture.—The simplest and least artificial mode by which mechanical division is effected, is by breaking. The circumstances which influence the production of fracture by extension, compression, lateral strain, and torsion, have been considered in the second chapter of this work. In general, a force acting suddenly is more liable to occasion fracture, than one which acts more gradually; for in this case the parts which are first strained may give way, before the stress is proportionally distributed among the remaining parts. A mass of plastic clay, or of warm sealing wax, will bear to be gradually bent, but will break if the motion is sudden. In like manner, percussion occasions fracture more readily than pressure. A crack, or partial fracture, in a body, greatly promotes the separation of the remainder, whenever a lateral force is applied; because the strength of the small parts tends to throw the strain more immediately upon the weakened points, as explained on page 48.

Cutting.—Cutting instruments act, in dividing bodies, upon the same principle as the wedge. The blade of the instrument is in general a thin wedge, but the edge itself is usually much more obtuse. Mr Nicholson has estimated the angle which is formed ultimately by the finest cutting edge, at about 56 degrees. If the edge of an instrument were not angular, but rounded or square, it would still act as a wedge, by pushing before it a wedge-shaped portion of the opposing particles, as is done by obtuse bodies moving in fluids. In general an oblique motion is more favorable to cutting than a direct, and this is because the edges of steel instruments are rough with minute asperities, like saw teeth. This circumstance, however, is of less importance when the material operated upon is very firm and the cutting is deep; for in this case the friction and compression consume more force, than the actual division. This takes place with axes and chisels, which are necessarily made thick, to secure the requisite strength.

The quality in tools which is called *temper*, is opposed to brittleness on the one hand and to flexibility on the other. Independently of the quality of the metal, it appears to be somewhat influenced by temperature, since axes and other tools are liable to break, or gap, in frosty weather, and razors cut best after being immersed in hot water.

The kind of cutting which is performed by scissors, depends upon the process called *detrusion*, in which the coherent particles are pushed by each other in opposite directions. In this case, the cutting edges require to be angular, but the angle not very acute. The shearing of woollen cloths, the slitting and punching of metals, the cutting of nails, and various other mechanical processes, are performed on this principle.

Cutting Machines.—A variety of fibrous and woody substances, used by druggists and dyers, require to be reduced to a coarse powder like saw dust, to facilitate the extraction of their soluble matter. This is not easily done in any of the common mills, owing to the toughness of the material. It is sometimes effected by machinery with circular rasps or saws, but a more economical application of a dividing force in these cases, is obtained by the rapid revolutions of a sharp cutting instrument. In a machine for cutting straw, a number of blades revolve upon an axis, with a fly. In Bramah's *surface planing machinery*, and in Blanchard's ingenious engine for cutting definite forms by a pattern, sharp instruments of different forms, are made to revolve upon axles, or slide in grooves, while the material operated on is put in motion, so as to place itself in the proper position to receive the cut.

Penetration.—Bodies are penetrated either by pushing aside a portion of their substance, as in driving a nail; or by removing a portion, as in boring and drilling. In addition to the force of cohesion, the resistance opposed by a solid, or even by a soft substance, to the motion of a body tending to penetrate it, appears to resemble, in some measure, the force of friction, which is nearly uniform, whether the motion be slow or rapid, destroying a certain quantity of momentum in a certain time, whatever the whole velocity may be, or whatever may be the space described. Hence arises an advantage in giving a great velocity to a body which is to penetrate another, since the distance to which a body penetrates will be nearly as the square of its velocity.* The same remark applies equally to the action of cutting instruments. The effect of a hammer in driving a nail, depends partly on the influence of velocity in modifying friction, and partly upon the momentum accumulated in the hammer, the effect of which resembles that of a fly wheel.

Boring and Drilling.—The processes of boring and drilling, performed by gimlets, augers, centrebits, drills, &c., is a species of circular cutting, in which a cylindrical portion of the sub-

* See Young's Natural Philosophy, vol. i. p. 225, and Playfair's, vol. i. p. 97.

stance is gradually removed. Drills are made to turn rapidly, either in one direction by means of a lathe wheel and pulley, or alternately in opposite directions, by a spiral cord which coils and uncoils itself successively upon the drill, and is aided by a weight or fly. In boring cannon, the tool is at rest, while the cannon revolves, and by this arrangement the bore of the cannon is formed with more accuracy than according to the old method of putting the borer in motion, perhaps because the inertia of so large a mass of matter assists in defining the axis of the revolution with more accuracy. The borer is kept pressed against the cannon by a regular force. Cylinders of steam engines are cast hollow, and afterwards bored; but in this case the borer revolves, and the cylinder remains at rest. In either case, it is important that the axis of the borer, and that of the cylindrical material, should coincide; for when it is otherwise, if the borer revolves, it will perforate obliquely, and if the material revolves, the perforation will be conical.

Turning.—Turning is an elegant operation, used to produce regular figures, the section of which is circular. Like boring, it is a species of circular cutting, and is performed in a well known machine called a *lathe*, in which the material to be cut revolves about its axis, while the tool is kept stationary and supported by a rest. Besides circular forms, it may also be used to produce regular curvilinear figures, which may be multiplied indefinitely. The effect of most lathes of complicated construction, depends on a certain degree of motion, of which the axis is capable. If this motion be governed by a frame producing an elliptic curve, any number of ovals having the same centre may be described at once; and if a moveable point connected with the work, be pressed by a strong spring against a pattern of any kind, placed at one end of the axis, a copy of the same form may be made at the other end of the axis. Geometrical lathes, governed by eccentric wheels, and capable of describing an indefinite variety of complex figures, upon a metallic plate, are used for bank notes and ornamental designs.

Attrition.—The action of files, rasps, grindstones, and hones, consists in successively cutting or breaking away minute particles from the surface of bodies. They are used chiefly for wearing off portions of hard substances, particularly metals. The surface of grindstones and whetstones, is kept moist with water or oil, the use of which is not so much to obviate the production of heat by friction, as to prevent the adhesion of foreign particles from filling up the interstices of the grit. In the finer kinds of grinding and polishing, certain hard substances are used in the form of powder, such as emery, tripoli, sand, putty, oxide of iron, &c.

Sawing.—*Saw Mill.*—A saw, in many respects, resembles a rasp, and acts by cutting or breaking away large particles in the direction of its own plane. The thinner the saw is, the easier is the operation, since a smaller amount of substance is removed by the teeth. For the sake of this advantage, and for economy of the material, the blades of saws are made thin, and often stretched upon frames, to compensate the want of rigidity. Saw mills erected for cutting logs into boards, consist usually of saws attached to frames, which have a reciprocating motion communicated to them by a crank connected with a water wheel or steam engine. A ratchet wheel is connected with the saw by means of a bar and click; so that at every stroke of the saw, the wheel is turned the length of one tooth. The ratchet wheel acts by means of a rack, upon a carriage, which supports the log, causing it slowly to advance, until the whole length of the log has passed the saw.

Circular Saw.—Circular saws, revolving upon an axis, have the advantage that they act continually in the same direction, and no force is lost by a backward stroke. They also are susceptible of much greater velocity than the reciprocating saws, an advantage which enables them to cut more smoothly. The size of circular saws, however, is limited; for, if made too large, and of the usual thinness, they are liable to waver, and bend out of their proper plane; and, on the other hand, if made thick enough to secure an adequate degree of strength, they waste both the power and the material, by cutting away too much. Hence, they are not commonly applied to the slitting of large timber, but are nevertheless very useful in smaller works, for cutting off bodies which can be included within a certain distance of the axis, and thus allow the saw to be of small size. Circular saws, however, of large size, are used in cutting thin layers of mahogany for *veneering;* for in this case the saw can be strengthened by thickening it on one side towards the centre, the flexibility of the layer of wood allowing it to turn aside, as fast as it is sawn off. Circular saws may be rendered more steady by giving them a greater velocity, so that the centrifugal force shall assist in confining the saw to its proper plane.

An ingenious machine has been invented in Maine, for sawing off sheets of wood of an indefinite length, for veneering, by cutting a spiral layer from the surface of a cylindrical log, the layer being turned off like a ribbon when unwound from a roller. The sheets of *rice paper*, mentioned on page 56, *note*, are said to be cut in the same spiral manner.

The sawing of marble is performed by saws made of soft iron, and without teeth. A quantity of sand and water is kept interposed between them, and the sand, becoming partly imbedded in the iron, serves to grind away the marble. These saws are worked horizontally for the convenience of retaining the sand, and are moved either by hand, or by reciprocating machinery. The cylindrical blocks which form the tambours, or frusta, of columns, are sometimes cut out of marble, by perforating the block at the centre, and inserting an iron axis, to the ends of which are attached frames, upon which a narrow or a concave saw is stretched parallel to the axis. An alternating motion is then given to the frame, until the saw has cut its way round the axis.

Crushing.—When materials require to be broken into minute parts, or when the texture of vascular substances is to be destroyed, that they may yield their fluid contents, the operation of crushing is resorted to. It is performed either by percussion, with hammers, stampers, and pestles, or by simple pressure, with weights, rollers, and runner stones.

Stamping Mill.—For reducing the ores of metals to powder, a number of heavy vertical bars, called stampers, are alternately raised, and suffered to fall, by the action of cams, or wipers, projecting from the arbor of the mill wheel. The ore is placed in a trough or mortar beneath, where it is acted upon by the stampers until it is sufficiently comminuted. A stream of water continually runs through the stamping trough, carrying with it the particles, which have become fine enough to pass through a screen provided for the purpose.

Bark Mill.—The bark used by tanners is reduced to a coarse powder in various ways. One of the most common methods, is to crush the bark by the revolutions of a circular stone, called a *runner stone*, which resembles the wheel of a carriage, travelling round in a continued circuit. The axis of the stone is connected with a vertical shaft, so that the stone has two motions, one round its own axis, which is horizontal, and the other round the vertical shaft. The bark is raked up into a ridge before the stone, and is crushed or ground up, by the edge of the stone rolling over it. In some more complicated mills, the bark is successively cut with knives, beaten with hammers, and ground with stones, or cylinders.

Oil Mill.—The oleaginous seeds from which oil is expressed, require to have their substance previously broken up by the operations of a mill. In one of the best forms of the oil mill, the seeds are first bruised to the consistence of paste, by the action of runner stones. The paste is received in troughs perforated with holes, through which a portion of the oil drips, and this part is considered the most pure. The paste is then put into strong bags, and subjected to pressure as long as it yields oil. The remaining paste, or *oil cake*, is next taken out of the bags, broken to pieces, and put into mortars. It is here beaten by the action of heavy stampers, until reduced to a very minute state of subdivision. The oil which is next pressed out from it, is inferior in quality to the first, in consequence of its containing more mucilage and farinaceous particles. The seeds are nevertheless subjected to another pressure, after having been exposed to heat, which enables them to yield a quantity more of oil, but of a still poorer quality.

Sugar Mill.—The machine by which sugar canes are crushed, usually consists of three vertical rollers, the middle one of which is turned by a horse, or other power, and turns the remaining two by friction, or by toothed wheels; the latter method being most advantageous. The canes are supplied by attendants, and are drawn in and crushed between the first and second rollers, after which they return and pass between the second and third. The juice which is pressed out by the same operation, flows into a trough beneath.

Cider Mill.—When the substances to be crushed are so large that they cannot readily be drawn in between smooth cylinders, it is necessary that the rollers should be indented at their circumference. The common cider mill is formed with two indented cylinders, the teeth of one of which enter the indentations of the other. By this arrangement, the fruit to be ground is caught by the projecting parts of the rollers, and regularly carried forward and crushed. Formerly it was the custom to grind apples by runner stones, similar to those used in bark mills. And at the present day cylindrical rasps are sometimes employed, being supposed capable of destroying the texture of the fruit more effectually.

Grinding.—Grinding, in its most limited sense, may be considered as a species of crushing, or breaking, in which the force acts partly in a lateral direction, so as to lacerate, rather than compress the material acted upon. It is frequently produced in small mills, by a cylinder or cone, turning within another, which is hollow, the surfaces of both being cut obliquely into teeth. In larger mills, it is commonly performed by one stone moving upon another.

Grist Mill.—The common mill for grinding grain, is constructed with two circular stones placed horizontally. Buhrstone is the best material of which mill stones are made, but sienite and granite are frequently used, for indian corn and rye. The lower stone is fixed, while the upper one revolves with considerable velocity, and is supported by an axis passing through the lower stone, the distance between the two being capable of adjustment, according to the fineness which it is intended to produce in the meal, or flour. When the diameter is five feet, the stone may make about 90 revolutions in a minute, without the flour becoming too much heated. The corn or grain is shaken out of a hopper by means of projections from the revolving axis, which give to its lower part or feeder, a vibrating motion. The lower stone is slightly convex, and the upper one somewhat more concave, so that the corn which enters at the middle of the stone, passes outward for a short distance, before it begins to be ground. After being reduced to powder, it is discharged at the circumference, its escape being favored by the centrifugal force, and by the convexity of the lower stone. The surface of the stones is cut into grooves, in order to make them act more readily and effectually on the corn; and these grooves are cut obliquely, that they may assist the escape of the meal, by throwing it outward. The operation of *bolting*, by which the flour is separated from the bran, or coarser particles, is performed by a cylindrical sieve placed in an inclined position, and turned by machinery. The fineness of flour is said to be greatest when the bran has not been too much subdivided, so that it may be more readily separated by bolting. This takes place when the grinding has been performed more by the action of the particles upon each other, than by the grit of the stone. For this sort of grinding, the buhrstone is peculiarly suited.

Color Mill.—The various coloring substances used by painters, when they are not soluble in oil or water, require to be reduced to an impalpable powder by grinding. This is commonly performed upon a smooth stone slab, by trituration with another stone, called a *muller*. When the grinding is performed by machinery, a large muller of the shape of a pear, having a groove cut in it for the admission of the paint, is made to revolve in a mortar, the bottom of which is of a corresponding shape. In some color mills a horizontal stone cylinder revolves in contact with another stone, which is concave, and covers a part of its convex surface. In most cases, the substance to be ground is mixed with oil or water. As some of the substances used for pigments are of a poisonous character, they should be ground in close cavities, or under water.

MODES OF UNION.

Insertion.—The mechanical modes of attaching bodies to each other, usually consist in the insertion of their parts among each other, or in the application of other substances specially adapted for the purpose of connexion. Insertion is performed by various modes, the principal of which are, 1. *Mortising*, in which the projecting extremity of one timber is received into a perforation in another. 2. *Scarfing* and *interlocking*, in which the ends of pieces overlay each other, and are indented together, so as to resist longitudinal strain by extension, as in tie beams, and ends of hoops. 3. *Tongueing* and *rabating*, in which the edges of boards are wholly, or partly, received by channels in each other. 4. *Dovetailing*, when the parts are connected by wedge-shaped indentations, which permit them to be separated only in one direction. 5. *Linking*, where the ends of flexible rods are bent over each other. 6. *Folding*, when the edges of flexible plates are connected in a similar manner. 7. To these may be added the combinations of flexible fibres, by tying, twisting, weaving, &c., in which the permanency of the union depends upon friction.

Interposition.—When two substances are mechanically united by the intervention of a third, the latter, from its smaller size, should be made of the strongest material. *Nails* are a common connecting medium in wooden structures. The stability of a nail depends upon its friction, or adhesion, and is increased by its roughness, the smallness of the angle made by its sides, and the elasticity of the material into which it is driven.

When the force tending to produce separation is great, nails do not afford an adequate security. In such cases, it is common to employ *screws*, which are inserted by the force of torsion and cannot be withdrawn by that of extension, while the material is sound. Where great strength is required, ***bolts*** of metal are used, which pass through the substances to be connected, and are secured at their smaller extremity by a nut and screw, or by a transverse key. *Rivets* are short bolts, the two ends of which are headed, or spread by hammering, after they are inserted.

Binding.—In some cases the materials to be connected are not perforated, but surrounded by the connecting substance. Hoops and bands of metal, wood, and flexible fibres, are used for this purpose. In cases where it is applicable, binding ordinarily affords the strongest mode of connexion, but is attended with the greatest expenditure of the connecting material.

Locking.—For the temporary connexion of parts, which require to be often repeated, latches, bolts, hooks, buttons, and locks are employed. Of these, the *lock* is the only one whose structure is at all complicated. The principle upon which locks depend, is the application of a lever to an interior bolt, by means of a communication from without. The lever is the key, and the bolt receives from it a progressive motion in either direction. The security of a lock depends upon the number of obstacles which can be interposed between the movement of the bolt, and the action of any instrument, except the proper key. The *wards* of locks are impediments of this kind, and to enable the key to pass them, certain portions of its substance are cut away. Various complicated and difficult locks have been constructed by Messrs Bramah, Taylor, Spears, and others. In a very ingenious lock invented by Mr Perkins, twentysix small blocks of metal, of different sizes, are introduced, corresponding to the letters of the alphabet. Out of these an indefinite number of combinations may be made. The person locking the door, selects and places the blocks necessary to spell a particular word known only to himself, and no other person, even if in possession of the key, can open the door, without a knowledge of the same word.

Cementing.—Cements are, for the most part, soft or semi-fluid substances, which have the property of becoming hard in time, and cohering with other bodies to which they have been applied. A variety of these substances are used for uniting different materials. The compounds of lime and sand, which constitute the ordinary building cements, have been considered in Chapter First. For uniting pieces of marble, plaster of Paris, dried by heat, and mixed with water, or with rosin and wax, is employed. A cement for iron is made by mixing sulphur and muriate of ammonia with a large quantity of iron chippings. This is used for the joints of iron pipes, and the flanges of steam engines. Turners, and some other mechanics, confine the material on which they are working, by a cement composed of brick-dust and rosin, or pitch. The cement used by glaziers, under the name of *putty*, is a mixture of linseed oil and powdered chalk. China ware is cemented by common paint, made of white lead and oil, or by resinous substances, such as mastic and shell lac, or by isinglass dissolved in proof spirit or water. Bookbinders, and paper hangers, employ *paste*, made by boiling flour, and a similar but more elegant article under the name of *rice glue*, is prepared by boiling ground rice in soft water to the consistence of a thin jelly. *Wafers* are made of flour, isinglass, yeast, and white of eggs, dried in thin strata upon tin plates, and cut by a circular instrument. The color is given by red lead, and other pigments. *Sealing wax* is composed of shell lac and rosin, and is commonly colored with vermillion.

Glueing.—For uniting wood and similar porous substances, common glue takes precedence of all other cements. It is dissolved by heating it with water, and is applied with a brush to both the surfaces to be united. Glue does not adhere so readi-

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ly, if the surfaces be in the least oily, or if a coating of old glue is previously upon them, or, indeed, if the pores are filled with any foreign substance. The cementing power of glue depends upon the strength which it possesses when dry, and the hold which it obtains upon the wood, by penetrating its pores. It does not furnish a sufficient bond of union for surfaces which are not porous, as those of metals; and it is not durable when exposed to the action of water.

Welding.—Certain metals, such as iron and platinum, which are exceedingly difficult of fusion, are capable of being united by the process of welding. This consists in hammering them together while they are at a very high temperature. Bar iron cannot be welded without raising it to a heat of nearly 60 degrees of Wedgewood's pyrometer. Cast steel would be melted at this temperature, and therefore in welding iron to steel, the steel is raised only to a common white heat. Care is taken to prevent the surfaces which are to be welded from being oxidized too much, or else to detach the scales when the metal is brought to a welding heat. The union of welded pieces probably depends on an incipient fusion of their surfaces. When properly conducted, the metal is supposed to be as strong in the welded part as in any other.

Soldering.—The process of soldering consists in uniting together parts of the same, or of different metals, by the intervention of a metallic substance employed in a state of fusion. It is necessary that the uniting substance should melt sooner than the substance to be soldered, that it should adhere firmly to its surface, and, as far as practicable, approach to the metal soldered, in hardness and color. Iron is usually soldered with brass, and hence the process is commonly called *brazing.* An alloy of tin and iron is sometimes used instead of brass for the same purpose. Copper may be united either by a hard solder made of brass and zinc, or a soft solder composed of zinc and lead. Tin is soldered with pewter made of tin and lead, with sometimes a portion of bismuth. Gold and silver are united with solders made of gold or silver, alloyed with copper or brass. Platinum is soldered with gold. The adhesion of solders depends upon an alloy being formed between the surfaces in contact.

As the oxidation of the surface of metals tends to prevent the adhesion of the solder, it is common to unite with the solder some additional substance, which may obviate this difficulty. In soldering copper, brass, iron, &c., it is common to employ borax, a salt which fuses at the time when the metals would be most liable to oxidate, and by enveloping the metallic surface, prevents the farther action of the oxygen of the atmosphere. Potash, soda, tartar, and various salts are used for the same purpose. Muriate of ammonia has a remarkable effect in freeing the surfaces of metals from oxygen, which it does, apparently, by combining with the metallic oxide, and carrying it off as it sublimes. In soldering the more fusible metals, as tin and lead, a carbonaceous substance is employed, such as rosin, or oil, which tends to cover the surface, and also to reduce the oxide to its metallic state, as fast as it is formed.

Casting.—The process of fusion, or melting, affords in many substances, the most effectual method both of destroying the cohesion of their particles, and of afterwards restoring it under new arrangements. Many substances, both simple and compound, such as metals, glass, wax, &c., may become liquid and again solid, without essentially changing their physical qualities. On the other hand, many natural bodies, crystallized minerals, and organic combinations, cannot be fused without changing their characteristic properties. Some substances are with difficulty fusible when alone, but become more fusible when combined with another substance, as is the case of sand with an alkali, or iron with carbon. Others again have their fusibility lessened by combination, as happens in metals when they become oxidized.

Fluxes.—The name of *fluxes* has been given to certain substances which assist fusion, either by expediting the process, or by protecting the substance melted from alteration. In separating metals from their ores, fluxes are employed to render the substances with which the metal is combined, capable of fusion. Thus if the ore abound with siliceous earth or stone, an alkaline flux, such as potash, soda, or tartar, has the effect of combining with the siliceous substances, and forming with them a vitreous compound, which floats upon the top of the melted metal. Tartar also contains a portion of vegetable matter, the carbon and hydrogen of which serve to deoxidize, the metal: Borax, common salt, and many other saline bodies, when melted, prevent the oxidation of metals, by protecting their surface from the atmosphere. Muriate of ammonia, rosin, fatty substances, powdered charcoal, &c., prevent or remove oxidation, by combining either with the oxygen, or with the oxide when formed.

Moulds.—The moulds used for casting melted bodies must be suited to the temperature at which the body melts. For metals which melt at a high heat, as copper, brass, cast-iron, &c., the moulds are made of some refractory substance, such as loam, sand, pounded brick with plaster, or clay, &c. Glass is cast in moulds made of copper, but these require to be frequently cooled. Those bodies which melt at temperatures below that of ignition, as tin, lead, wax, &c., may be cast in moulds of any convenient metal, or of wood, and other inflammable materials.

The forms of some bodies may be changed, and their separation or union effected, without the agency of fusion, in various ways. It may be done by mixture with water, as in clay and plaster; by solution in water, as in glue, rice, and gum; and by sublimation, as in camphor, and muriate of ammonia.

YOUNG's Lectures on Natural Philosophy;—GREGORY's Mechanics;—NICHOLSON's Operative Mechanic, 8vo.;—GRAY's Operative Chemist, 8vo. 1828;—REES' Cyclopedia, and BREWSTER's Edinburgh Encyclopedia, under various heads.

CHAPTER XV.

ARTS OF COMBINING FLEXIBLE FIBRES.

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 twisted 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, consist of a considerable number of yarns thus twisted together, generally from sixteen to twentyfive; a *halser* consists of three strands, *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 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 180 yards in length, to 135 yards, has been found to be stronger than when reduced

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

to 120 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.*

COTTON MANUFACTURE.

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

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

jenny. This machine was invented by Richard 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 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

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

seeds, at the plantation, by the operation of *ginning*, described on page 34, 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 ground work 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 ribbands 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 ribbands are *plied* or united into one sliver.

The operations of drawing and plying serve to equalize still farther 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 caid ends. Hitherto the cotton has acquired no twist, but is received into moveable 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 roving 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 axis, but by friction applied to their surface by small wooden cylinders which revolve in contact with them. In this way the ve-

* Instead of band cones, an ingenious mode of using geared cones, now introduced in several American factories, has already been described, page 239.

† By Mr Danforth, of Massachusetts.

locity 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 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*,

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

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 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 167 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

* 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.

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.

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 the same force of lateral adhesion which retains the twisted 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 moveable 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 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. 1 is shown a magnified

Fig. 1.

section of a piece of plain cloth, in which the woof passes alternately over and under every thread of the warp. In Fig. 2

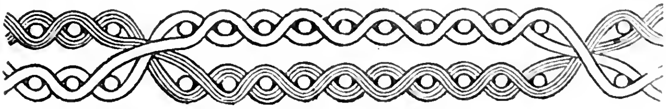
Fig. 2.

is a piece of twilled cloth, in which the thread 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 position 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 susceptible of ornamental variations. Jeans, dimoties, 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. 3.

Fig. 3.



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. 4 represents the cross weaving used in common gauze.

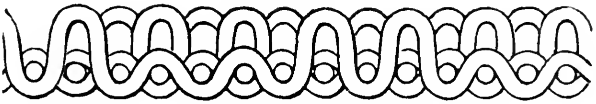
Fig. 4.

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 despatch. 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* carpeting 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. 5, and to render them

Fig. 5.



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 knap, 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 knap, 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 knap, 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 very 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.

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 knap, 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 knap, 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 fingers 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 knap, 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.

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*;—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 XVI.

ARTS OF HOROLOGY.

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 740 years before Christ. The first sun dial at Rome was set up by Papirius Cursor, about 300 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 Pl. IV. Fig. 13. 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 pressure 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.

* 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.

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. X. 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 14th century, but were formed in a rude and imperfect manner, until the middle of the 17th. 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 connexion.

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, page 240.

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 inclosing a quantity of quicksilver in a tube, near the bottom of the pendulum.

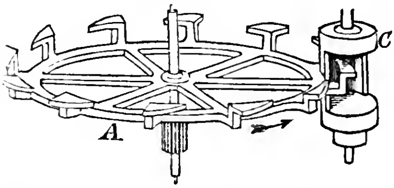
Balance.—As the pendulum depends upon the force of gravity for its motions, it obviously cannot be employed for watches, or portable timekeepers, which are liable to change their position. A substitute is found in the *balance*, which is commonly a wheel moving on an axis, and which, when thrown backward 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 12 hours in 24, 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 245. The *horizontal* scapement, Fig. 1, 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 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 op-

Fig. 1.



posite side. Before it can escape, the cylinder 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 introduced 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. X, 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. X, 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 Figures 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 ninetysix 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 64 teeth, on the same arbor, called the centre wheel, turning the wheel 60 by a pin-

* 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.

ion 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 30 teeth. The parts *d h*, are the pallets of the scapement fixed on an arbor *c*, Fig. 1st, 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, suspended 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 $39\frac{1}{8}$ 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; 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 30 teeth, it will revolve once in 60 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 60. The pinion of eight on its arbor is turned by a wheel of 60, which consequently will turn once in seven turns and a half of the other, or in seven minutes 30 seconds, or in one eighth of an hour. Its pinion of eight is moved by a wheel of 64, 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 12 times the number of the pinion eight, will turn once in 12 hours, and the barrel *a* with it. The cord of catgut goes round 16 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 40 teeth on its lower end, indicated by a dotted circle. This turns another wheel 40, of 40 teeth, which has a pinion of six teeth on its arbor, turning a wheel 72, of 72 teeth. The two wheels 40 will both turn in an hour; and 72 in 12 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 78 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 48. This turns another pinion of eight, and wheel *p*, of 48, 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 78 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 78 teeth, it will turn once in 12 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 *r* *x* 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, Y, 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 12 hours. The snail is divided into 12 equal angles, of 30 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 *i k* 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 farther. 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*. Immediately 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 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 *i k*, 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 1 to 12.

Description of a Watch.—In Pl. XI. 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, consist 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, E E, 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 rivetted 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 filled 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 C D 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, *a b*; 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 fusee, 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 9½ 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 28 or 30 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 48 teeth on its circumference, which take into and turn a pinion of 12 teeth, fixed on the same arbor with the

Centre wheel, H, so called from its situation in the centre of the watch; it has 54 teeth to turn a pinion of six leaves, on the arbor of the

Third wheel, I, which has 48 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 48 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 15 teeth, by which it impels the balance *o p*. 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, *i k*, 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 45 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 mean time the balance, *o s p r*, attached to the axis of the pallets, continues to move in the direction *r o s p*, 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 *o s p r*, 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 seconds 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 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 12 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 48 teeth, which is fitted on a pin fixed in the plate, and its pinion, *x*, of 16 leaves, which is fixed to it, turns

The hour wheel, Y, of 48 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 12 revolutions of the other; therefore one turns round in an hour, and the other turns round once in 12 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 *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, *r r*, 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, *r r*, 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 toward 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.

CUMMING's Elements of Clock and Watch Work, 4to. 1766;—BERTHOUD *Histoire de la Mesure du Temps par les Horloges*, 2 tom. 4to. 1802;—HARRISON on Clock Work and Music, 8vo. 1775;—ROBISON's Mechanical Philosophy, article Watch Work, vol. iv.;—MARTIN's Circle of Mechanical Arts, 4to. 1818;—and the Encyclopedias of BREWSTER, REES, and NICHOLSON, under various heads.

CHAPTER XVII.

ARTS OF METALLURGY.

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 farther 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 sometimes 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, inclosed 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 24 equal parts, these imaginary parts being termed *carats.* If perfectly pure or unalloyed, it is said to be gold 24 carats fine; if alloyed with one part of any other metal, or mixture of metals, it is said to be 23 carats fine. In this way the proportion of alloy is expressed. The standard gold coin of the United States and Great Britain, is 22 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.*

* 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 12, 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

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 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 ribband as thin as paper. This ribband 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 150 of these squares. All these squares are interlaid with leaves, first of vellum, and afterwards of gold beater's skin, a thin membranous 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

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.

* 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.

taken out, and eachcut into four part ; sand the 600 pieces thus produced, are again interlaid in the same manner with skins, and the beating repeated with a lighter hammer. They are afterwards redivided 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 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.*

* 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

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 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 cupeliation, 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

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.

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 soldering. 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 18 pennyweights of copper in a pound Troy of silver; and in the United States 1664 grains of silver contain 179 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 engraved edging. One of these plates is fixed, and the other is moveable 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 19,000 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 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

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

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 12 to 25 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 *pinchbeck*, *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 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 10 or 12 parts in 100. It is of a greyish 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.*

* 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

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.

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.

* Mr Edwards, by an extensive series of experiments on the proportions of these metals, and the effects of different additions, succeeded in forming alloys much superior in brightness to those that had been before used. That which he preferred, was composed of 32 ounces of copper, 15 or 16 oz. tin, according to the purity of the copper, to which were added brass, arsenic, and silver, of each one ounce; the copper and the tin being melted in separate crucibles, when in fusion, the one being added to the other, and the composition, when well stirred, being poured into cold water. The other metals are added in a second fusion. The arsenic appears to give a greater degree of density and compactness to the alloy, the brass more tenacity, and the silver adds to the whiteness. According to the more recent experiments of Mr Little, the best composition, is 32 parts of bar copper, four parts of brass, sixteen and a half parts of tin, and one and three quarters of arsenic.

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 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, common salt, with sal ammoniac. *Tin foil* is made by rolling, 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.

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

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, horizontal 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, depends upon the degree of regularity and polish which the glass possesses.

In silvering concave and convex mirrors, instead of a stone table, the tinfoil 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 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 siliceous 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 metal, 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.

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, according as one or other of the principles predominate.

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 employed 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 inclosed 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 mould, 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 object 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 grey 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 siliceous 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. IX. Fig. 2. A B is the hammer, which turns upon the fulcrum C. At D is a wheel or cylinder furnished with wipers, *a b c*, &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 motions 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 16 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 semicircular 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 mandrel; and several such instruments of different sizes are employed in succession. The breech of the barrel 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 stocks, are soldered on. The construction of the lock, and other appendages, is readily understood from inspection.

Steel.—When malleable iron is recombined 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 affected 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 rendered 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 farther 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' 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. †

* 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.

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 1-500th of its weight of silver, is superior to wootz, or to the best cast steel in hardness. The alloy of steel with 100th 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 exceeds 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 inclosing 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 430 degrees of Fahrenheit, the color is pale, and but slightly inclining to yellow. This is the temperature at which lancets are tempered. At 450 degrees, a pale straw color appears, which is found suitable for the best razors and surgical instruments. At 470 degrees a full yellow is produced, suitable for penknives, common razors, &c. At 490 degrees, a brown color appears, which is used to temper shears, scissors, garden hoes, and chisels intended for cutting cold iron. At 510 degrees, the brown becomes dappled with purple spots, which show the proper heat for tempering axes, common chisels, plane irons, &c. At 530 degrees, a purple color is established, and at this degree the temper is given to table knives and large shears. At 550 degrees, a bright blue appears, used for swords and watch springs. At 560 degrees, the color is a full blue, and is used for fine saws, augers, &c. At 600 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 600 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' 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, hand 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

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

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.

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.

MURRAY'S System of Chemistry, 4 vols. 8vo. 1806;—PARKES' Chemical Essays, 2 vols. 8vo. 1823;—GRAY'S Operative Chemist, 8vo. 1828;—DUMAS, *Traité de Chimie Appliquée aux Arts, &c.* 4 tom. 8vo. 1828-9;—FOURCROY, *Systeme des Connaissances Chimiques*, 11 tom. 1801;—AIKEN'S Dictionary of Chemistry and Mineralogy, 2 vols. 4to. 1807;—MARTIN'S Circle of Mechanic Arts, 4to. 1818;—Emporium of Arts and Sciences, Philadelphia, 1812-14;—Franklin Journal, Philadelphia, 1826, and after;—REES' Cyclopedia, various heads;—URE'S Dictionary of Chemistry;—THENARD, *Traité de Chimie*, 5 tom. 8vo. 1824;—Works of BERGMAN, KLAPROTH, LEWIS, &c.

CHAPTER XVIII.

ARTS OF COMMUNICATING AND MODIFYING COLOR.

An extensive branch of industry has for its object the effecting of changes in the natural colors of bodies. The artificial modifications, produced in color, may be either mechanical and superficial, or chemical and intrinsic. In painting, gilding, and similar processes, the original color of a substance is not altered, but it is mechanically concealed by another substance which covers it from view. On the other hand, in bleaching and dyeing, the color of the whole substance is intrinsically changed, by a chemical action. This difference of character has given rise to distinct arts in coloring, the processes of which are for the most part dissimilar.

OF APPLYING SUPERFICIAL COLOR.

Painting.—Common painting, when disconnected with design, has for its object to produce a uniform and permanent coating upon surfaces, by applying to them a compound, which is more or less opaque. In many cases painting is applied only for ornament, but it is more frequently employed to protect perishable substances from the changes to which they are liable when exposed to the atmosphere, and other decomposing agents. The effect and durability of different coverings employed in this way, depends upon the kind of pigment used, and still more upon the vehicle, or uniting medium, by the intervention of which it is applied.

Colors.—The coloring substances, employed by painters, comprise a great variety of articles derived from the mineral, vegetable, and animal kingdoms. They are employed in a state of minute subdivision, and commonly mixed with a fluid which is more or less viscid and tenacious. When applied upon the surface of canvass, wood, or other bodies, they communicate their color, by covering and concealing the original color of the surface, while they substitute their own in stead. Those which are perfectly opaque, are called *body colors*, such as white lead, and vermilion; while those which are partially pellucid, are called *transparent colors*, as prussian blue, terra di sienna, and lake. Transparent colors do not wholly conceal the colors beneath them, but produce the combined effect of the two. The process called by painters *glazing*, consists in laying a transparent color over one of a different tint. Transparent colors are sometimes mixed with a white earth, to give them a body, where it is necessary to cover entirely the previous surface. Common whiting is usually employed for this purpose.

The following list comprises the principal coloring substances, used as paints, exclusive of those which belong only to the art of dyeing.

Blues.—*Ultramarine* is the richest and most durable of all the blues. It is not altered by time, and bears exposure to a red heat without changing its color. It is made only from the *lapis lazuli*, a stone brought from several parts of Asia, which bears an extremely high price.

Prussian blue is a strong and durable color. In the present language of chemistry, it is a ferrocyanate of the peroxide of iron. It is made from blood, and other animal matters, dried and heated to redness with an equal weight of pearl-ash. The residue, which consists chiefly of cyanuret of potassium, and carbonate of potass, is dissolved in water, and after being filtered, is mixed with a solution of alum and protosulphate of iron. A greenish precipitate ensues, which, by exposure to the atmosphere, passes through different shades, till it arrives at a fine blue color.

Blue verditer is a nitrate of copper combined with hydrate of lime. It is made by adding quicklime to a solution of copper in nitric acid, and mixing the precipitate with a small portion more of lime. It is a full blue, much used in paper staining, but is liable to grow dull.

Smalt is a powdered glass, which derives its blue color from the oxide of cobalt. It is chiefly used by strewing it on a ground of some other color.

Bice consists of smalt finely levigated. It is rather lighter, and very durable, but not extensively used.

Indigo is the deepest of all the blues in common use. It is very durable, but more used in dyeing (which see) than in painting. *Stone blue*, *Fig blue*, *Queen's blue*, &c., consist of indigo reduced by starch.

Reds.—*Vermilion* is a bisulphuret of mercury, formed by fusing sulphur with about six times its weight of mercury, and subliming in close vessels. The product is called *Cinnabar*, and, when powdered, vermilion. It is of a bright scarlet color, and stands tolerably well.

Red lead, otherwise called minium, is a deutoxide of lead, formed by exposing lead, or litharge, to heat in a furnace, in open vessels, with a current of air passing over it. The metal is gradually converted into an oxide of a bright orange red. Red lead is extensively consumed in the manufacture of flint glass. As a pigment, it is brilliant at first, but liable in time to turn black.

Chrome red is a fine scarlet, formed by boiling carbonate of lead with an excess of chromate of potass. By Dulong's method, 67 parts of white lead are boiled with 82 parts of chrome yellow, in water.

Colcothar, also called *crocus martis*, and *rouge d' angleterre*, is an impure brown red oxide of iron which remains after the distillation of the acid from sulphate of iron. It forms a durable color, but is most used by artists in polishing glass and metals.

Ochres.—The ochres are various earths containing iron in a greater or less degree of oxidation. *Venetian red* is a coarse ochre of a dark red color. *Indian red* is an ochre brought from the East Indies, and has a shade inclining to purple. *Red ochre* is formed from yellow ochre by exposing it to heat. *Burnt sienna* is made from the raw terra di sienna by exposure to heat, by which process its color is changed from yellow to red. *Bole* is a fine clay, colored by oxide of iron, of which there are many varieties, from yellowish red to brown.

Carmine, the most beautiful of all the reds, is an animal substance made from the cochineal insect, or *coccus cacti*. It is deposited from a decoction of powdered cochineal in water, to which alum, carbonate of soda, or oxide of tin is added; but the preparation of the finest varieties is kept secret by the manufacturers, and probably depends much upon the delicacy of the manipulations. A fine color is said to be made by adding acetic acid to a solution of carmine in ammonia.

Lakes of various shades are formed from cochineal precipitated by salts of tin, and other agents. Beautiful lakes are also prepared from madder, by a process of Sir H. Englefield, in which the coloring substance is precipitated from an infusion of madder, by adding solutions of alum, and carbonate of potass. The lake called *rose pink*, is an extract of Brazil wood, mixed with whiting and alum.

Rouge is made from the flowers of the *Carthamus tinctorius*, or Dyer's saffron, also called safflower; by dissolving an alkali in the infusion, and precipitating the coloring matter by lemon juice. It is very fugacious. Under the same name other pigments are also used.

YELLOWS.—*Gamboge* is the concrete juice of a tree growing in the East Indies, *(Stalagmitis cambogioides.)* It is externally of a dull orange color, but becomes of a bright yellow, when wet, or thinly spread upon a white surface. It is partially soluble in water and alcohol, and is chiefly used in water colors.

Orpiment is a sulphuret (sesquisulphuret) of arsenic. The paint called *king's yellow*, is made from this substance, or from its constituents. It is a brilliant, but not very durable color, and its use is in some cases dangerous to the health.

Naples yellow is prepared by exposing lead and antimony with potass, to the heat of a reverberatory furnace. It stands tolerably well, but turns black upon the contact of iron. A native pigment of this kind is also obtained from a species of lava.

Yellow ochre is a native earth, the finer particles of which, are separated by washing, as in similar substances. Although not very bright, its cheapness and durability have caused it to be extensively used.

Terra di sienna is also an ochre, of a deeper and brighter yellow than most of the others.

Massicot, or *masticot*, is the protoxide of lead, prepared by collecting the gray film which floats upon the surface of melted lead, and exposing it to heat and air until it assumes a yellow color.

Chrome yellow is a chromate of lead. It is precipitated by adding chromate of potass in solution, to a solution of nitrate, or acetate, of lead. It forms one of the most brilliant yellows, and is extensively manufactured in this country, from the chromate of iron found near Baltimore.

Turpeth mineral is a subsulphate of mercury, or rather a sub-bisulphate. It is a pale yellow, and moderately durable.

Patent mineral yellow is a fused muriate of lead, made by decomposing common salt by means of litharge, triturating the product with water, washing away the soda, and drying and fusing the muriate.

Dutch pink is a cheap color used by paper stainers, composed of whiting colored by a decoction of dyers' wood, quercitron, or French berries, with alum.

GREENS.—*Verdigris* is an acetate of copper, or strictly, an impure acetate of the peroxide of copper. It is manufactured in the south of

France by covering plates of copper with the refuse of the grapes, after making wine. It may also be formed by exposing copper to the vapor of vinegar.

Terra verte is a native blue-green ochre. It is semitransparent and durable, but not very bright.

Brunswick green, called also *mineral green*, is an ammoniaco-muriate of copper, much used for paper hangings, and occasionally in oil painting.

Sap green is the inspissated juice of the berries of the buckthorn, (*Rhamnus catharticus.*) It is semitransparent, and chiefly used in water colors.

Many of the greens in common use are compound colors, made by the admixture of blue with yellow.

Browns.—*Umber* is a light brown ochre. Burnt umber is the same substance, having its color darkened by exposure to heat. It is durable in both states.

Spanish brown is a coarse durable ochre, its color inclining to red.

Bistre is prepared from common soot of wood, by pulverizing and washing. The soot of the beech is said to afford the best.

Asphaltum is prepared from the bituminous substance of that name. When dissolved in oil of turpentine, it is semitransparent, and is used as a glaze.

Ox gall consists of the biliary concretions found in the gall bladder of cattle. It is not soluble in water or alcohol, but dissolves readily in a solution of potass. It is of a yellowish brown, and is much valued for the brightness and permanence of its tint. The liquid ox gall is used by painters to facilitate the laying on of colors.

Blacks.—*Lamp black* is a light carbonaceous substance, thrown off during the combustion of resinous and oily substances. The chips of fir and pine trees are burnt under tents, to the inside of which the lamp black adheres.

Frankfort black. This is a charcoal made from the lees of wine. It is used in the ink of copper plate printers.

Ivory black, called also *Cologne black*, is made from the shavings and dust of ivory, heated in covering iron pots. Various other carbonaceous colors are made from cork, vine twigs, peach stones, &c., converted into charcoal.

Indian ink is said to be made from different sorts of lamp black, mixed with water and glue. The black is obtained from the smoke of oil, of fir wood, or of horse chesnuts. A solution of lac with borax, in water, is said to be the vehicle of the lamp black in some kinds.

Sepia is the black liquid obtained from the cuttle fish. It is of a viscid consistence, and is preserved by drying it upon saucers or shells.

WHITES.—*White lead*, formerly *ceruse*, is a carbonate of lead, prepared by exposing coils of sheet lead, in earthen pots, to the vapor of vinegar for several weeks. It is sometimes also formed by precipitation with carbonic acid from a solution of acetate of lead in water.

Flake white consists of the densest and thickest scales, which are separated in making the foregoing article from sheet lead. It is very pure, whereas the white lead of commerce is adulterated with chalk.

Pearl white is the subnitrate of bismuth, formerly called magistery of bismuth, precipitated by water from its solution in nitric acid. It has been used as a cosmetic, but grows yellow by age and light.

Whiting.—Common chalk separated in the form of an impalpable powder by washing. *Blanc de Troyes* is similar to whiting.

Zinc white is the oxide of zinc. It does not work easily, but is thought very durable. Various marls and clays from *Bougival*, *Rouen*, *Moudon*, &c., are used for white pigments.

Preparation.—Coloring substances, before being used in painting, require to be reduced to a state of extreme fineness. For this purpose they are ground in a color mill, and levigated with a stone and muller. In many cases, colors which are insoluble in water, are separated by washing, the water being first made turbid with the coloring substance, and left to stand a short time, till the coarser particles have subsided. The upper part of the fluid with the finer particles in suspension is then poured off, and the second deposit which takes place from this is sufficiently fine for mixing. When a greater degree of tenuity is required, the washing is repeated.

Application.—As colors are first prepared for use by simply reducing them to powder, it is necessary that some tenacious fluid should be introduced to make their particles adhere to the surface on which they are spread. To effect this end, various fluids are employed, and the difference of the material used, with the method of employing it, has given rise to the modes of painting in water, in oil, in fresco, in distemper, &c.

Crayons.—The most simple mode of applying colors is by the use of crayons. Crayons are cylinders, or sticks of dry colors, cemented into a friable mass like chalk, by the assistance of gum or size, and sometimes of clay. They are used by simply rubbing them upon paper, and afterwards blending and softening the shades by means of a *stump*, or small roll of leather, or paper. But drawings in crayons and chalks, have always the disadvantage that they do not adhere to the paper, but are rubbed off, and defaced, with the slightest attrition. In this state they can be safely kept and examined only in frames under glass. Various modes have been practised for fixing crayon drawings upon paper, so as not to be liable to defacement. Among other means, this end may be effected by brushing the back of the paper with a strong solution of isinglass, or by passing the drawing through a powerful press, in contact with amoist paper.

Water Colors.—The most common mode of painting on paper, is by the use of water colors. These are formed into hard cakes or lozenges with a larger quantity of gum, than is employed for crayons. When used, they are rubbed down with water upon glass, or a glazed surface, and applied while wet with a camels' hair pencil. The gum with which they are mixed causes them to adhere so closely to the paper that they cannot be rubbed off.

Distemper.—Painting in *distemper* is used for works to be executed upon a larger scale, such as stage scenery, the walls of apartments, &c. The colors are used in the form of powder, and are mixed with water rendered glutinous by size, or other solutions of animal glue. The mixture requires, in many cases, to be used warm, as the solution becomes stiff upon cooling. Skimmed milk also serves as a vehicle for painting in distemper, and its tenacity is increased by adding small portions of lime, and of linseed or poppy oil. The mixture dries speedily, the oil being converted into a soap by the lime.* Distemper in *badigeon* is employed by the French to restore the original color to stone walls which have become brown by time; and consists in washing them with powder of the same kind of stone, properly mixed. *Chipolin* is a varnished distemper.

* This method is highly recommended by Tingry, who gives the following recipe. Skimmed milk 4 pounds; lime newly slaked 6 ounces; linseed, nut or poppy oil 4 ounces; spanish white (white clay) 3 pounds.

Fresco.—Paintings in *fresco* are executed upon walls recently plastered, before they have become dry. The coloring substance mixed with water being applied while the wall is wet, sinks in and incorporates itself with the grain of the mortar, so as to become very durable. When a wall is to be done in fresco, it is covered with a coating of stucco or fine mortar, which is applied in successive portions, no more being put on at once than can be painted before it is dry. This mode of finishing by piecemeal, renders it necessary that the artist should have his whole design either drawn upon paper, or thoroughly digested in his mind before he begins. The drawings which are executed upon large paper to serve as patterns for fresco paintings, are called *cartoons.* They are transferred to the walls by puncturing through the outlines with a sharp point.* Many of the greatest works of the most eminent Italian masters are executed in fresco, upon the walls and ceilings of the different churches and cathedrals.

Encaustic Painting.—The ancients made use of a mode denominated *encaustic painting*, the knowledge of which at the present day is lost. From the writings of Pliny it appears that the material with which the colors were incorporated, was wax, and that this was applied by the assistance of heat. It is represented as having been very brilliant and durable, though no specimens of it remain at this day. The principal paintings which have been discovered upon the walls at Herculaneum and Pompeii, appear to have been done in fresco.

Oil Painting.—Painting, in oil, which on many accounts has a great superiority over other methods, was first applied to the execution of designs about the year 1410, by John Van Eyck, in Flanders. The oils used for painting must be of the class denominated drying oils. Of these, linseed oil is the kind most commonly employed, and its tendency to dry is increased by its being boiled. Its color renders it sometimes injurious to light tints; so that in delicate pieces it is better to em-

* Cartoons are also used as patterns in tapestry and mosaic.

ploy nut oil, or poppy oil, which are nearly transparent, and do not turn dark in drying. The drying of paint is owing, not so much to evaporation, as to a chemical combination of the oil with the pigment, especially when the latter is a metallic oxide, or other substance, having a direct affinity for the oil. The oxygen of the atmosphere appears also to enter into this combination. The drying will be frustrated if a small quantity of any fat oil be present. Hence in painting old surfaces, which have been exposed to contract any greasiness, it is necessary first carefully to cleanse them, or to wash them with lime in water, or with some alkaline solution, which combines with the oil. The latter method is practised by house painters.

Oil paintings of designs are executed either on canvas, on wood, or on copper. When the colors used are chiefly of the kind denominated body colors, each successive layer conceals those beneath it, so that the work may be heightened, amended, or altered, at pleasure during any stage of the process. Paintings in oil are very durable, and acquire a mellowness from age which improves rather than injures their effect, provided permanent colors have been used.

Painting in the large way, with uniform colors mixed in oil, is employed not so much for ornament, as for the protection of perishable substances from decay. Thus wood may be preserved from decomposition, and metals from oxidation, for an indefinite time, by keeping them covered with a thick coating of paint, which is impervious to air and moisture.

Varnishing.—The name of varnishes is given to certain compounds, chiefly solutions of resinous substances, which, after being spread over surfaces, and dried, possess the qualities of hardness, brilliancy, and transparency. They are employed to give lustre and smoothness to painted surfaces, and to defend them from the action of the air.

The principal substances which form the basis of varnishes, are copal, mastic, animé, sandarac, lac, benzoin, amber, and asphaltum. Of these, *copal* is a hard, shining, transparent resin, of a light citron color, originally brought from Spanish

America, and erroneously considered as the product of the *Rhus copallinum*.* True copal is soluble in oil, but is difficult of solution in alcohol. It is commonly made into varnish by dissolving it in hot linseed oil, rendered drying by quicklime, and diluting the solution with oil of turpentine. By mixture with camphor, it becomes soluble in alcohol, or in oil of turpentine. *Mastic* is a resinous substance, in the form of tears, of a pale yellow color, brittle and semitransparent. It comes from the Levant, and is produced by the *Pistacia lentiscus*. A greater part of it is soluble in alcohol and in oil of turpentine. *Animé* is brought from Spanish America, and is said to be obtained from the *Hymenæa courbaril*. It resembles copal very much in its appearance, but is easily soluble in alcohol, while copal is not. It is often sold under the name of copal. *Sandarac* is the resin of the *Thuya articulata*, which grows in Barbary. It resembles mastic, but is rather more transparent and brittle. When chewed, it crumbles to powder, whereas mastic softens in the mouth. It is soluble in alcohol and oil. *Lac* is deposited on certain trees in the East Indies, by an insect called *Coccus lacca*. The substance in its natural state incrusting the twigs, is called *stick lac;* when broken off and boiled in water, till it loses its red color, it is termed *seed lac*, and when melted and reduced to a thin crust, it is called *shell lac*. Stick lac has a deep red color, and yields to water a red substance which is used as a dye. Lac is soluble in alcohol. *Benzoin* is the product of the *Styrax benzoe*, a tree growing in Sumatra. It is a solid, brittle substance, in yellowish white tears, joined together by a brown substance, and is sometimes wholly brown. It is a balsam, and affords benzoic acid. *Amber* and *asphaltum* are mineral substances, already mentioned in the first chapter.

* The Rhus copallinum is a common shrub in the United States, and is not known to produce any substance resembling copal. According to Hernandez the copal of Spanish America is obtained from various trees. I am informed that the copal used in this country comes almost wholly from the East Indies. It is probably the produce of the *Elæocarpus copalifera*.

Varnishes are divided into three kinds, according to the menstruum in which the resinous substance is dissolved. These are *spirit* varnishes, in which the solvent is alcohol; *essential* varnishes, in which a volatile oil, commonly oil of turpentine, is used; and *oil* varnishes, which consist of a resin dissolved in a drying oil. Some vegetable juices may be applied in their liquid state. Thus the viscid juice of the *Rhus vernix* affords the celebrated black varnish used in Japan. The same shrub, which grows in this country, affords a whitish juice, which, upon boiling, yields a strong, glossy black varnish.*

An elastic varnish may be made by dissolving caoutchouc in linseed oil and oil of turpentine; but this preparation dries slowly. Besides the solvents mentioned in the first chapter of this work, it is found that the naptha of coal tar dissolves caoutchouc readily, and on drying leaves its properties unaltered. †

Japanning.—Japanning is the art of varnishing in colors, and is therefore a species of painting. It is most easily executed upon wood and metal, or such other substances as retain a determinate form, and are capable of sustaining the operation of drying the varnish. Paper and leather, when wrought into forms in which they remain stretched, stiff, or inflexible, are common subjects for japanning.

The article to be japanned is first brushed over with two or three coats of seed lac varnish, to form the *priming*. It is then covered with varnish previously mixed with a pigment of the tint desired. This is called the *ground color*; and if the subject is to exhibit a design, the objects are painted upon it, in colors mixed with varnish, and used in the same manner as for oil painting. The whole is then covered with additional coats of transparent varnish, and all that remains to be done, is to dry and polish it.

Japanning requires to be executed in warm apartments, and

* See American Medical Botany, vol. i. p. 101. The shrub is poisonous to many persons.

† Annals of Philosophy, vol. xii.

the articles are warmed before the varnish is applied to them. One coat of varnish, also, must be dry before another is laid on. Ovens are employed to hasten the drying of the work.

The same pigments which are employed in oil or water, answer also in varnish. For painting figures, shell lac varnish is considered best, and easiest to work; it is therefore employed in most cases where its color permits. For the lightest colors, mastic varnish is employed, unless the fineness of the work admits the use of copal dissolved in alcohol.

Polishing.—Pictures, and other subjects, to which only a thin coat or two of varnish is given, are generally left to the polish which the varnish naturally possesses, or are brightened only by rubbing them with a woollen cloth when dry. But whenever several coats of varnish or japan are laid on, a more glossy surface can be produced, by means similar to those which are used to polish metals; the surface having first been suffered to become completely dry and hard. Where the coat of varnish is very thick, the surface is first rubbed with pumice stone and oil, till it becomes uniformly smooth; the pumice having been previously reduced to a smooth flat face, by rubbing it on freestone. The japanned or varnished surface may afterwards be rubbed with pumice reduced to an impalpable powder, the workman using oil and leather to lay on the powder. The finishing may be given by oil and a piece of woollen only.

Where the varnish is thinner, and of a more delicate nature, it may be rubbed with tripoli, or rotten stone, in fine powder, finishing with oil as before. Where the ground is white, putty, or Spanish white, finely washed, may be used instead of rotten stone, of which the color might have some tendency to injure the ground.

Lacquering.—Lacquering consists in the application of transparent varnishes to metals, to prevent their tarnishing, or to give them a more agreeable color. When the color of the metal to be lacquered is to be changed, the varnish is tinged with some coloring matter; but where preservation from rust, or tarnish, is the sole object, any of the transparent varnishes will answer, the best and hardest being used where the greatest durability is required. Shell lac is the most common basis of the varnishes used in lacquering. An imitation of gilding is effected by covering the surface of tin or lead with a clear varnish tinged with annotto, turmeric, or gamboge. The Chinese gilt paper appears to be made in this manner.

Gilding.—The process of gilding on metals, described in a former chapter, depends on a chemical union, or alloy, between the gold and the metal to which it is applied. But gilding, as it is commonly performed upon wood, leather, &c., is a mechanical process, and consists in cementing gold leaf upon surfaces, for which it has no affinity. In common *oil gilding*, the surface to be gilt is covered with an adhesive coating of paint or gold size, composed of yellow ochre ground in oil. When this is partially dried, so as to feel adhesive, the gold leaf is laid upon it and pressed down with cotton wool. When the whole surface is covered, it is left to dry, and the superfluous gold leaf brushed off. In *burnish gilding*, the surface to be gilt is first covered with a mixture of whiting and size, prepared by boiling shreds of parchment or skins, in water. This is rubbed smooth, and covered with a gilding size containing a little ochre or Armenian bole. This is suffered to dry, and is rubbed smooth with a linen rag. The gilding is then performed by moistening successively the parts of the sized surface with water, and applying the gold leaf before it becomes dry. When the work has become firm, it is burnished by rubbing it with a hard polished substance, such as agate, dog's tooth, or steel.

Gilding on leather and on paper may be performed by applying gold leaf with gum arabic or size. The edges of paper and of books are gilded with a size composed of whites of eggs, beaten with three or four times their quantity of water, and mixed with a little Armenian bole. Bookbinders gild the leather of books by coating it two or three times with whites of eggs, and suffering it to dry. A minute quantity of tallow is then rubbed on, and the gold leaf laid loosely upon the surface. The stamps and letters are cut in brass; or printing types are used. These are moderately heated, as much as the leather will bear, and are then pressed upon the gold leaf, by which a portion of gold corresponding to the letters is made to adhere; after which the superfluous gold leaf is brushed off.

Shell gold is prepared by grinding up gold leaf with honey until it is completely subdivided; the honey is then washed away with water, and the gold powder mixed with gum water or some other adhesive fluid. It is usually kept for use on shells, and is applied with a pencil or brush in the manner of common painting.

OF CHANGING INTRINSIC COLOR.

The processes considered in the previous part of this chapter, are used to produce an external modification of color, and consist in mechanically covering the surfaces upon which they are applied. The remaining division includes those arts which depend more exclusively upon chemical processes, and which, by operating on the internal texture of bodies, produce a total and intrinsic change of color. Of this kind are the arts of bleaching, dyeing, and calico printing. The operations, however, which belong to these arts, are too extensive to be considered in all their details in this place.

Bleaching.—Bleaching is the process by which fibrous textures, such as linen, cotton, silk, &c. are deprived of their color, and rendered white. The coloring matter, which is inherent in vegetable fibres, appears to be of a resinous character, and the effect of the operation of bleaching is to dissolve, or discharge it. In manufactories of linen and cotton goods, the yarn or cloth passes through a number of successive processes, the principal of which are the *steeping*, in which the goods are fermented in an acescent liquid at a temperature of about 100 degrees, Fahrenheit—the *bucking* and *boiling*, in which a hot alkaline ley is made to percolate through them for some time—the *souring*, performed with diluted sulphuric acid—the bleaching with *chlorine*, in which the stuff is exposed to the action of some compound of that substance, usually *chloride of lime* called *bleaching salt.* Various mechanical operations, washings, and repetitions of the processes, are commonly practised to complete the discharge of the color. Formerly the process of bleaching was very tedious, and was effected by alkaline leys and by exposure to the sun and air, with frequent irrigations, for many weeks. The discovery of the bleaching power of chlorine has greatly abridged and simplified the process.

Chemists explain the effect of chlorine in bleaching,* by supposing that it unites with the hydrogen of the coloring matter, and forms muriatic acid, which again acts upon the color in its altered state. The acid may be detected in the altered coloring matter. In bleaching, which is performed by exposure to the air and moisture, it is supposed that oxygen combines with the coloring matter, and renders a portion of it more easy of solution, during the other parts of the process.

The fibres of wool and silk are not bleached by chlorine, but after being deprived of the saponaceous or gummy matter, which adheres to them, are exposed to the fumes of burning sulphur to discharge their color.

Dyeing.—The art of dyeing consists in impregnating cloths and other flexible fabrics, with coloring substances, in such a manner, that the acquired color may remain permanent under the common exposures to which the stuffs may be liable. It is effected by producing a chemical union between the material to be dyed and the coloring matter. It is found that different materials not only possess different attractions for dye stuffs, but that they absorb the coloring matter in different proportions. Wool appears in this respect to have the greatest attraction for

* Gay Lussac, *Cours de Chimie*, Lec. 30, p. 21.—Ure's Notes to Berthollet, ii. 344.

coloring substances; silk comes next to it, then cotton, and lastly hemp and flax.

Mordants.—The coloring substances used in dyeing have been divided by Dr Bancroft into *substantive* and *adjective* colors. Substantive colors are those which communicate their tint immediately to the material to be dyed, without the aid of any third substance. Adjective colors require the intervention of a third substance, which possesses a joint attraction for the coloring matter and the stuff to be dyed. The substance capable of thus fixing the color, is called a *mordant*, and by Mr Henry, a *basis*.

The agents which are capable of acting in some way as mordants, are very numerous, including many oxides and salts. But those which are principally employed in practice, are the *acetate of alumina*, the *sulphate* or *acetate of iron*, and the *muriate of tin*. The substance to be dyed is first impregnated with the mordant, and then passed through a solution of the coloring matter. The mordant fixes the color, and, in many cases, alters or improves and heightens its tint.

Dyes.—The coloring substances capable of being used as dyes, are very numerous, but a few of the most important have in practice taken precedence of the rest. Indigo, madder, quercitron, and some of the woods are consumed in vast quantities by dyers, and are capable of producing an indefinite variety of tints, under the action of different mordants. They are somewhat differently treated, according as the substance to be dyed is of wool, silk, or cotton.

Blue Dyes.—*Indigo* is the chief substance employed for giving the blue dye. The best indigo is obtained from a plant cultivated in warm climates, the *indigofera tinctoria*. The plant is cut a short time before its flowering, and put into large vats covered with water, when fermentation spontaneously ensues, during which the indigo subsides in the form of a pulverulent, pulpy matter. Its color is at first green, but by exposure to the air, it absorbs oxygen and becomes blue.

Indigo is a light brittle substance, of a deep blue color, and without either taste or odor. At 550 degrees Fahrenheit it sublimes, forming a violet vapor with a tint of red, and condensing into long flat acicular crystals, which appear red by reflected, and blue by transmitted light. The process of subliming indigo is one of considerable delicacy, owing to the circumstance that the temperature at which it sublimes, is very near that at which it is decomposed. Indigo, in its dry state, may be preserved without change; but when kept under water it is gradually decomposed. It is quite insoluble in water and alcohol, and is attacked by the alkalies in a partial manner. Its only proper solvent is concentrated sulphuric acid. When indigo is put into this acid, a yellow solution is at first formed, which, after a few hours, acquires a deep blue color. If the indigo is pure, sulphurous acid is not generated, nor is the acid decomposed; but the indigo undergoes a change, for it is rendered soluble in water. To the indigo thus modified, Mr Crum has applied the name *cerulin*, and he regards it as a compound of one atom of indigo and four atoms of water. This solution properly diluted with water, is employed by dyers for forming what is called the *Saxon blue*. Mr Crum has also described another compound of indigo and water, under the name of *Phœnecin*, because it acquires a purple color on the addition of a salt. It appears to consist of one atom of indigo and two atoms of water.

When indigo, suspended in water, is brought into contact with certain deoxidizing agents, it is deprived of oxygen, becomes green, and is rendered soluble in water, and still more in the alkalies. This effect is produced, for example, by sulphuretted hydrogen, by the hydrosulphuret of ammonia, by the protoxide of iron, precipitated by lime or potass, or by a solution of the sulphuret of arsenic in potass. On dipping cloth into a solution of deoxidized indigo, it receives a green tint, which becomes blue by exposure to the air. This is the usual method of dyeing blue by means of indigo, a color which adheres permanently to cloth without the intervention of a basis.

Woad is prepared from the leaves of the *Isatis tinctoria*, a plant cultivated in Europe. Gay Lussac, and others, consider it chemically as a species of indigo. It is prepared by grinding, and several processes of fermentation. Cloth dyed in woad liquor is at first green, but turns blue on exposure to the air, in the same manner which takes place with indigo.

Red Dyes.—The chief substances which are employed for giving a red dye, are madder, cochineal, archil, Brazil wood, logwood, and safflower, all of which are adjective colors.

Madder, which is one of the most valuable drugs in the art of dyeing, is the root of the *Rubia tinctorum*, a plant extensively cultivated in Europe, and particularly in Holland. It is properly classed with red dyes, but by the use of different mordants, it is made to produce every shade of red, purple, and even black. In calico printing, a piece may be stamped with several mordants, which are bases of different colors; and upon immersing it in a madder bath, as many colors will appear as there are mordants used. The quality of madder is said to be improved by age, provided it is kept packed in casks which exclude the air. Its quality is also affected by the mode of cultivating and curing it, and the judgment which is used in separating the samples.

Cochineal is obtained from an insect already mentioned, which feeds upon the leaves of several species of the cactus, and which is supposed to derive this coloring matter from its food. It is very soluble in water, and is fixed on cloth by means of alumina or the oxide of tin. Its natural color is crimson, but when the bitartrate of potass is added to the solution, it yields a rich scarlet dye. Cochineal, according to Pelletier and Caventou, is composed of, 1. Carminium, which is the name given to the coloring matter. 2. A peculiar animal matter. 3. A fatty substance. 4. Salts of lime and potass.

Archil.—The dye called *archil*, is obtained from a kind of lichen, (*lichen roccella*) which grows chiefly in the Canary Islands, and is employed by the Dutch in forming the blue pigment called *litmus* or *turnsol*. The coloring ingredient of litmus is a compound of the red coloring matter of the lichen and an alkali; and hence, on the addition of an acid, the coloring matter is set free, and the red tint of the plant is restored. Litmus is not only used as a dye, but is employed by chemists for detecting the presence of a free acid.

Logwood is a dense, heavy wood, derived from the *Hæmatoxylum Campechianum*, which grows in the tropical parts of America. A decoction made from this wood, is of a fine red, inclining a little to violet or purple. This, if left to itself, becomes in time yellowish, and at length black. The violet color of logwood is fixed by alum, and a blue is obtained from it by verdigris. But the great consumption of logwood is for blacks, to which it gives a peculiar depth, and velvety lustre. The coloring principle of logwood has been procured in a separate state by M. Chevreul, who has applied to it the name of *hematin*. It is obtained in crystals, by digesting the aqueous extract of logwood in alcohol, and allowing the alcoholic solution to evaporate spontaneously.

Brazil wood is the heart, or central part of the *Cæsalpinia echinata*, a large tree of Brazil. It produces very lively and beautiful red tints, with solutions of alumina and tin, but they are deficient in permanency. *Sappan* wood, brought from the East Indies, and *Nicaragua wood*, or *Peachwood*, from Central America, are also said to be species of Cæsalpinia, and resemble Brazil wood in their properties, but yield a smaller amount of coloring matter. *Braziletto* and *Camwood* are among the poorest of the red dyes.

Safflower is the dried flowers of the *Carthamus tinctorius*, and affords a bright but fugitive red. See *Rouge*.

Yellow Dyes.—The chief yellow dyes are the quercitron bark, turmeric, hickory, weld, fustic, and saffron. They are all adjective colors.

Quercitron bark, which is one of the most important of the yellow dyes, is an extract made from the bark of the *Quercus tinctoria*, or common black oak of the United States, and was introduced into notice by Dr Bancroft. With a basis of alumina, the decoction of this bark gives a bright yellow dye. With the oxide of tin it communicates a variety of tints, which may be made to vary from a pale lemon color to deep orange. With the oxide of iron it gives a drab color.

Hickory.—Several species of American walnut or hickory, particularly the *Juglans*, or *Carya alba*, yield a yellow dye from their bark, leaves, and rinds, resembling quercitron, but less abundant in quantity.

Weld is derived from a European plant, *Reseda luteola*. When fixed with a basis of alum, it gives a lively and permanent yellow.

Fustic is the wood of the *Morus tinctoria*, a tree of the West Indies. It affords, with an aluminous basis, a less brilliant, but more durable yellow, than the preceding articles. It is also employed to produce certain greens and drab colors.

Annotto, otherwise called *Rocou*, is a soft substance prepared from the seeds of the *Bixa orellana*, a shrub of tropical America. The coloring matter is combined with a resin which renders it difficult of solution in water. An alkali facilitates the solution and improves the color.

Turmeric is the root of the *Curcuma longa*, a native of the East Indies. Paper, stained with a decoction of this substance, constitutes the turmeric or curcuma paper employed by chemists as a test of free alkali; by the action of which it receives a brown stain.

Saffron.—The coloring ingredient of *saffron* (*Crocus sativus*) is soluble in water and alcohol, has a bright yellow color, is rendered blue and then lilac by sulphuric acid, and receives a green tint on the addition of nitric acid. From the great diversity of colors which it is capable of assuming under different circumstances, M. M. Bouillon, Lagrange, and Vogel, have proposed for it the name of *Polychroite*.

French Berries.—The unripe berries of the *Rhamnus infectorius* afford a lively but fugitive yellow.

Black Dyes.—The black dye is made of the same ingredients as writing ink, and therefore contains usually a compound of the oxide of iron with gallic acid and tannin. From the addition of logwood and acetate of copper, the black receives a shade of blue.

Galls.—The common nutgall is an excrescence produced upon an Asiatic species of oak, (*Quercus infectoria*) by the puncture of an insect, a species of *cynips.* It contains tannin, gallic acid, and according to Dr Bancroft, a coloring matter distinct from these. Galls produce a black color with salts of iron, well known as the basis of writing ink.

Maple.—The common red maple of this country *(Acer rubrum)* when applied with the sulphate or acetate of iron, produces, according to Dr Bancroft, a more intense and perfect black than any of the common vegetable dyes. With the aluminous basis, it produces a lasting cinnamon color, both on wool and cotton. Both the bark and leaves may be used.

Butternut.—The bark of the butternut *(Juglans cathartica)* affords a durable brown upon cotton with an aluminous basis, and upon wool without any mordant.

By the dexterous combination of the four leading colors, blue, red, yellow, and black, all other shades of color may be procured. Thus green is communicated by forming a blue ground with indigo, and then adding a yellow by means of quercitron bark.

One of the latest improvements in the art of dyeing, consists in the employment of colors derived from the mineral kingdom. Prussian blue, orpiment, chromate of lead, and other mineral compounds, have by appropriate processes been made to communicate their colors to different stuffs. An abstract of the processes is given in Ure's notes to Berthollet on dyeing.

Calico Printing.—Calico printing is a combination of the arts of engraving and dyeing, and is used to produce upon woven fabrics, chiefly of cotton, a variety of ornamental combinations, both of figure and color. In this process the whole fabric is immersed in the dyeing liquid, but it is previously prepared in such a manner, that the dye adheres only to the parts intended for the figure, while it leaves the remaining parts unaltered. In calico printing, adjective colors are most frequently employed. The cloth is prepared by bleaching and other processes, which dispose it to receive the color. It is then printed with the mordant, in a manner similar to that of copperplate printing, except that the figure is engraved upon a cylinder, instead of a plate. The cylinder, in one part of its revolution, becomes charged with the mordant mixed to a proper consistence with starch. The superfluous part of the mordant is then scraped off by a straight steel edge, in contact with which the cylinder revolves, leaving only that part which remains in the lines of the figure. The cloth then passes in forcible contact with the other side of the cylinder, and receives from it a complete impression of the figure in the pale color of the mordant. The cloth is then passed through the coloring bath, in which the parts previously printed become dyed with the intended color. When it is afterwards exposed, and washed, the color disappears from those parts which are not impregnated with the mordant, but remains permanently fixed to the rest. When additional colors are required, they are printed over the rest with different mordants, suited to the color intended to be produced. This secondary printing is in most instances performed with blocks, engraved in the manner of wood cuts, and applied by hand to the successive parts of the piece.

In some articles, white spots upon a dark ground are produced by covering the parts with wax, tallow, pipe clay, or other materials, which prevent the contact of the color. Sometimes the color is discharged in places by the application of chlorine. A preparation of one of the salts of copper, applied in spots, or figures, has the effect to oxygenate indigo, so as to render it insoluble, and consequently incapable of dyeing these spots, when the stuff is immersed. To these and similar processes, the name of *resist work* has been given.

Fast Colors.—The following are the dye stuffs used by the calico printers for producing fast colors.* The mordants are thickened with gum, or calcined starch, and applied with the block, cylinder, plates, or otherwise.

* Ure's Dictionary.

1. *Black.* The cloth is impregnated with acetate of iron (iron liquor) and dyed in a bath of madder and logwood.

2. *Purple.* The preceding mordant of iron, diluted; with the same dyeing bath.

3. *Crimson.* The mordant for purple, united with a portion of acetate of alumina, or red mordant, and the above bath.

4. *Red.* Acetate of alumina is the mordant, and madder is the dye stuff.

5. *Pale red* of different shades. The preceding mordant diluted with water, and a weak madder bath.

6. *Brown* or *Pompadour.* A mixed mordant, containing a somewhat larger proportion of the red than of the black; and the dye of madder.

7. *Orange.* The red mordant; and a bath first of madder, and then of quercitron.

8. *Yellow.* A strong red mordant; and the quercitron bath, whose temperature should be considerably under the boiling point of water.

9. *Blue.* Indigo, rendered soluble and greenish yellow colored, by potash and orpiment. It recovers its blue color, by exposure to air, and thereby also fixes firmly on the cloth. An indigo vat is also made, with that blue substance, diffused in water with quicklime and copperas. These substances are supposed to deoxidize indigo, and at the same time to render it soluble.

Golden-dye. The cloth is immersed alternately in a solution of copperas and lime water. The protoxide of iron precipitated on the fibre, soon passes, by absorption of atmospherical oxygen, into the golden-colored deutoxide.

Buff. The preceding substances, in a more dilute state.

Blue vat, in which white spots are left on a blue ground of cloth, is made, by applying to these points a paste composed of a solution of sulphate of copper and pipe clay; and after they are dried, immersing it stretched on frames for a definite number of minutes, in the yellowish-green vat, of one part of indigo, two of copperas, and two of lime, with water.

Green. Cloth dyed blue, and well washed, is imbued with the aluminous acetate, dried, and subjected to the quercitron bath.

In the above cases, the cloth, after receiving the mordant paste, is dried, and, after some preparation, put into the dyeing vat of copper.

Fugitive Colors.—All these colors are given, by making decoctions of the different coloring woods; and receive the slight degree of fixity they possess, as well as great brilliancy, in consequence of their combination or admixture with the nitro-muriate of tin.

1. *Red* is frequently made from Brazil and Peachwood.

2. *Black.* A strong extract of galls, and deuto-nitrate of iron.

3. *Purple.* Extract of logwood and the deuto-nitrate.

4. *Yellow.* Extract of quercitron bark, or French berries, and the tin solution.

5. *Blue.* Prussian blue and solution of tin.

Fugitive colors are thickened with gum tragacanth, which leaves the cloth in a softer state than gum senegal; the goods being sometimes sent to market without being washed.

TINGRY's Painter and Varnisher's Guide, 8vo. translated 1816;—ELMES' Dictionary of Fine Arts, 8vo. 1826;—JAMES' Panorama of Science and Art, 2 vols. 8vo. 1816;—BANCROFT on permanent Colors, 2 vols. 8vo. 1814;—BERTHOLLET, Elements of the Art of Dyeing, translated by Ure, 2 vols. 8vo. 1824;—GAY LUSSAC, *Cours de Chimie*, 2 vols. 8vo. 1828;—BRANDE's Chemistry, 1820;—TURNER's Chemistry, 1828;—PARKES' Chemical Essays, 1823;—URE's Dictionary;—VITALIS, *Cours élémentaire de teinture*, 1823.

CHAPTER XIX.

ARTS OF VITRIFICATION.

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 siliceous 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

* 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.

minute division, not requiring to be pulverized. Pure siliceous 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 pearl ash is used, or soda procured by decomposing 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 siliceous 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 30 or 40 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 ves-

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

sels 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. 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 pearl ash, 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 to make the two surfaces parallel, a heavy roller of polished copper, weighing 500 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 commerce 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 surface of the wheel.

Stained Glass.—The name of *staining* has been applied 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,

* Particularly at Lechmere's Point, and Sandwich.

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 pearl ash, 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 are found to 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 viewedby 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 semiopaque 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 greyish 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.

* *Journal de Physique*, 1804.—*Thenard, Chimié*, ii. 473.

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.

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 inclosed or incrusted, with glass. This art was first attempted by inclosing in glass small figures made of a peculiar kind of clay; but these experiments were but in few instances sucessful, 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.

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 180 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 imperfect 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.

PARKES' Chemical Essays, 8vo. vol. ii.;—LOYSEL, *Essai sur l'Art de la Verrerie*, 8vo. 1800;—BROGNIART, *Art de l'Emailleur*, *Annales de Chimié*, tom. ix. and other works;—Franklin Journal, v. 80;—Article Glass in Rees' Cyclopedia, and in the Edinburgh Encyclopedia;—CHAPTAL, *Chimié Appliquée aux Arts*, 4 vols. 8vo. 1806;—GRAY'S Operative Chemist, 8vo, 1828;—THENARD, *Traitè de Chimié*, vol. ii.;—BRANDE'S Chemistry;—BECKMAN'S History of Inventions, 4 vols. 8vo. translated 1797;—Works of NERI, BLANCOURT, KUNCKEL, REAUMUR, &c.

CHAPTER XX.

ARTS OF INDURATION BY HEAT.

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 inscripions 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 fall, 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

* Some travellers have even advanced an opinion that the Pyramids of Egypt are constructed with an artificial stone.

of a 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 exe-

* For different forms of tiles used at Florence, Trieste, &c. see Cadell's Journey in Italy and Carniola, Plate X.

cuted, both by the ancients and moderns. Not only vases, but imitations of sculpture, and 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 siliceous earths capable of communicating to them a semitransparency, 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 siliceous. 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 siliceous 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 siliceous 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 twofold. 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 80 or 90 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 inclosed in cases, or boxes, of burnt clay, called *saggars*, in which it is heated red hot, by the flame circulating among the cases. The fire is kept up from 24 to 48 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 ra-

* 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.

tio 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 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 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 semitransparency. 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 semitransparent 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.

* See the article Porcelain, in the Edinburgh Encyclopedia, ascribed to M. Brogniart.

Parkes' Chemical Essays, vol. ii.;—Rees' Cyclopedia and Edinburgh Encyclopedia, articles Pottery, Porcelain, &c.;—Chaptal, *Chimié Appliquée aux Arts*, tom. iii.;—Gray's Operative Chemist, 8vo. 1828.

CHAPTER XXI.

ON THE PRESERVATION OF ORGANIC SUBSTANCE.

Decomposition.—THE compounds which are spontaneously formed by organic bodies, both vegetable and animal, are of a different nature from those which exist in unorganized matter. They are the peculiar results of vital processes, and neither their structure nor composition can be imitated by art. During life, the elements of organic bodies are held together by vital affinities, under the influence of which they were originally combined. But no sooner does life cease, than these elements become subject to the laws of inert matter. The original affinities, which had been modified, or suspended, during life, are brought into operation; the elementary atoms react upon each other, new combinations are formed, and the organized structure passes sooner or later into decay.

The rapidity with which decomposition takes place in organic bodies, depends upon the nature of the particular substance, and upon the circumstances under which it is placed. Temperature, moisture, and the presence of decomposing agents, greatly affect both the period, and extent of this process. By regulating, or preventing, the operation of these causes, the duration of most substances may be prolonged, and many materials are rendered useful, which, if left to themselves, would be perishable and worthless. The preservation of timber, of fibrous substances, of leather, of food, and of various objects of art, are subjects of the highest importance, and have received, at various times, much attention from scientific experimentalists.

Temperature.—The influence of temperature, in accelerating or retarding the decay of organized substances, is generally known. Cold tends to check the progress of destructive fermentation, and when it extends so far as to produce congelation, its preservative power is complete. Bodies of men and animals have been found frozen, in situations where they had remained for years, and even ages; and the recent discovery of an elephant in the ice of Siberia, shows that the period of this preservation is unlimited. On the other hand, in warm seasons and in hot climates, everything tends to corruption and decay. Both animal and vegetable substances, pass rapidly into the putrefactive fermentation; alimentary substances are difficult to preserve, and when moisture is combined with heat, ships, houses, and other structures of wood, as well as cordage, canvass, and clothing, have the period of their duration greatly abridged.

Dryness.—Although certain degrees of heat, especially when combined with moisture, tend greatly to promote decomposition, yet if the degree of heat, and the circumstances under which it acts, are such as to produce a perfect dissipation of moisture, the further progress of decay is arrested. The exertion of chemical affinities usually requires that one of the agents at least should be in a fluid state. And while a body is in a state of perfect dryness, no internal chemical change is likely to befall it. The beams and furniture of houses, often remain entire for centuries. In the arid caverns of Egypt, the wood of sarcophagi appears to have undergone no alteration in the lapse of two or three thousand years, the fibres of linen textures are found distinct and perfect, though weakened in strength, and the dried flesh of the mummies themselves discover no marks of decomposition. In cabinets of Natural History, the specimens, so long as they are kept perfectly dry, undergo no alteration from spontaneous decay. They are, however, extremely liable to the depredations of insects, from which they require to be protected, either by impregnating them with poisonous substances, or by inclosing them in cases which are hermetically tight.

Wetness.—Some materials, especially wood, are capable of lasting for a long time, if kept continually immersed in water, especially at low temperatures. Thus the lower part of a pump log is much more durable than the upper, if kept always under water. The effect of pure water is to dissolve and carry off the soluble parts, leaving the fibrous structure in a state less liable to fermentation than before. Some animal substances, likewise, such as leather, bear immersion in water for a considerable time. It must be observed, however, that the effect of wetness upon most organized bodies, is to soften their texture, and render them less able to support mechanical violence, than when dry. Wood, after having been long immersed, if taken out and dried, is found to be more brittle than it was before.

But the state which most rapidly promotes decay, is that of alternate moisture and dryness, attended with exposure to the atmospheric air. It appears in regard to wood, that in each wetting, a sensible portion of substance is dissolved, and that in each drying, a new portion of soluble matter is formed. In a ship, under common circumstances, the parts which first decay, are those which are situated between wind and water, or are subjected to alternate dryness and moisture. So also in a post standing in the earth, the part which first decays, is usually that which is nearest the surface of the ground. Exposure to the vicissitudes of weather, is also one of the most common and active causes of decomposition.

Antiseptics.—A certain class of substances has received the name of antiseptics, from their power, when present, of resisting putrefaction in organic bodies, as well as in their products. Such are charcoal, tannin, resins, camphor, bitumen, sugar, chlorine, alcohol, oils, acids, and salts of various kinds. The manner in which they exert their preservative agency is not fully understood. It appears, however, that in some cases they combine with the substance to be preserved, forming a less perishable compound, as in the instance of leather; and probably in other instances they unite with and qualify the decomposing agents which are present.

Timber.—A vast expense is every year created by the premature decay of wood, employed in ships and other structures, which are exposed to vicissitudes of weather, and especially if they are subjected to the influence of warmth combined with moisture. Trees of different species, vary greatly in the durability of their wood, yet none of the species commonly employed, are capable of withstanding, for many years, the effect of unfavorable exposures and situations. The decay of timber is sometimes superficial, and sometimes internal. In the former case, the outside of the wood first perishes and crumbles away, and successive strata are decomposed, before the internal parts become unsound. In the other species, which is distinguished by the name of the *dry rot*, the disease begins in the interior substance of the wood, particularly of that which has not been well seasoned, and spreads outwardly, causing the whole mass to swell, crack, and exhale a musty odor. Different fungous vegetables sprout out of its substance, the wood loses its strength, and crumbles finally into a mass of dust. This disease prevails most in a warm, moist, and confined atmosphere, such as frequently exists in the interior of ships, and in the cellars and foundations of houses. Its destructive effects in ships of war, have given rise of late to numerous publications. Some writers consider that the dry rot is not essentially different from the more common kinds of decay, but there seems to be sufficient reason for the distinction which has usually been drawn. The prevention of the evil has been attempted in various ways, and with some degree of success.

Felling.—It is agreed by most writers that the sap of vegetables is the great cause of their fermentation and decay. Hence it appears desirable, if there is any season, in which the trunk of a tree is less charged with sap than at others, that this time should be selected for felling it. The middle of summer and the middle of winter, are undoubtedly the periods when the wood contains least sap. In the months of spring and fall, in which the roots prepare sap, but no leaves exist to expend it, the trunk is overcharged with sap; and in many trees, as the maple and birch, sap will flow out at these seasons, if the trunk is wounded. In summer, on the contrary, when the leaves are out, the sap is rapidly expended, and in winter, when the roots are dormant, it is sparingly produced; so that no surplus of this fluid apparently exists. From reasoning *a priori*, it would seem that no treatment would be so effectual in getting rid of the greatest quantity of sap, as to girdle the tree, by cutting away a ring of alburnum, in the early part of summer, thus putting a stop to the further ascent of the sap, and then to suffer it to stand until the leaves should have expended, by their growth, or transpiration, all the fluid which could be extracted by them previously to the death of the tree.* The wood would thus probably be found in the driest state to which any treatment could reduce it in the living state. Buffon has recommended stripping the trees of their bark in spring, and felling them in the subsequent fall. This method is said to harden the alburnum, but the cause is not very apparent, nor is the success at all certain.

Seasoning.—At whatever period timber is felled, it requires to be thoroughly seasoned, before it is fit for the purposes of carpentry. The object of seasoning is partly to evaporate as much of the sap as possible, and thus to prevent its influence in causing decomposition; and partly to reduce the dimensions of the wood, so that it may be used without inconvenience from its further shrinking. Timber seasons best, when placed in dry situations, where the air has a free circulation round it. Gradual drying is considered a better preservative of wood, than a sudden exposure to warmth, even of the sun; for warmth abruptly applied, causes cracks and flaws from the sudden and unequal expansion produced in different parts. Two or three years' seasoning is requisite to produce tightness and durability in the wood work of buildings. It must be observed that seasoning in the common way, only removes a portion of the

* See McWilliam on the Dry Rot, pages 151, and 158.

aqueous and volatile matter from the wood. The extractive and other soluble portions still remain, and are liable to ferment, though in a less degree, whenever the wood reabsorbs moisture. Such, indeed, is the force of capillary attraction, that wood, exposed to the atmosphere in our climate, never gives up all its moisture.

Preservation of Timber.—When wood is to be kept in a dry situation, as in the interior of houses, no other preparation is necessary than that of thorough seasoning. But when it is to be exposed to the vicissitudes of weather, and still more when it is to remain in a warm and moist atmosphere, its preservation often becomes extremely difficult. Numerous experiments have been made, and many volumes written, upon the preservation of timber, and the prevention of the dry rot; but the subject is not yet brought to a satisfactory conclusion. The methods which have hitherto been found most successful, consist in extracting the sap, in excluding moisture, and in impregnating the vessels of the wood with antiseptic substances.

For extracting the sap, the process of *water seasoning* is recommended. It consists in immersing the green timber in clear water for about two weeks, after which it is taken out and seasoned in the usual manner. A great part of the sap, together with the soluble and fermentable matter, is said to be dissolved or removed, by this process. Running water is more effectual than that which is stagnant. It is necessary that the timber should be sunk, so as to be completely under water, since nothing is more destructive to wood, than partial immersion. Mr Langton* has proposed to extract the sap by means of an air pump, the timber being inclosed in tight cases, with a temperature somewhat elevated, and the sap being discharged in vapor by the operation of the pump.

It appears extremely probable, that if trees were felled in summer, and the buts immediately placed in water without removing the branches, a great part of their sap would be ex-

* Repertory of Arts, 1826. Franklin Journal, ii. and vi.

pended by the vegetative process alone, and replaced by water. It is well known that branches of plants, if inserted in water, continue for some days, to grow, to transpire, and to perform their other functions. This they probably do at the expense of the sap, or assimilated fluid, which was previously in them, while they replace it by the water they consume. This state of things continues until the juices are too far diluted to be capable of any longer sustaining life.

The *charring* of timber by scorching, or burning its outside, is commonly supposed to increase its durability, but on this subject the results of experiment do not agree. Charcoal is one of the most durable of vegetable substances, but the conversion of the surface of wood into charcoal, does not necessarily alter the character of the interior part. As far, however, as it may operate in excluding worms, and arresting the spreading of an infectious decay, like the dry rot, it is useful. Probably also, the pyroligneous acid which is generated when wood is burnt, may exert a preservative influence.

The exclusion of moisture by covering the surface with a coating of paint, varnish, tar, &c., is a well known perservative of wood which is exposed to the weather. If care is taken to renew the coat of paint, as often as it decays, wood on the outside of buildings, is sometimes made to last for centuries. But painting is no preservative against the internal or dry rot. On the contrary, when this disease is begun, the effect of paint, by choking the pores of the wood, and preventing the exhalation of vapors and gases which are formed, tends rather to expedite, than prevent the progress of decay. Paint itself is rendered more durable, by covering it with a coating of fine sand. Wood should never be painted, which is not thoroughly seasoned.

The impregnation of wood with tar, bitumen, and other resinous substances, undoubtedly promotes its preservation. It is the opinion of some writers,* that 'woods abounding in re-

* Tredgold's Elementary Principles of Carpentry, page 166.

sinous matter, cannot be more durable than others,' but the reverse of this is proved every year in the pine forests of this country, where the *lightwood*, as it is called, consisting of the knots and other resinous parts of pine trees, remains entire, and is collected for the purpose of affording tar, long after the remaining wood of the tree has decayed. A coating of tar or turpentine, externally applied to seasoned timber, answers the same purpose as paint in protecting the wood, if it is renewed with sufficient frequency. Wood impregnated with drying oils, such as linseed oil, becomes harder, and more capable of resisting moisture. It is frequently the custom, in this country, to bore a perpendicular hole in the top of a mast, and fill it with oil. This fluid is gradually absorbed by the vessels of the wood, and penetrates the mast to a great distance. Animal oils, in general, are less proper for this purpose, being more liable to decomposition.

The preservative quality of common salt (muriate of soda), is well known. An example of its effect is seen in the hay of salt marshes, which is frequently housed before it is dry, and which often becomes damp afterwards from the deliquescence of its salt, yet remains unchanged for an indefinite length of time. In the salt mines of Poland and Hungary, the galleries are supported by wooden pillars, which are found to last unimpaired for ages, in consequence of being impregnated with the salt, while pillars of brick and stone, used for the same purpose, crumble away in a short time by the decay of their mortar. Wooden piles driven into the mud of salt flats and marshes, last for an unlimited time, and are used for the foundations of brick and stone edifices. In canals which have been made in the salt marshes about Boston and other places, trunks of oak trees are frequently found with the heart wood entire and fresh, at a depth of five or six feet below the surface. At Medford, Mass. the stumps of trees are found standing in the gravelly bottom of the salt marsh where the tide rises in the canals four or five feet above them. This bottom must originally have constituted the surface of the ground, and must have settled long enough ago for the marsh mud to have accumulated, as it has done for miles round, apparently since that period.

The application of salt in minute quantities, is said rather to hasten than prevent the decay of vegetable and animal bodies. Yet the practice of *docking* timber, by immersing it for some time in sea water, after it has been seasoned, is generally admitted to promote its durability. There are some experiments which appear to show, that after the dry rot has commenced, immersion in salt water effectually checks its progress, and preserves the remainder of the timber.* In some of the public ships built in the United States, the interstices between the timbers in various parts of the hull, are filled with dry salt. When this salt deliquesces, it fills the pores of the wood with a strong saline impregnation, but it has been said, in some cases, to render the inside of the vessel uncomfortably damp. If timber is immersed in a brine made of pure muriate of soda, without the bitter deliquescent salts which sea water contains, the evil of dampness is avoided.

A variety of other substances besides common salt, act as antiseptics in preventing the dry rot, and the growth of the fungus which attends it. Nitre and alum have been recommended for this purpose, and some of the metallic salts are considered still more effectual. Of these, the sulphates of iron, copper, and zinc, have the effect to harden and preserve the timber. Wood boiled in a solution of the former of these, and afterwards kept some days in a warm place to dry, is said to become impervious to moisture. Corrosive sublimate, which is recommended by Sir H. Davy, is a powerful preservative of organized substances from decay, and proves destructive to

* The British frigate Resistance, which went down in Malta harbor, and the Eden, which was sunk in Plymouth Sound, were both affected with dry rot. These ships, after remaining many months under water, were raised, and it was found that the disease was wholly arrested. Every vestige of fungus had disappeared, and the ships remained in service afterwards, perfectly sound from any further decay. Supplement to the Encyclopedia Britannica, iii. 682.

parasitic vegetables and animals; but its safety, in regard to the health of crews if used in large quantities about the wood of a ship, may be considered as doubtful.

An opinion has been supported in this country, that the decay of timber in ships, by dry rot, is owing to the impure atmosphere generated by bilge water, and that it is to be remedied by constructing ships with a view to their free and effectual ventilation.*

Preservation of Animal Textures.—The solid and fibrous portions of organic bodies, such as wood, bone, shell, horn, hair, cotton, &c., are most easy of preservation. But the soft and succulent parts, such as the pulp of vegetables, and the flesh of animals, are extremely perishable, owing to the decomposing influence of their fluid contents; and require the assistance of art to communicate to them any degree of durability. These substances, when they cannot be dried, are usually preserved by enveloping or impregnating them with antiseptics. For alimentary substances the antiseptics used are sugar, alcohol, salt, and the acetous and pyroligneous acids; while, for scientific specimens and preparations, alcohol, oil of turpentine, resinous and bituminous varnishes, alum, and corrosive sublimate are found most effectual.

Embalming.—As the art of embalming can hardly be ranked among the useful arts, any further than it can be made subservient to the promotion of anatomy, or natural history, it is not much cultivated at the present day. The ancient Egyptians converted the dead bodies of their friends into mummies, by removing the viscera from the large cavities, and replacing them with aromatic, saline, and bituminous substances, particularly asphaltum; and also enveloping the outside of the body in cloths impregnated with similar materials. These impregnations prevented decomposition, and excluded insects, until perfect dryness took place. In times comparatively modern, embalming has been practised with great success, particularly

* See a pamphlet on Dry Rot, by Commodore Barron, Norfolk, 1828.

where bodies have remained at a low and uniform temperature, and have been protected from the access of the air. The body of king Edward the First, of England, appears upon record to have been embalmed. He died in July, 1307, and was buried in Westminister Abbey. In 1770, his tomb was opened, and the contents examined, and after this lapse of 463 years, the body of the monarch remained entire. The flesh upon the face was a little wasted, but not putrid. The body of Canute, king of Denmark, who invaded England in 1017, was found very fresh in 1776, by the workmen employed in repairing Winchester Cathedral. The bodies of William the Conqueror, and of Matilda his wife, both buried at Caen, were found entire in the sixteenth century. In like manner, the remains of various other princes, and persons of note, have been discovered to be undecayed some centuries after their decease. In certain cases, bodies not embalmed have been preserved, merely by the exclusion of air, and a uniform low temperature.

But the most perfect of all the modes of preserving the animal body, without continued immersion, appears to be a thorough impregnation with corrosive sublimate. This may be performed, by saturating the soft solids with a strong solution, consisting of about four ounces of bichloride of mercury to a pint of alcohol. This is injected into the blood vessels, and after the viscera are removed, the whole body is immersed for three months in the same solution. At the end of this period it easily dries, and is afterwards nearly imperishable.*

In what are called by anatomists *wet preparations*, the objects are kept immersed in alcohol, and last for an indefinite time. Oil of turpentine answers the same purpose, and in the Museum of Natural History, in Paris, there is a head prepared in this way, more than a hundred years ago, by the celebrated Ruytch, which preserves all the vivacity of its colors. In cold weather the liquid becomes opaque, but is again rendered transparent in the spring.

* See a paper by Dr J. C. Warren, on Embalming, in the Boston Journal of Arts, vol. i. p. 269.

Tanning.—The skins of animals, when prepared by merely drying them, are stiff, incapable of resisting water, and liable to decay. If, however, they are impregnated with the *tannin* which is found in astringent vegetables, that substance combines with the gelatin of the skin, and forms a durable compound, which is no longer soluble in water. Common tanned leather is prepared in this way. The skins are previously prepared by soaking them in lime water, which facilitates the separation of the cuticle and hair. A slight degree of putrescency assists the same object. They are then immersed in the tan pits, in a strong infusion of some astringent vegetable. Oak bark, from its cheapness, and the quantity of tannin it contains, is commonly employed in the preparation of leather, both in this country, and in Europe. The bark of the hemlock spruce, and of the chesnut, the leaves of the different species of sumach, and various other astringent vegetables, are used in sections of country where oak is scarce. The strength of the astringent infusion is increased from time to time, until the skin is saturated with tannin. A portion of extractive matter likewise combines with the hide, and to this the brown color, which is common in leather, is owing. The presence of this extractive is supposed to render leather more tough and pliable.

When strong or saturated solutions of tannin are used, the leather is formed in a much shorter time, but it is observed that leather tanned in this way is more rigid and more liable to crack, than that made in the common manner, with weaker infusions, gradually increased in strength. But sole leather, the most important requisites of which are firmness and resistance to water, is immersed in an infusion kept nearly saturated by alternate strata of bark. The full impregnation requires from 10 to 18 months.

The *currying* of leather is performed by covering the skin or leather, while yet moist, with common oil, which, as the moisture evaporates, penetrates into the pores of the skin, giving it a peculiar suppleness, and rendering it, to a certain extent, water proof. During the process, it is pared, washed, and rubbed, to increase its flexibility. The black color is also imparted by the currier, by rubbing the outside with a solution of copperas, or any solution of iron, which immediately turns it black, by combining with the tannin in the leather.

Tawing is the method by which skins are dressed of a white color, and it is performed without the use of bark. The skins are first prepared by steeping them in lime water, and subjecting them to various processes of scraping and fulling. They are then fermented with wheat bran, and afterwards impregnated with a solution of alum and common salt. Before being dried, they are fulled with wheat bran and yolks of eggs, and are thoroughly trodden, steeped, and washed. In this process, the place of tannin appears to be supplied by some principle extracted from the alum.

As examples of the foregoing processes, common sole leather is simply *tanned*, the upper leather of boots and shoes, is *tanned* and *curried*, the white leather for gloves is *tawed*, and fine morocco leather is *tawed*, and afterwards slightly *tanned* with sumach, and dyed. *Chamois*, and other kinds of *wash leather*, are steeped in lime pits, and afterwards fulled with oil. Before the dressing is finished, the superfluous oil is scoured out with an alkaline liquor.

Parchment.—Parchment used for writing, is prepared from the skins of sheep and goats. These, after being steeped in pits impregnated with lime, are stretched upon frames and reduced by scraping and paring, with sharp instruments. Pulverized chalk is rubbed on with a pumice stone resembling a muller, which smooths and softens the skin, and improves its color. After it is reduced to something less than half its original thickness, it is smoothed and dried for use. *Vellum* is a similar substance to parchment, made from the skins of very young calves.

Catgut.—The strings of certain musical instruments, the cords of clock weights, and those of some other machines and implements, are made of a dense strong, animal substance, among us usually denominated *catgut*. It is derived from the intestines of different quadrupeds, particularly those of cattle and sheep. The manufacture is chiefly carried on in Italy and France. The texture from which it is made, is that which anatomists call the *muscular* coat, which is carefully separated from the peritoneal and mucous membranes. After a tedious and troublesome process of steeping, scouring, fermenting, inflating, &c., the material is twisted, rubbed with horsehair cords, fumigated with burning sulphur, to improve its color, and dried. Cords of different size, and strength, and delicacy, are obtained from different domestic animals. The intestine is sometimes cut into uniform strips with an instrument made for the purpose. To prevent offensive effluvia during the process, and to get rid of the oily matter, the French make use of an alkaline liquid called *eau de Javelle.*

Gold Beater's Skin.—This delicate membrane is also manufactured from the intestines of animals. The workman strips off that part of the peritoneal membrane which surrounds the *cæcum.* He then takes about two feet of it in length, turns it inside out, and leaves it to dry. It is afterwards steeped in a weak solution of potash, cleansed by scraping, and cut open. It is then stretched to dry upon wooden frames, and notwithstanding the tenuity of the membrane when dry, every piece of it is double, or consists of two membranes glued together. It is finished by washing it with a solution of alum, and coating it with isinglass and whites of eggs, together with some aromatics to repel insects.*

Specimens in Natural History.—Preparations of animals intended to show their external form and characters, are made by detaching their skins, and stuffing or mounting these so as to represent the natural figure and attitudes of the animal. Quadrupeds and birds are preserved by extracting the body through an opening on the under side, at the same

* See Franklin Journal, iii. 223, and London Mechanics Magazine, vi. 63; also the Prize Essay of Labarraque, 1822.

time inverting the skin. The fleshy parts of the limbs are extracted through the same opening, also the neck, brain, and eyes, leaving the skull, if the animal be small. Care is taken not to injure the hair, or plumage. When the fleshy parts are removed, the inside of the skin is rubbed with some poisonous substance, usually arsenic,* to prevent insects. The skin is then returned to its natural situation, and filled with cotton or tow, or, what is still better, an artificial body, shaped out of wood, cork, or dried clay, may be introduced within the skin. The opening is sewed up, and wires are passed longitudinally through the legs and neck. These are afterwards bent into the proper position to give the attitude desired. Glass eyes are inserted, and the hair and feathers rendered as smooth as possible, and retained, while drying, in paper bandages.

Reptiles, and fishes without scales, are extracted by carefully separating the bones of the neck through an opening in the throat, or gills, and inverting the skin. In serpents, the whole body is easily extracted through the mouth. Fishes with scales cannot be turned without injury. It is therefore necessary to detach the skin carefully, without doubling it. Insects may be killed, without hurting their texture, by the fumes of burning sulphur, or prussic acid, or, in many cases, by pinching the breast. They are then secured by pins, and placed to dry with the wings and legs in the natural attitudes. Arsenic, or corrosive sublimate, is generally necessary to secure them from the depredations of other insects.

An Herbarium, or collection of dried plants, is usually formed by subjecting the plants, while fresh, to a sufficient pressure between folds of paper, to preserve their natural smoothness and regularity, until they become dry. The plants should be gathered at a time when their characters are most perfectly developed. A specimen in flower should be

* The following is the *arsenical soap* of Becœur, much used in France: Camphor 5 ounces, powdered arsenic 2 pounds, white soap 2 pounds, salt of tartar 12 ounces, lime 4 ounces, melted and triturated together.

preserved, and, if possible, one also in fruit. The plant must be carefully spread out on smooth, bibulous paper, so that the leaves, petals, &c., may be displayed as perfectly as possible. In this situation it is retained, and another sheet of paper turned gradually over it, commencing at one side, till the whole is covered. Several sheets of paper are then to be added to each side, and the whole placed to dry under a strong, equal pressure. In this way many plants may be preserved without further trouble, especially if the weather be warm and dry. The process, however, may be expedited by shifting the papers, or by passing over them occasionally a warm iron. These precautions are more necessary for succulent plants, or for others in cold and damp weather.

Appert's Process.—A method brought into notice by M. Appert, for preserving articles of food unchanged for several years, deserves to be noticed among the practical improvements of the present century. This method was partially known at a much earlier period, but its most successful modes of application were undoubtedly discovered by M. Appert. It consists in a very simple process. The articles to be preserved are inclosed in bottles, which are filled to the top with any liquid; for example, with the water in which the article, if solid, has been boiled. The bottles are closely corked, and cemented, to render them hermetically tight. They are then placed in kettles filled with cold water, and subjected to heat till the water boils. After the boiling temperature has been kept up for a considerable time, in some cases an hour, but varying with the character of the article to be preserved, the bottles are suffered to cool gradually. In this state, meats, vegetables, fruits, milk, and other substances, are preserved perfectly fresh, without any condiments, for long periods, of from one to six years. Instead of bottles, tin canisters are sometimes used, and rendered tight by soldering.

The remarkable effect of this process has been explained, by attributing the preservation of the articles to the total exclusion of atmospheric air. But as air, in common cases, is always present in sufficient quantities to excite fermentation, it is supposed that the application of heat serves to fix the small portion of atmospheric oxygen which is present, by combining it with some principle in the other substances; so that it is no longer capable of producing the fermentative action, which in parallel cases leads to decomposition.

CHAPMAN'S Treatise on the Preservation of Timber, 8vo. 1817;—TREDGOLD'S Elementary Principles of Carpentry, 4to. 1820;—McWILLIAM, on the Dry Rot, 4to. 1818;—Article *Dry Rot*, in the supplement to the Encyclopedia Britannica;—AIKEN'S Chemical Dictionary, article Leather;—LABARRAQUE, *l'Art du Boyaudeur; Bulletin, de la Société de l'Encouragement pour l'Industrié*, 1822;—LETTSOM'S Naturalist's Companion, 8vo.;—Taxidermy, or the Art of Collecting, Preparing, and Mounting Specimens in Natural History, London, 1823;—APPERT, Art of Preserving Animal and Vegetable Substances, London, translated, 1812;—Edinburgh Review, vol. 23, p. 104.

APPENDIX.

Safety of Steam Engine Boilers. The accidents which have happened to the boilers of steam engines may properly be divided into two classes; those of simple *rupture*, and those of *explosion*. These two casualties apparently occur under different states of things. The simple *rupture* of boilers has usually taken place at a temperature not greatly exceeding that at which engines are commonly worked, and has in many instances been the consequence of some weakness or defective condition of the metal. In such cases, the elastic force of the steam not being very great, the strain has been gradual, the accident has in some cases been preceded by a swelling out, or gradual yielding of the weakened part; and when the rupture has taken place, the consequences have not usually been of a very alarming nature. Against this accident a sufficient remedy is found in attending to the proper preservation of the metal, and regulation of the safety valves.

The *explosions* of boilers, in which the contents and fragments are projected to a distance with great force, are in many cases apparently the result of an extraordinary *initial* force in the steam, and are probably caused by a portion of the metal which is not in contact with the water, becoming excessively heated; so that when water is brought suddenly into contigu ity with it, steam of great elastic force is suddenly generated. In this case, as in fire-arms, the bursting takes place before the *inertia* of surrounding moveable objects can be overcome, so that the water and safety valve, which would yield easily under *gradual* pressure, become insurmountable obstacles under *sudden* pressure.

Unfortunately, no remedy for this evil can well be applied to engines as they are now fitted up for use. In steam boats particularly, the sudden rolling and pitching of the vessel in rough weather, may cause heated portions of the boiler which were raised above the surface of the water at one minute, to be depressed below it at another. When this motion is regular, it serves to correct its own effects; but when it suddenly takes place in a greater degree than before, it is not free from danger. In still water the same thing may happen by the changing of the passengers or freight from one side of the boat to another. Even stationary boilers on land, may, in case of violent ebullition, be caused to explode, if the water is suffered to get too low, so that the metal becomes over-heated, and therefore capable of forming steam of great elastic force, when a sudden effervescence brings the water near to the heated parts.

The method which promises most effectually to obviate the danger, is that proposed by Mr Treadwell, and originally published in the Boston Daily Advertiser of May 17, 1830. This is a proposed plan for working steam at a pressure not exceeding that of the atmosphere. The importance of this paper will justify the insertion of the principal part of it at length, in the author's own words.

After speaking of the frequency and causes of these accidents, and the utter impossibility of guarding against the carelessness of attendants and subordinate agents employed about the engines, Mr Treadwell goes on to remark:—

'These considerations naturally suggest the question; whether it be possible to obtain a power, from steam, particularly for steam boats, without any pressure over that of the atmosphere? for this, and this alone, would put an end to all possibility of accident. Before attempting to show that there is no obstacle whatever in the way of this, it may be well to state briefly the mode in which engines are made to operate. I speak here altogether of the low pressure, or, more properly, the condensing engine; this, as I have before stated, being the most safe, although by no means free from danger. In working an engine, of this sort, it is usual to raise the steam in the boiler to exert a pressure of about 12 pounds, *above the pressure of the atmosphere*, upon every square inch of the surface which surrounds it. A portion of this steam is then suffered to pass into one end, suppose the top, of the cylinder, where it exerts, essentially, the same pressure which it possessed in the boiler. By this the piston is made to move through the cylinder to the bottom. When the piston has thus arrived at the bottom of the cylinder, the steam, with which the cylinder is now filled, is, by the operation of a peculiar apparatus, which it is not necessary to describe, condensed; at the same time, more steam, from the boiler, is let in to the bottom of the cylinder, and the piston is driven to the top, when this steam is condensed, and the piston is, by a further supply of steam, at the top of the cylinder, driven again to the bottom; and these operations are continually repeated.

'Let us now examine the force with which the piston is moved through the cylinder, under the conditions here named. If we take the steam to possess an elastic force of 12 pounds upon every inch of the area of the piston, above the pressure of the atmosphere, its whole elastic force must be 27 pounds, the force of the atmosphere never varying much from 15 pounds. Suppose the piston to be 50 inches in diameter, it will then contain an area of 1950 square inches nearly. We have then a force of 52,650 pounds pressure upon the end of the piston exposed to the steam. Now, on the opposite end of the piston, the steam having been condensed as much as possible, there is a vacuum. It is perfectly practicable to carry the condensation as low as 3 pounds to the inch; which, multiplied by 1950 inches, as before, gives 5850 pounds; and this small force only is opposed to the 52,650 pounds, which I have shown to be the pressure of the steam upon the piston. The piston will then move with a force of 52,650, less 5850 or 46,800 pounds. Let us now suppose that instead of using steam of an elastic force of 12 pounds *above* the pressure of the atmosphere, we use it at precisely the atmospheric pressure. It is evident that the force on the piston will then be 1950, the number of square inches, multiplied by 15, the pressure on each inch, or 29,250 pounds. The resistance on the opposite end will be as before, 5850 pounds, leaving the effective force 23,400 pounds. The same piston then will, if wrought with steam which exerts no pressure whatever, on the boiler, above the force of the atmosphere, give half as much force as when wrought with steam of 12 pounds to the inch.—To obtain an equal force, then, we have only to double the area of the piston, or to make its diameter 70,7 inches instead of 50. A boiler for such steam may be made of any material whatever, that will hold water. It may be made of sheet iron, of tin, of sheet lead; I might almost say of paper, for it is possible to boil water in a paper vessel. The boiler may be closed with a common pot-lid, and can no more burst than a tea-kettle.

'The facts before stated are so familiar to all engineers, that I ought not, perhaps, to have detailed them. They may not, however, have been known to all persons who yet travel in peril of life and limb. It is not to be expected that any change of this kind will be made in engines, unless they can be constructed and wrought without a greater cost than is required in the present mode. It is perfectly easy to show that this will be the case; for, first, no greater cost would be required in any part, except in the cylinder, piston, steam-pipes and valves, which must be made of double size, in this to the common engine, to furnish an equal force. The piston rod, lever beam, or cross head, connecting rods, shafts, cranks, indeed all the other moveable parts would be required of like size, for engines of like force, in either form of construction. The increase of size required in the cylinder and piston would be much more than compensated, by a diminution in the cost of the boiler. There would in fact be a very great saving of expense by adopting this mode of construction. The cost of working an engine consists principally in the maintenance of the fire; it is therefore directly as the quantity of fuel consumed or the quantity of heat required for the production of the steam. Now it may be said that for an engine of this construction, as the cylinder must be of twice the size of that ordinarily used, to produce an equal force, therefore a double quantity of steam must be used, and, consequently, a double quantity of fuel will be required for its production. This will, on examination, be found altogether fallacious. It is true that a double *volume* of steam will be required, but its density will be but little more than half as great as that of steam of double elastic force.—Now the heat contained in steam, from the boiler of an engine, is known to be, very nearly, in the direct ratio of its density. Two volumes therefore, the density of which shall be represented by 1, and one volume of a density represented by 2, will contain very nearly equal quantities of heat; and as the same quantity of heat may, in both cases, be obtained from the same fuel, we have the same power obtained at about the same cost, whether we use steam at the usual elastic force, or, merely sufficient to sustain the weight of the atmosphere.

'In the preceding statement I have constantly supposed the engines to be wrought in the ordinary mode, that is, at full pressure. If the steam were used expansively, there would be a difference in favor of that having the greater elastic force. But this is a hypothetical case, for the engines of steam boats are seldom used expansively, and, in the few instances where they are so used, it is not carried to an extent which would affect in any great degree the results above stated.

'There are many advantages incidental to the use of atmospheric steam, which are important besides those before enumerated. Amongst these are the saving of weight, in the boiler, the diminution of friction, in the piston, and the saving of a portion of the heat now lost by radiation.

'The mode of construction and use, here recommended, can hardly be called a new mode. The engine, as constructed by Newcomen, depended entirely upon the vacuum for its force; and the inprovements by which that engine has been superseded, consisted, not in increasing the elastic force of the steam, but, in a diffeient organization of the machine. In engines now used at the manufactories, in England, the steam is rarely raised to an elastic force greater than 4 pounds to the inch above the atmospheric pressure. Such engines are comparatively safe, and we seldom hear of accidents occasioned by them. Perfect safety, however, is only to be obtained by the use of steam of an elastic force not exceeding the weight of the atmosphere.'

FINIS.

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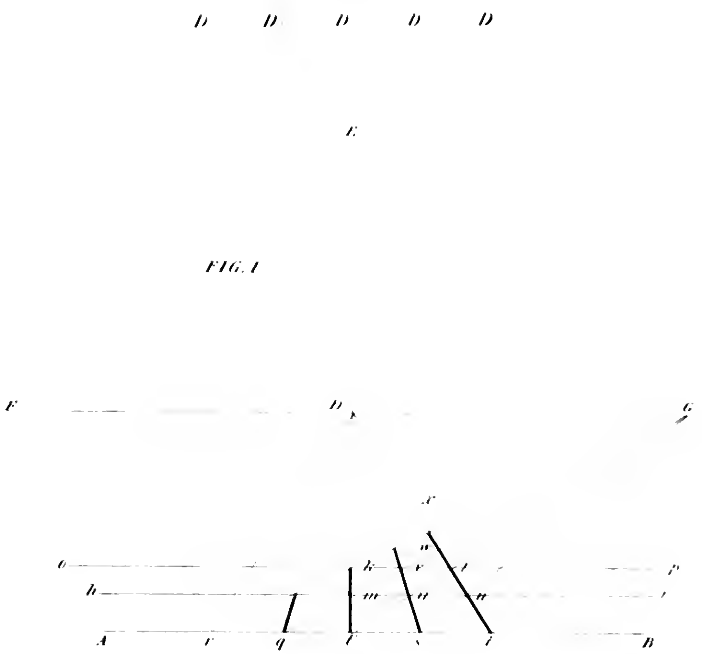

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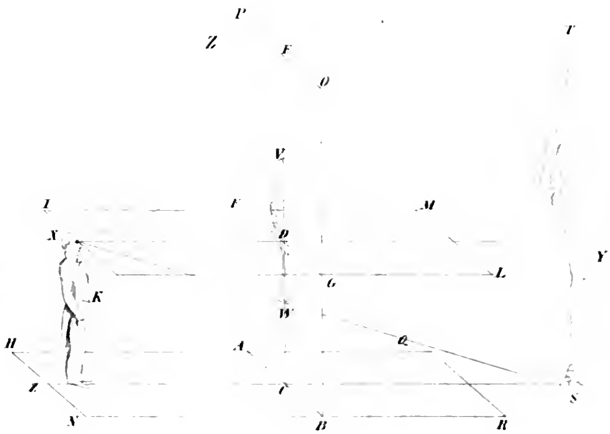

FIG. 2

FIG. 1

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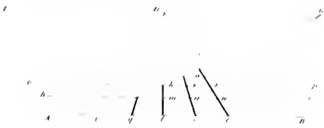

FIG. 2

Pl. III.

FIG. 5

FIG. 7

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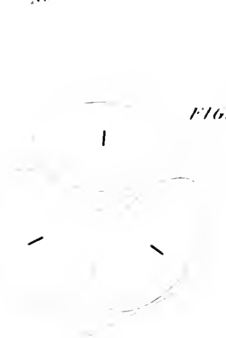
FIG. 9



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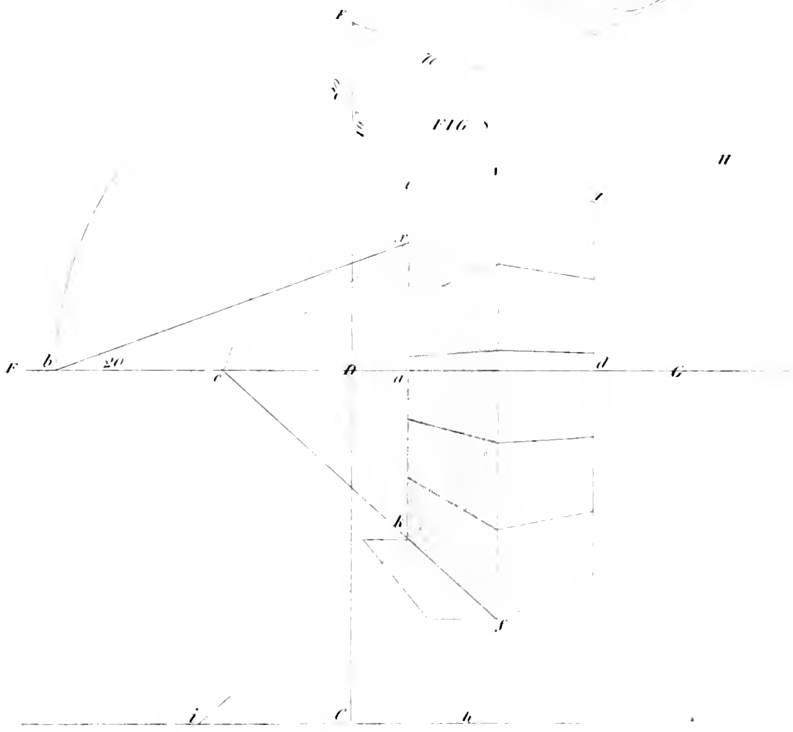
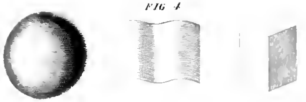


Pl. III.

FIG. 3

FIG. 4



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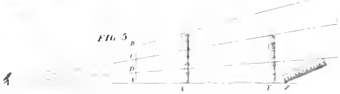

FIG. 6

FIG. 7

FIG. 7

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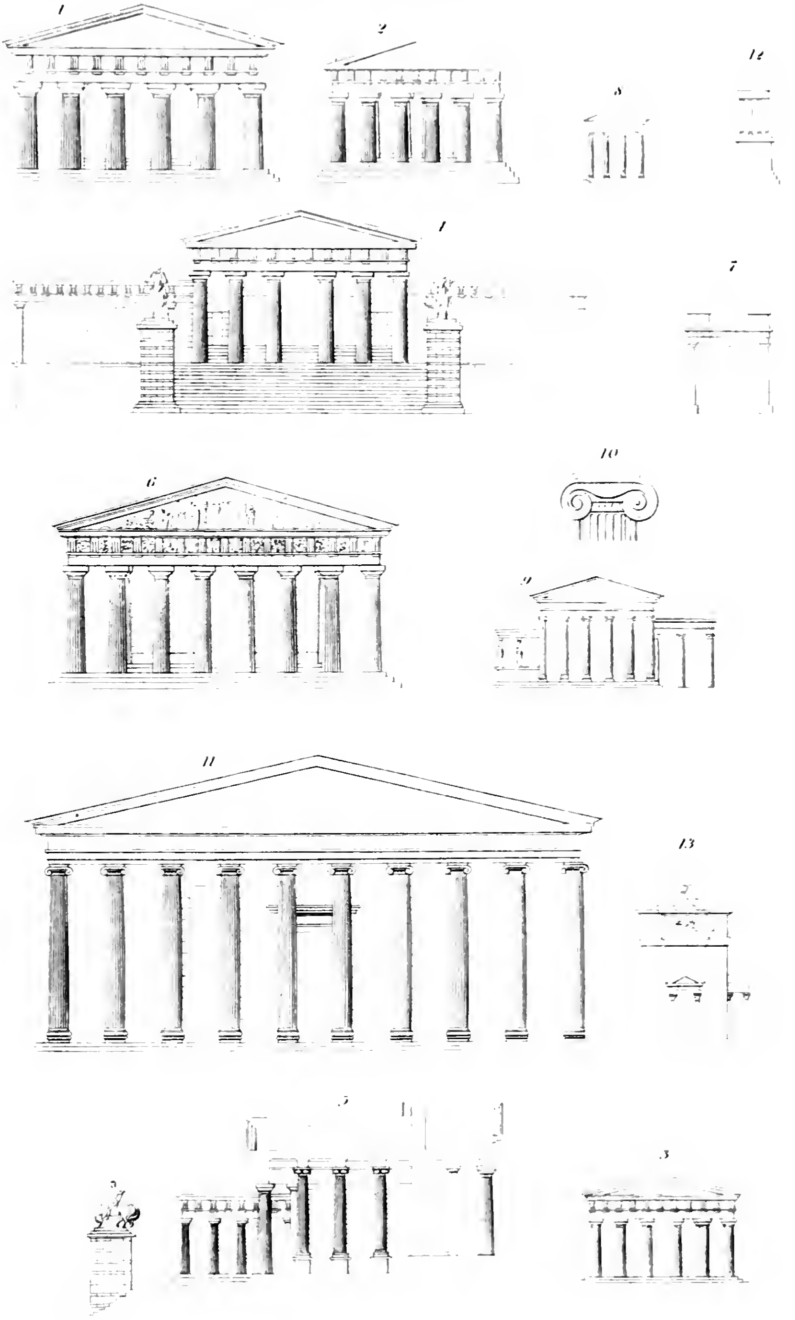

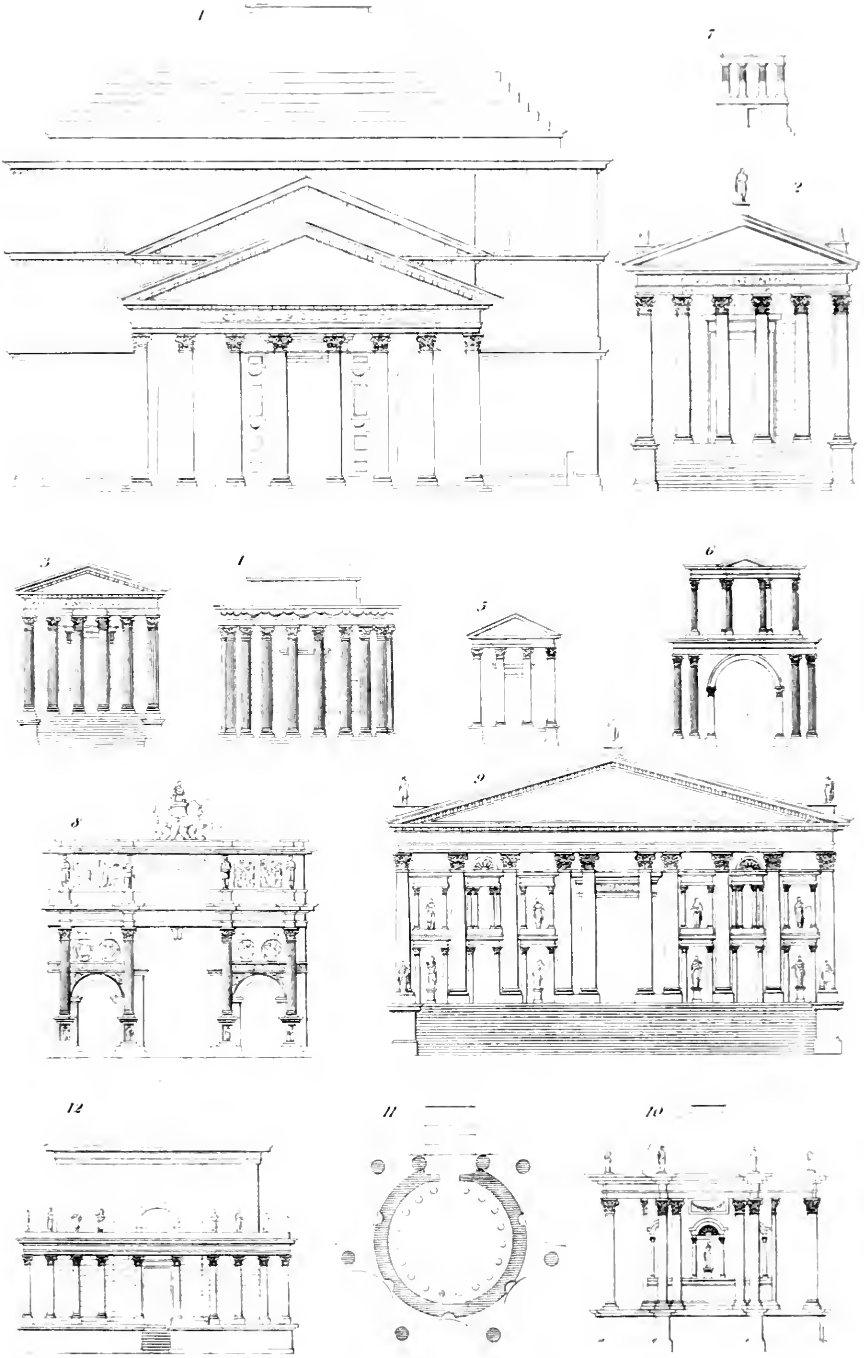
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EGYPTIAN, CHINESE, SARACENIC, & GOTHIC ARCHITECTURE.

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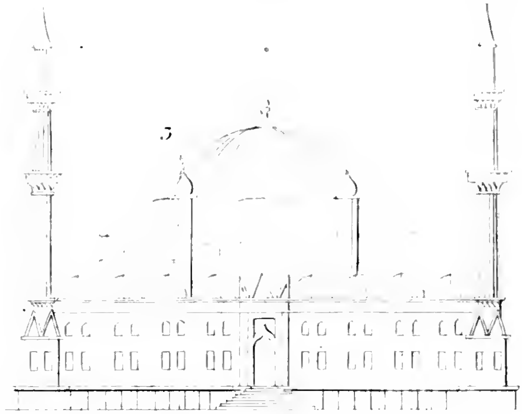

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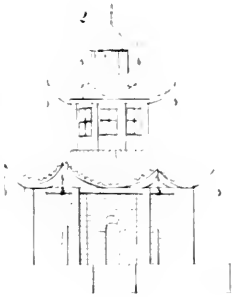

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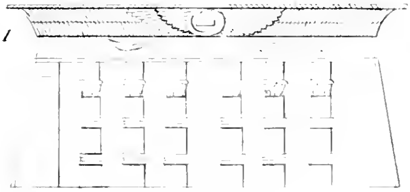

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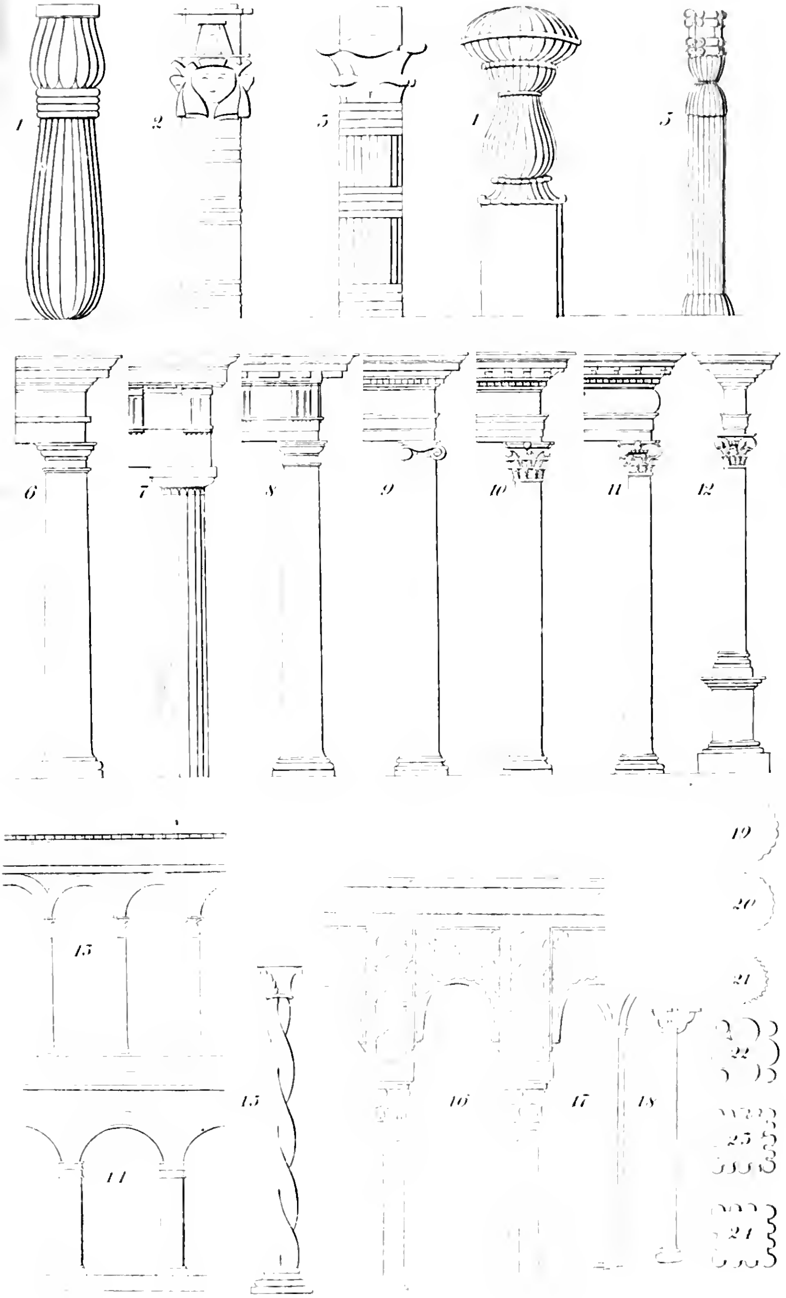
HISTORICAL SERIES OF COLUMNS AND ENTABLATURES.



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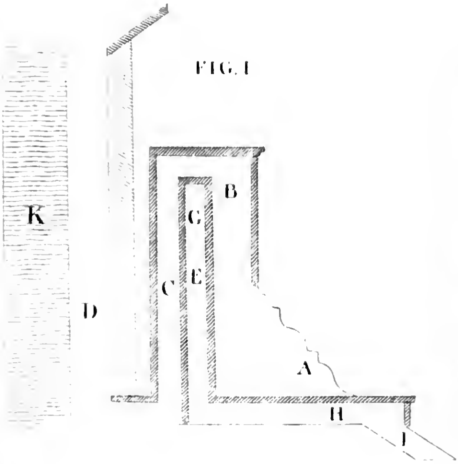

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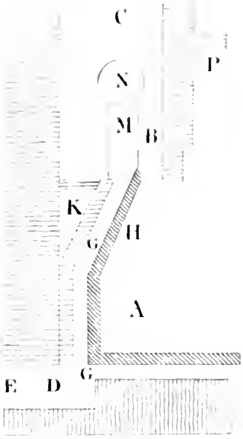

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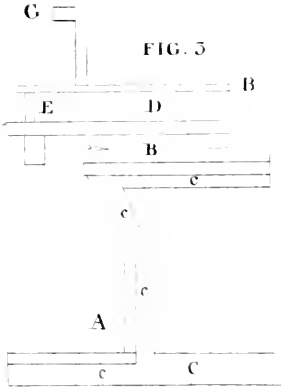

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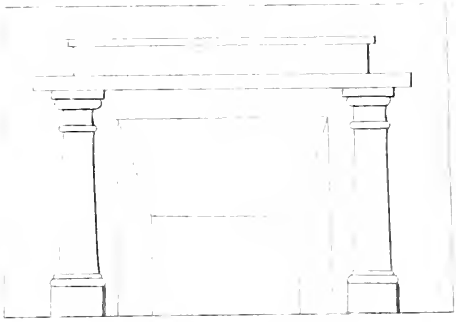

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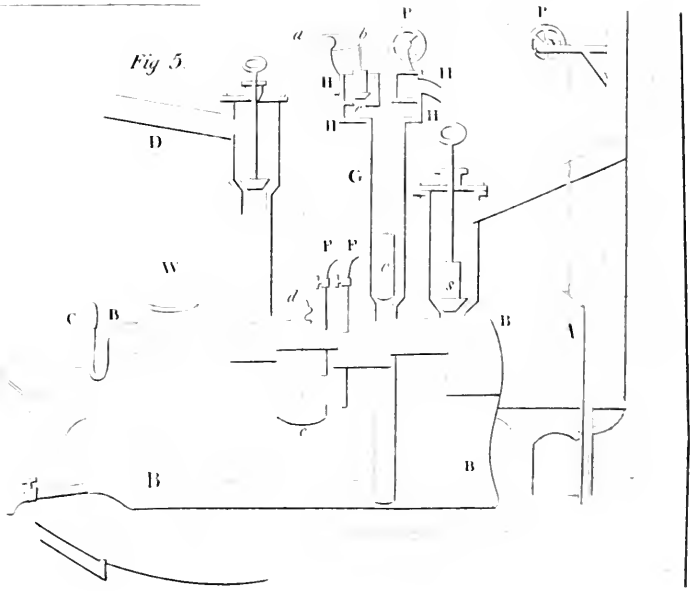

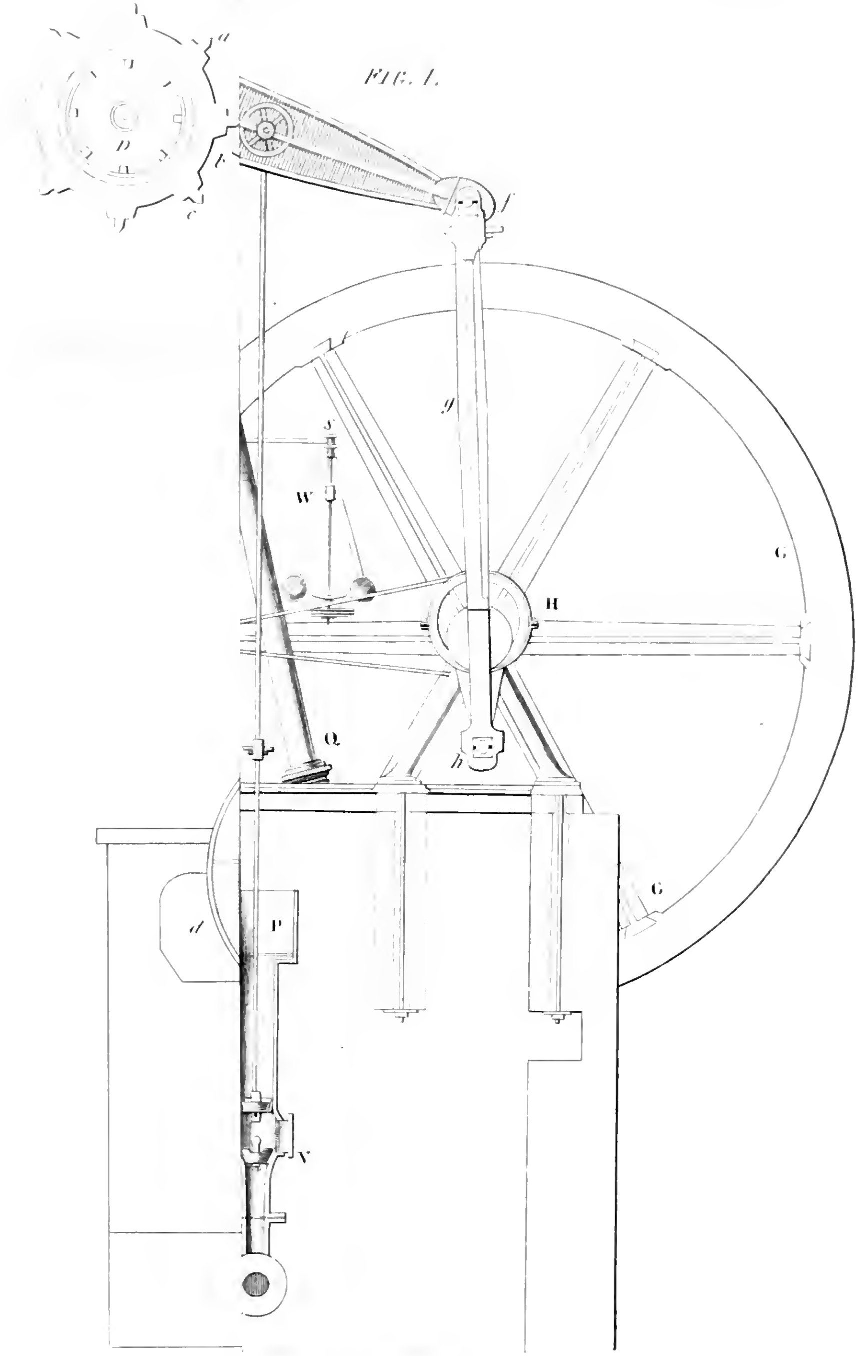
FIG. 1.
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V

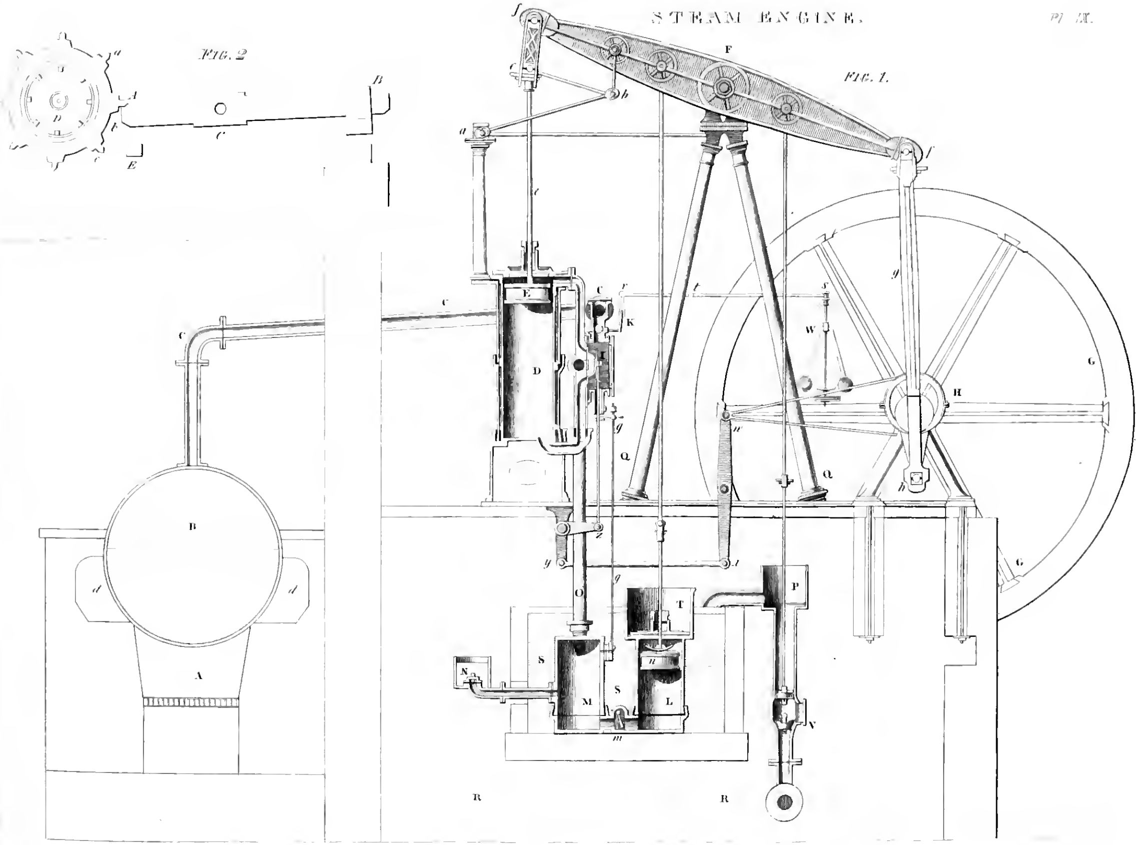


FIG. 2
FIG. 1.

HOROLOGY.

Pl. X.

Fig 1

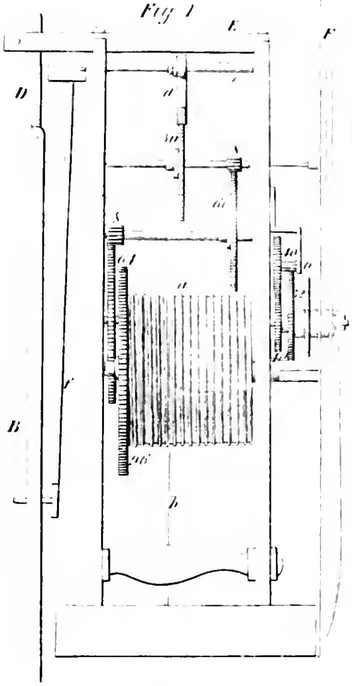


Fig 2

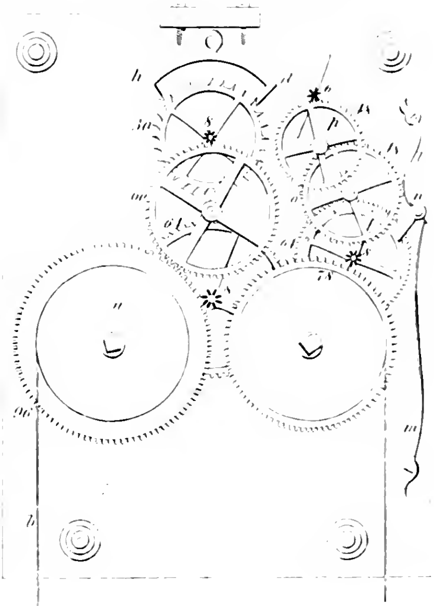


Fig 3

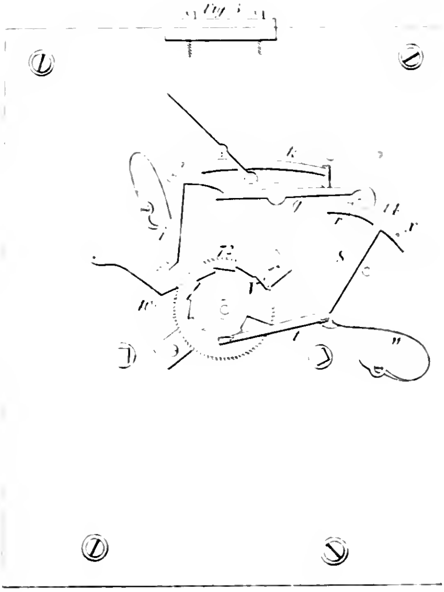


Fig 4

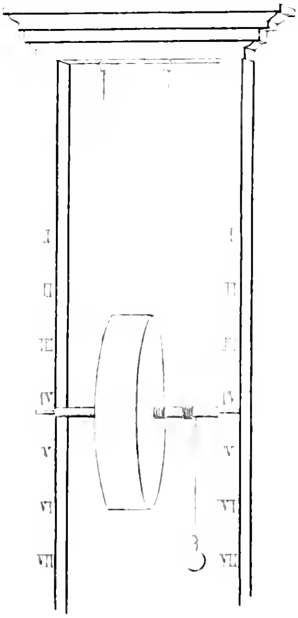


Fig 1

Fig 2

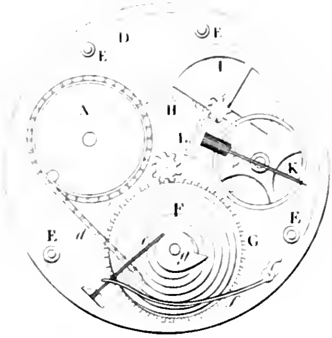


Fig 3

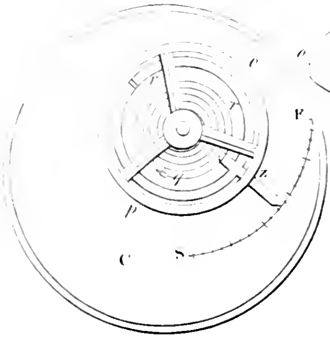
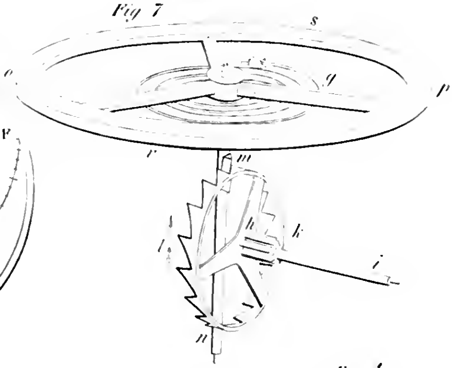


Fig 7



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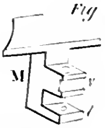
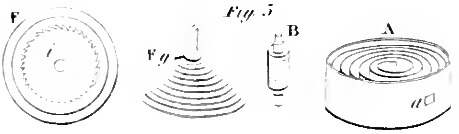


Fig. 5



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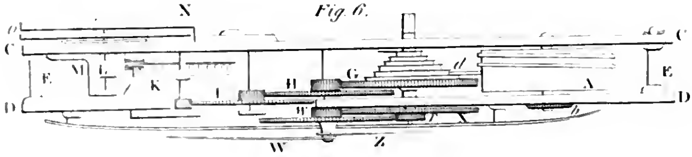
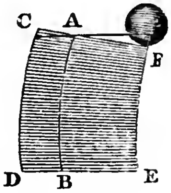


Fig. 1.



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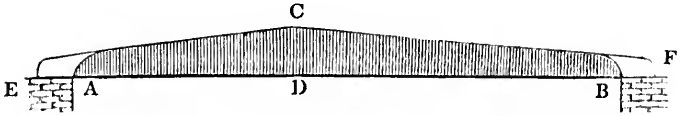

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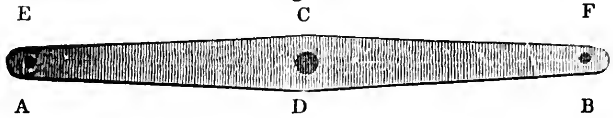

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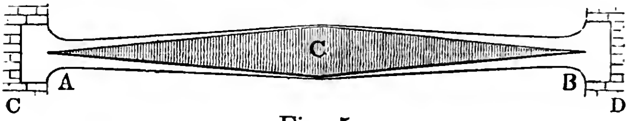

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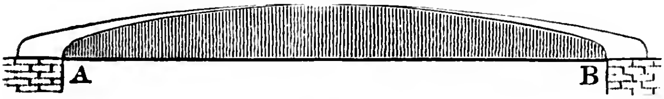

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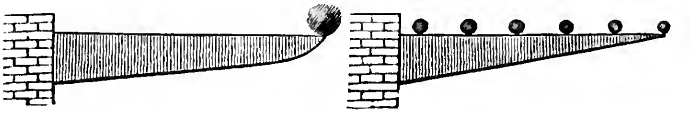

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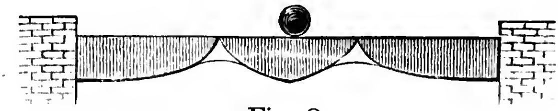

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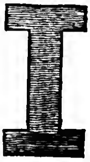
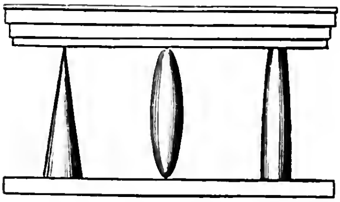


ARCHITECTURE. ILLUMINATION. PLATE XIII.

Fig. 1.



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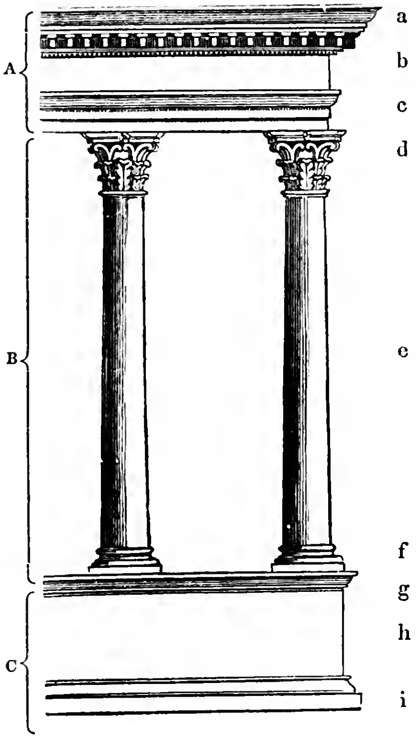
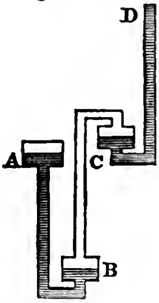


Fig. 1.



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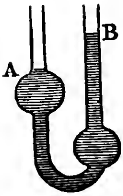

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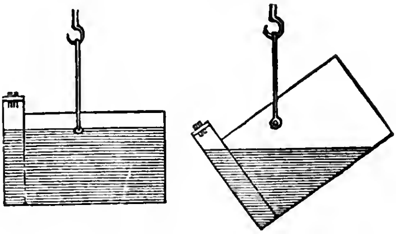

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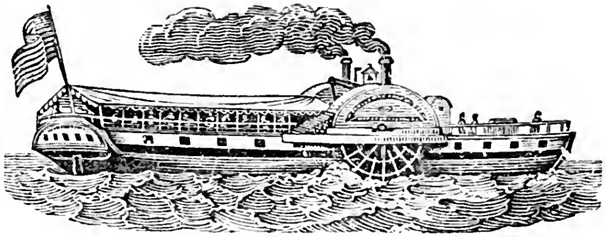

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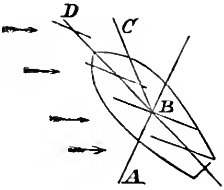

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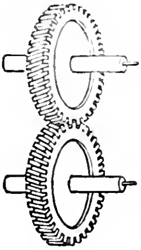

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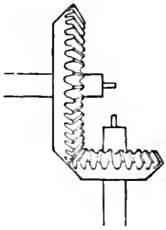

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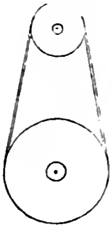

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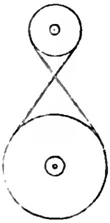

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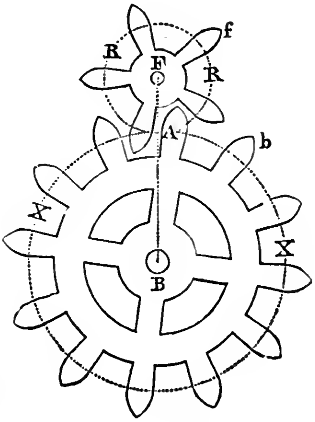

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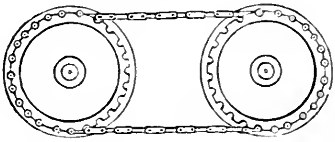

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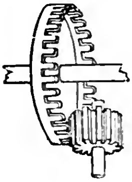

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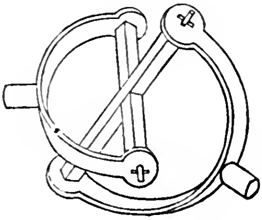

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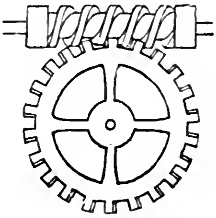

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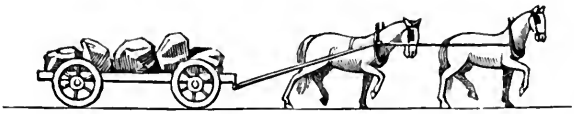

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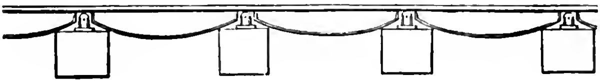

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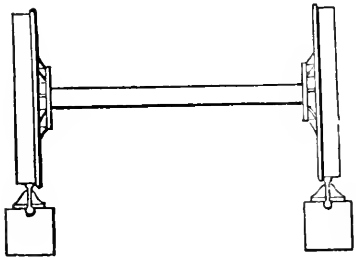

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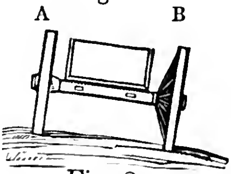

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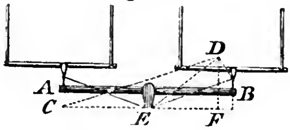

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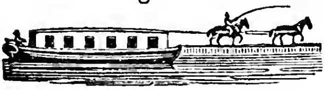

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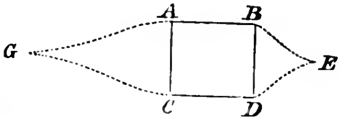

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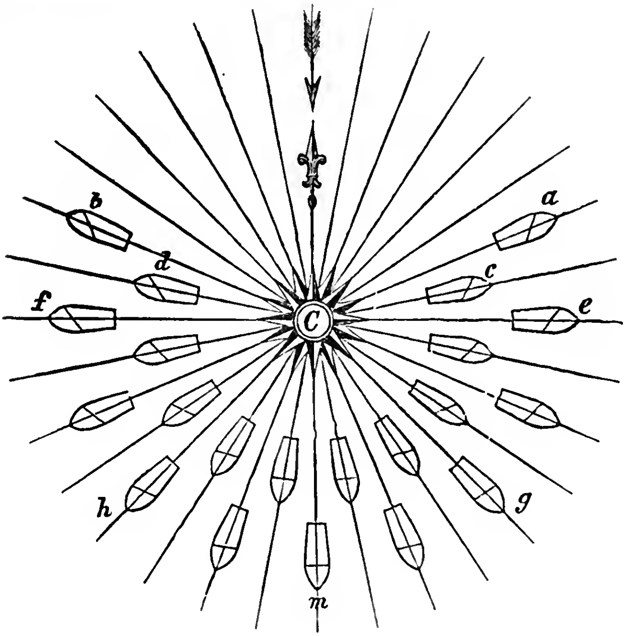

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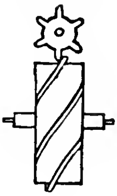

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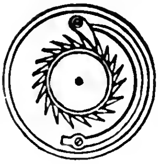
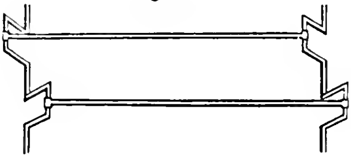


Fig. 12.

Fig. 13.



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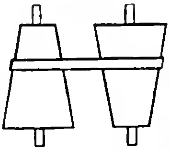

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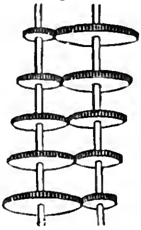

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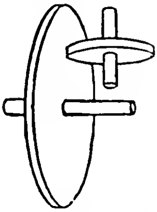

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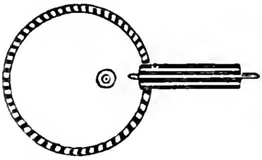

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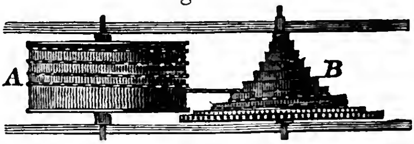

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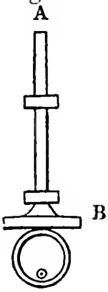

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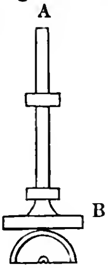

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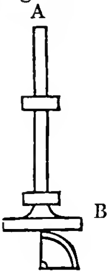

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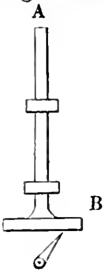

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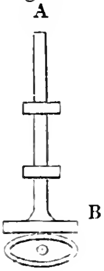

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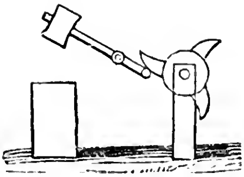

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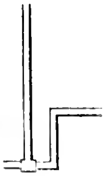

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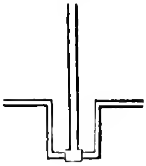

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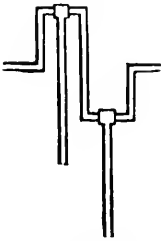

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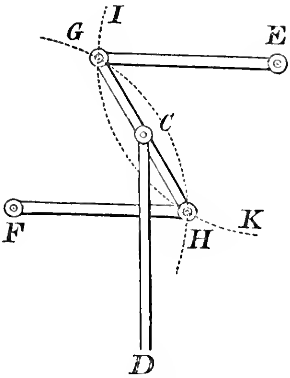

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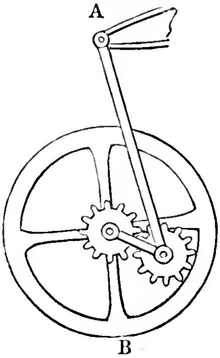

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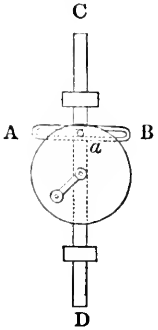

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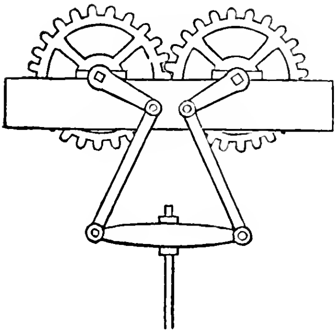

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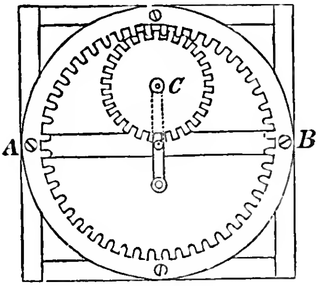

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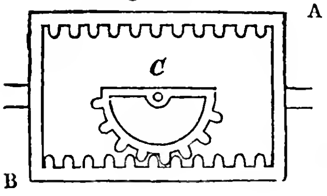

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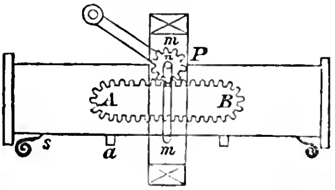

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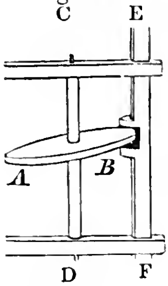

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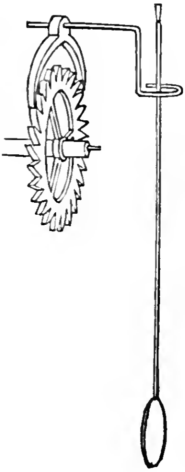

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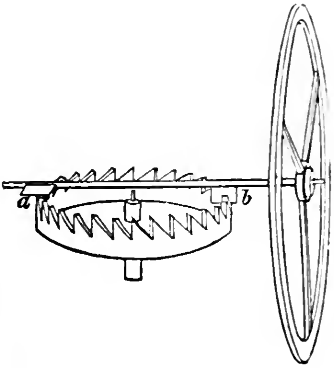

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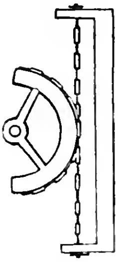

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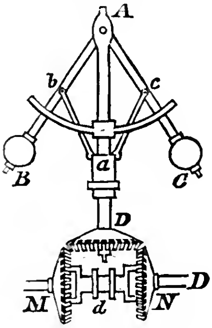

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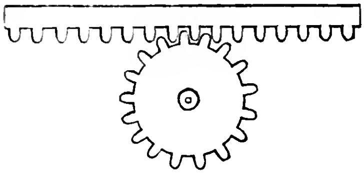

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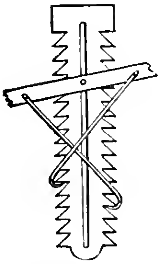


Fig. 41.

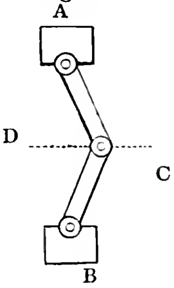
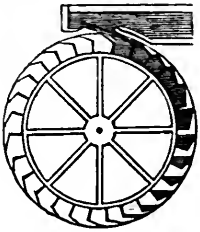


Fig. 1.



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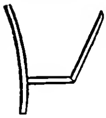

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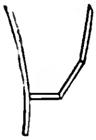

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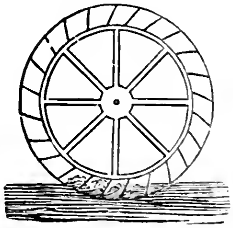

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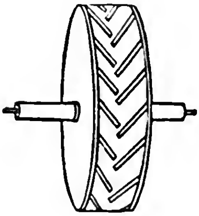

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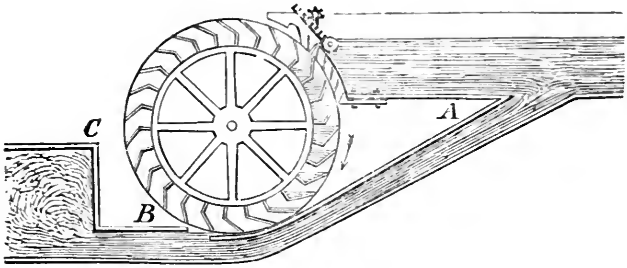

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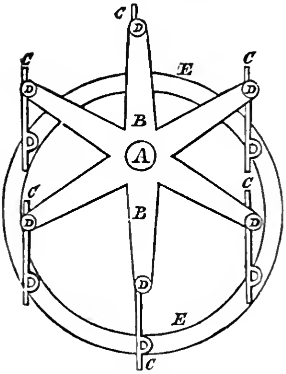

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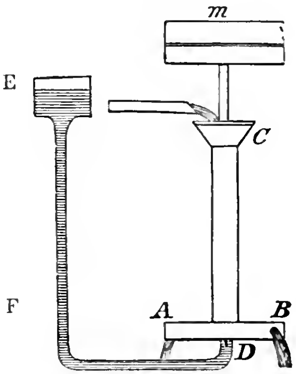

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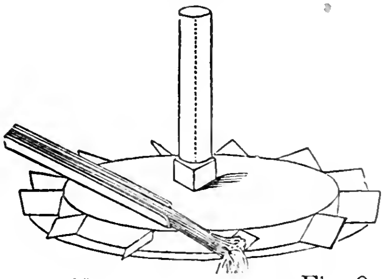

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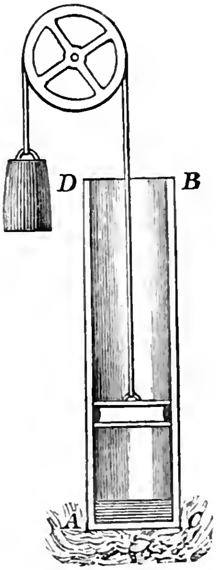


Fig. 4.

Fig. 9.

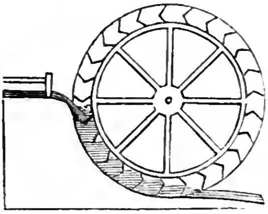


Fig. 1.

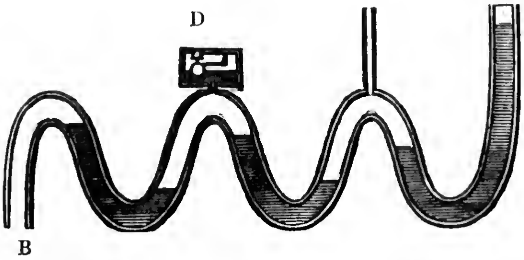
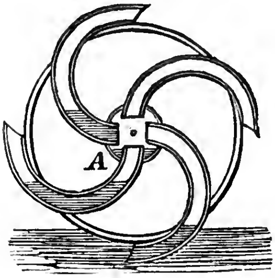


Fig. 2.



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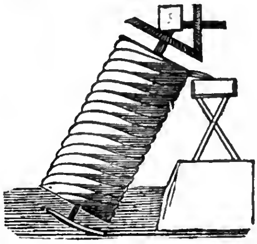

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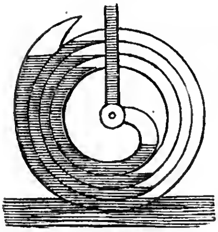

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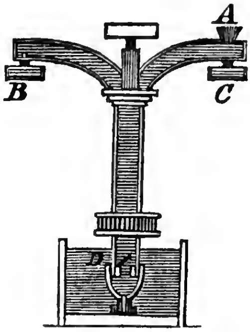

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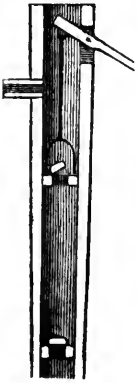

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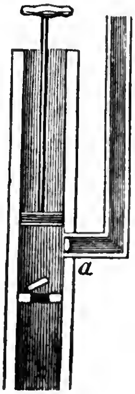

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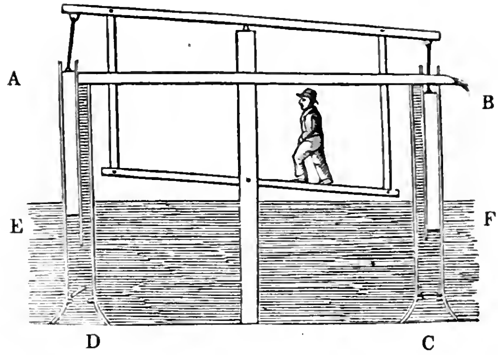
Fig. 8.



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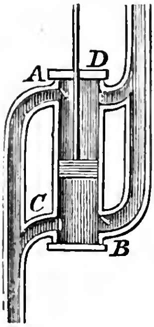

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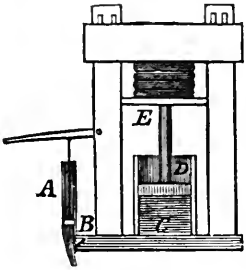
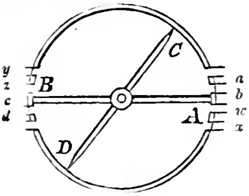


Fig. 12.

Fig. 13.



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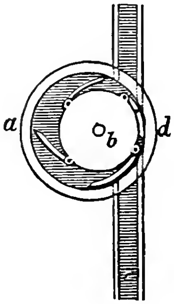

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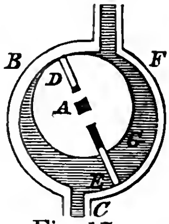

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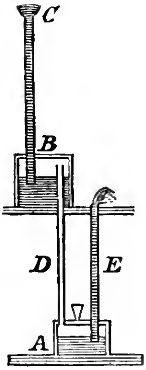

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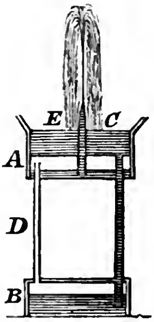

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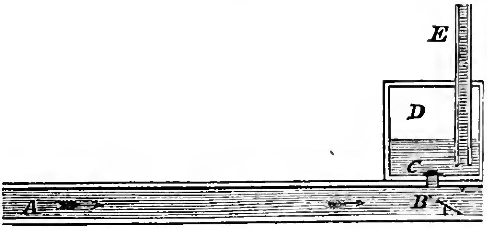

Fig. 1.

Fig. 2.

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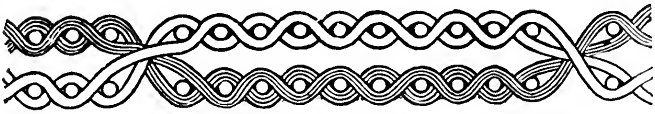

Fig. 4.

Fig. 5.

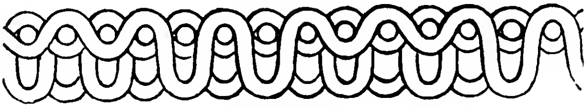

Fig. 1.