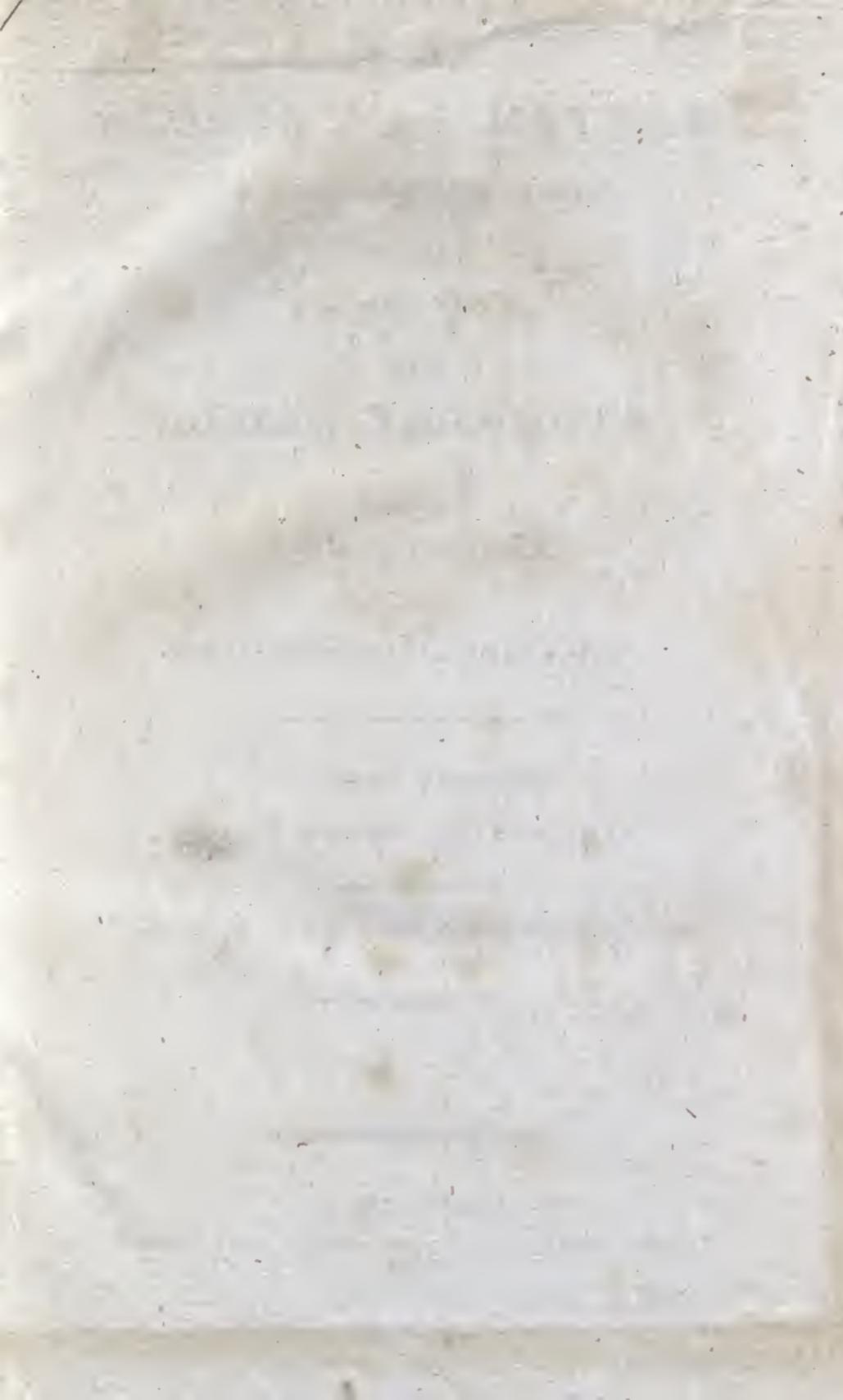




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THE
ECONOMY OF NATURE

EXPLAINED AND ILLUSTRATED

ON THE

PRINCIPLES

OF

MODERN PHILOSOPHY.

BY

G. GREGORY, D.D.

AUTHOR OF

ESSAYS HISTORICAL AND MORAL, &c.

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BOOK VI.

OF MINERAL SUBSTANCES, AND THE STRUCTURE OF THE EARTH.

CHAPTER I.

OF SALTS IN GENERAL.

Introductory Observations.—Definition of Salts.—Salts simple and compound.—What are called simple Salts are in reality compound Bodies.—Oxygenous Principle.

THE earth which we inhabit, though presenting to our senses an almost infinite variety of objects, is yet composed, as was already intimated*, of but few simple materials. It is the most pleasing occupation of the philosopher, to pursue the Proteus nature through her various and astonishing transformations; to develop those intricate combinations, which conceal from the eyes of common observers the elementary principles of things; to anatomize matter; and even to explain, as far as we are able, the processes by which substances, apparently contrary to each other in their general properties, become united, and form new bodies differing again in their most essential qualities from those of which they are composed.

In pursuing this really interesting inquiry, the plainest and the clearest method that presents itself to my mind, is to notice separately each peculiar and elementary substance, and afterwards to examine the effects of its combinations with other bodies. In treat-

* See book I. chap. 2. of elementary substances.

ing of mineral substances naturalists have generally classed them under four principal heads, salts, earths, metals, and inflammables. Perhaps modern philosophers might adopt an arrangement more consistent with recent discoveries; yet novelty in classification but seldom facilitates the labour of the student, and it is commonly safest to follow a beaten track in science, unless it leads to error.

Those substances are denominated salts which are fusible, volatile, soluble * in water, not inflammable, and sapid when applied to the tongue. The most simple state of salts, is a mass; white, brittle, and in some degree transparent. Salts in certain degrees of heat are fluid and transparent, like oil. They differ in their degree of fusibility and volatility. Some assume the form of vapour in the ordinary temperature of the atmosphere, others in a great degree of heat remain fixed †. Previous to treating of the particular substances of this class, it will be proper to make a few observations on the formation of salts in general. Salts are either simple or compound. Simple salts are distinguished into alkalis and acids; and from the union of an acid and an alkali are produced compound salts, which are also called neutral, because by this

* The distinction between solution and mixture has been already stated; but it may not be improper to remind the reader, that in solution the body which was solid is so completely in union with the fluid or menstruum, that the compound is completely transparent, though not always colourless. Common salt, for instance, with water, makes a colourless solution; but blue or green vitriol makes a blue or green solution with water. A mixture on the contrary is always muddy, and if left to stand, a sediment will be deposited. The point of *saturation* is when the fluid will hold no more of the solid body in clear solution, but *precipitates* it, or lets it fall to the bottom.

† Not volatile, or rising in vapour.

combination the characteristic properties both of the acid and alkali are lost, and a new body is formed, which is extremely inert, in comparison with the two substances of which it is composed. Several of the earths, and some of the metals, are also capable of being united with acids, and the compound forms a salt more or less perfect.

Alkalis and acids, at the time they obtained the name of simple salts, were supposed to be really such; modern discoveries, however, have now led to a different conclusion, and left no reason to doubt that all the acids, and at least one of the alkalis, are compound bodies. The doctrine of the formation of acids is now fully elucidated; the processes of combustion, and of the calcination of metals, which were formerly attributed to the expulsion of an imaginary substance, called phlogiston, are now proved to be only the formation of acids; or the union of the principle of acidity or oxygen contained in the atmosphere, with substances, the particles of which have, in certain circumstances, a stronger attraction for that principle, than it has for the matter of heat. The chief circumstance which favours the union of the principle of acidity, or, as it is called by the French chemists, oxygen, with other bodies, is a proper degree of heat; which, by removing the particles of bodies further from each other, diminishes their attraction, and allows room for the entrance of air into their interstices. In the calcination of metals, and in combustion, the oxygen gas of the atmosphere is decomposed, and while the basis is attracted by the inflammable substance or metal, the matter of heat is disengaged, and becomes sensible. Bodies, however, may be acidified or oxygenated without being exposed to the air; and this is performed by placing them in contact with bodies which are

already united with oxygen, but which have a weaker attraction for that principle than the body which is to be acidified. It is upon this principle that metals are deprived of oxygen, or reduced to the metallic state, by heating them in contact with charcoal, tallow, &c. In this case the inflammable substance having a stronger attraction for oxygen than the metal has, becomes oxygenated; while the metal, by being deprived of this principle, is reduced to the metallic state. Metals and combustible bodies may also be oxygenated in the humid way, by submitting them to the action of acids. In this process the acid furnishes the oxygen, and is therefore decomposed. The oxygenation of minerals in the bowels of the earth is probably chiefly effected by the decomposition of water, which is a compound of hydrogen and oxygen. A process of this kind is continually carried on before our eyes; the rust which iron acquires by being exposed to damp air is an oxygenation of that metal. Other metals, however, have less attraction for the principle of acidity, and this is remarkably the case with the perfect metals, platina, gold, and silver, which therefore do not become rusted by exposure to air.

In treating of salts, I shall first give an account of the alkalis, next of the acids, and lastly of their combinations, or the neutral salts. I shall defer speaking of the earthy and metallic salts till the earths and metals are described.

C H A P. II.

A L K A L I S.

Mineral fixed Alkali; where found.—Vegetable fixed Alkali; how obtained.—Use of the fixed Alkalis in the Arts.—Use of Alkalis in making Glass.—Process of making Soap.—Volatile Alkali; how obtained; a compound Body.—Alkaline Air.

MINERAL fixed alkali, soda or natron, is the salt which is found recorded in antient history under the name of nitre. It is said to be found in Egypt in tolerably pure crystals, and also in Persia, where it appears in a form resembling that of hoar frost. Even in Europe it is found in small quantities in mineral springs, and also on the surface of new walls, in the form of a damp and dewy efflorescence. In a compound state it is found in abundance; it makes half the weight of common salt, and is also occasionally found naturally combined with other acids. The mineral alkali cannot be obtained from the native salts containing it, without great labour and expence: what is used in the arts is procured by the burning of certain plants growing near the sea-side. The crude mineral alkali in commerce is called soda or barilla.

Alkalis are either mild or caustic: the latter is their most simple state, as when mild they are united with the carbonic acid, with which they form a kind of neutral salt. Though the carbonic acid has less affinity with the alkalis than any other acid, yet it is difficult to separate it entirely. The usual method of accomplishing it is to dissolve the mild alkali in water, to add to this solution some quick-lime, and then to filtrate the liquor, and evaporate it in closed vessels; the sa-

line substance left after evaporation is an alkali almost entirely deprived of carbonic acid. This process is founded on the greater attraction which the carbonic acid has for quick-lime than for the alkalis.

The VEGETABLE fixed alkali, pot-ash or kali, agrees in several circumstances with the former. It is acrid when applied to the tongue, requires as great a degree of heat to melt it; and in a very strong heat flies off totally in vapour. It differs from the fossil alkali in having a much stronger attraction for water. This alkali may be crystallized, but not so easily as the fossil. Little of the vegetable alkali has been found in a state of nature, and that only as entering into the composition of nitre. It is obtained in considerable quantities from the ashes of almost all land vegetables, by infusing them in water; the liquid, when strained from the dregs, will then contain the salt in a state of solution, and by evaporation we obtain the alkali in a solid form. It is also easily obtained from a substance called tartar, which is deposited by wine. The properties and uses of the vegetable alkali are very similar to those of the mineral.

The fixed alkalis are employed in several of the arts, and particularly in that of making glass; for though many substances will fuse the vitrifiable earths, and reduce them to a kind of glass, the alkalis are found the most effectual and convenient.

In the soap manufactory also the alkalis are a principal and essential ingredient. Common soap is indeed a combination of fixed alkali in a caustic state with fat and oily matters. A very fine species of soap is formed by the union of mineral alkali with olive-oil, or oil of sweet almonds. In the making of this substance, the alkali is first rendered caustic by boiling it with half its weight of quick-lime, which abstracts

its carbonic acid or fixed air by superior attraction. What is called soap-ley is a solution of the caustic alkali in water, which is evaporated to such a degree of density as to be able to sustain a new-laid egg. To make the finer soap, a part of this ley or lixivium (to speak in technical language) is to be diluted, and mixed with an equal quantity of olive-oil. The mixture is put on a gentle fire, and agitated, by which the union is accelerated. When the mixture begins to unite well, the rest of the lixivium is to be added to it, and the whole is to be digested with a gentle heat, till the soap is completely made. Good soap of this kind is white and firm when cold, and is not liable to become moist on exposure to air; it is entirely miscible with water, to which it gives a milky appearance, without exhibiting any particles of oil on the surface.

In the making of soft, liquid, green, or black soaps, cheaper oils are employed, as oil of nuts, of hemp, of fish, &c. but tallow is the ingredient used in our common hard soap.

Oil or fat may be separated from soap by the addition of an acid, without being much altered in its properties. On this account, waters which contain any acid, either in a disengaged state, or combined with any substance except fixed alkali, decompose soap, and will not completely mix with it.

In this decomposition, especially that effected by the vitriols of lime and magnesia, which are frequently contained in water, the vitriolic acid unites with the fixed alkali of the soap, and forms vitriol of soda, or Glauber's salt; and the lime or the magnesia combines with the oil, and forms a kind of soap scarcely at all soluble, which floats in a whitish curd-like masses on the surface of the water.

The VOLATILE alkali or ammonia is seldom or
B 4 never

never found in a simple state. It is met with in nature only compounded with other bodies, in nitrous ammoniac, or in common sal ammoniac, which is sometimes found in the neighbourhood of volcanoes, or coal mines which have burnt for a long time. The volatile alkali of commerce is chiefly produced from bones. This alkali is very different in its properties from the other two; its volatility is so great, that under the ordinary pressure of the atmosphere it is continually flying off in a very pungent vapour. It is sold in the shops under the name of smelling salts, sal volatile, or spirit of hartshorn. The process of putrefaction in animal matters, and in some vegetables, particularly cabbages, throws it off into the air, together with other volatile matters, which in some measure disguise its smell. Volatile alkali is now proved to be a combination of two other substances, namely, the bases of the azotic and hydrogen gasses. M. Berthollet has found by analysis that 1,000 parts of volatile alkali consist of about 807 parts of azote, combined with 193 of hydrogen. The volatile alkali of the shops, that is in its mild and concrete state, when heated to a certain degree, assumes the form of vapour, but by a diminution of the heat returns again to the concrete form. Volatile alkali, however, deprived of the fixed air which rendered it mild, is capable of receiving a permanently elastic form; in which state it is called alkaline air. When a mixture of alkaline air and marine acid air was made by Dr. Priestley over mercury, a beautiful white cloud was formed, and a diminution in the bulk of the airs took place. The cloud having subsided, was found to consist of common sal ammoniac, or a union of the volatile alkali with the marine acid. Nitrous air admitted to alkaline air, likewise occasioned

sioned a whitish cloud, which soon disappeared, leaving only a little dimness on the sides of the vessel. Fixed air admitted to alkaline air, produced a deposition of the common or concrete volatile alkali, in the form of oblong and slender crystals, which crossed each other, and covered the sides of the vessel like a network. Inflammable air admitted to alkaline air, produced no particular appearance. Water absorbed the alkaline air, and left the inflammable air as before. Azotic gas seemed to have no effect on alkaline air. Alkaline air is absorbed by water, in the proportion of $\frac{7}{8}$ of an ounce measure of air to $1 \frac{1}{4}$ grains of rain water; and the water is by these means made prodigiously stronger than any of the volatile spirit of sal ammoniac or hartshorn, obtained in the common way.

C H A P. III.

A C I D S

Of Acids in general—Vitriolic Acid; how obtained, &c.—Nitrous Acid; how obtained.—Muriatic Acid; how obtained, and its Use in the Arts.—Fluor Acid; dissolves Glass; employed to make Etchings on Glass—Acid of Borax—Phosphoric Acid.—Acid of Amber.

ACIDS are very active substances, and when concentrated are highly corrosive. They have so general a tendency to unite with other substances, that they are never obtained pure except by art. They are generally fluid, which seems, however, chiefly to be owing to their strong attraction for water, of which few of them can be entirely deprived, and which they copiously attract from the atmosphere. One of the marks by which the presence of uncombined acids may be ascertained, is their property of changing to a red, the blue colour of infusion of violets, which alkalis change to a green. Acids are distinguished into mineral, vegetable, and animal; the subject of this book will at present confine us to those of the first class.

The acids found in the mineral kingdom are the carbonic acid or fixed air, the vitriolic, the nitrous, the muriatic, the acid of spar, the acid of borax, the acid of phosphorus, and the acid of amber.

The CARBONIC acid has already been treated of under the head of gasses.

The VITRIOLIC acid takes its name from vitriol or copperas, from which it was formerly extracted by distillation. In the new chemical nomenclature, it is with

with much more propriety called the acid of sulphur, as it is now found to be a combination of that inflammable substance with oxygen. The pungent and suffocating fumes which are produced by the inflammation of sulphur, are an acid which is imperfect from a deficiency of oxygen; and which cannot be condensed without the aid of water. The vitriolic acid can never be entirely deprived of water, but admits of the greatest concentration of all the acids, and may be reduced to a state in which its specific gravity is double that of water. The dense and sluggish appearance of the concentrated vitriolic acid has given rise to the improper name of oil of vitriol, under which it passes in the shops.

M. Lavoisier makes a distinction between this acid, as it exists in an imperfect and gaseous state, and as it exists in the form of a transparent and ponderous liquid combined with water. In its former state he calls it, *acide sulphureux* (sulphureous acid) in the latter, *acide sulphurique* (sulphuric acid). A similar difference of termination is employed to express the different states of the nitrous acid, according as it is imperfectly or completely saturated with oxygen. A difference of termination is also given to the combinations of acids, according as they are perfectly or imperfectly saturated with oxygen. Thus the combinations of the sulphureous acid, are called *sulphites*; those of the sulphuric acid, *sulphats*, &c.

The vitriolic acid now used in commerce is prepared in the following manner:—A quantity of sulphur and salt-petre, grossly mixed, are placed in a vessel within a small room, lined with lead, and containing a few inches depth of water at bottom. The sulphur is lighted, and the room closed. The salt-petre serves to maintain the combustion, by the oxygenous

genous gas which it affords; and the acid fumes which are produced are absorbed by the water. The process is repeated till the water is thought sufficiently acid. The volatile fumes are then dissipated by exposure to air, and the acid is concentrated by distilling off the superfluous water.

The vitriolic acid is said to have become concrete by cold, but it probably was not in its most perfect state. It easily parts with its oxygen to inflammable substances; if oil is mixed with it, it is converted into a dark, viscid substance, and emits sulphureous and pungent vapours.

The vitriolic acid has been thought to exist in the atmosphere, but this is a mistake. It is discovered in some waters, but in small quantity; it exists in some ores of metals, and makes one of the constituent parts of gypsum.

The nitrous acid is a fluid of considerable weight, but does not admit of so much concentration as the vitriolic. In its most perfect form it is quite transparent and colourless, but in its ordinary state it is of an orange tawny colour, and when exposed to the air it constantly emits orange-coloured fumes, which are noxious. It very readily parts with its oxygen to inflammable substances and metals; and when mixed with oil of turpentine, it explodes and flames. The oil attracts the oxygen, and burns, while the azote is suddenly set at liberty, and occasions the explosion. When nitrous acid is diluted with an equal weight of water, it is called *aqua fortis*. The nitrous acid is considerably diffused in nature. All that is sold in the shops is obtained by distilling salt-petre with the vitriolic acid.

Azotic and oxygenous gas were mixed together by Mr. Cavendish, and the electric spark was passed through

through them. In these trials a diminution of bulk was always observed; indeed five parts of oxygenous gas being added to three of common air, almost the whole disappeared. By continuing his experiments, he found that an acid was produced, and that acid was the nitrous.

The MURIATIC acid, in its ordinary state, is a yellowish-coloured fluid, and emits fumes which do not give the air a red tinge like the nitrous acid, but produce an appearance of mist. These fumes are noxious to the lungs, and smell like burning foot. The muriatic acid is distinguished from the vitriolic and nitrous in the strong adhesion of its component parts, which is evinced by its not parting with oxygen, and of course its having little action on inflammable substances. So strong indeed is the attraction between the principles, whatever they are, which form this acid, that they have never been separated. Its basis therefore is wholly unknown to us, and we have no other evidence than analogy to lead us to conclude that, like other acids, it contains oxygen. M. Berthollet conjectures the radical of the muriatic acid to be of a metallic nature. The muriatic acid is by far the most abundant of all the acids in the mineral kingdom; it is naturally combined with lime, magnesia, and natron, or the fossil alkali; with the latter it forms the immense beds of sal gem or rock salt, and the saline matter which gives saltiness to the ocean.

As the muriatic acid can only subsist in the gaseous state in the ordinary temperature and pressure of the atmosphere, it is necessary to use water in order to condense it. But the ordinary muriatic acid is capable of being combined with an additional quantity of oxygen, by being distilled with the mineral substance called manganese, or with certain preparations of lead
and

and mercury, which readily part with oxygen. The acid resulting from this process, and which is called oxygenated muriatic acid, can only, like the former, exist in the gaseous state, and is absorbed in a much smaller quantity by water. When the impregnation of water by this gas is carried beyond a certain point, the superabundant acid precipitates to the bottom of the vessel in a concrete form. M. Berthollet has shewn that this acid gas is capable of being united with a great number of salifiable bases; the neutral salts which result from this union are capable of deflagrating with charcoal, and some of the metallic substances: these detonations are very violent and dangerous, from the great quantity of the matter of heat which the oxygen carries along with it into the composition of the oxygenated muriatic acid.

The muriatic acid in the oxygenated state has also a remarkable power of rendering vegetable and animal matters white. The reducing of this principle to practice has, indeed, been productive of a very essential improvement in the art of bleaching, and for this too we are indebted to M. Berthollet*. By various experiments he was enabled to ascertain that the oxygenated or dephlogisticated marine acid, as it was at first called, only differs from the common marine acid, in containing a superabundance of oxygen, with which it very readily parts. He discovered further, that oxygen has a remarkable property of destroying the colours of vegetable matters; that even the dew which falls from the atmosphere, and that which comes from the nocturnal transpiration of plants, were impregnated with oxygen, sufficiently to destroy the colour of paper, slightly tinged with tincture of

* Annales de Chymie.

turnsole. The ancient prejudices concerning the dew of the month of May, a season when the transpiration of plants is most abundant, he conceives to have originated in a similar observation.

Attributing, therefore, in his own mind the common effect of whitening linen in bleach-yards to the action of oxygen, he was led to imitate that process by applying leys, and the oxygenated muriatic acid alternately, and by these means was enabled to make linen, &c. permanently white, by a very quick and easy process. Observing further that it was the practice in common bleaching, to make the linen, &c. in the finishing, pass through sour milk, or a very weak mixture of the vitriolic acid with water; he also tried the passing of the cloth through a very dilute solution of the vitriolic acid, and observed that it was consequently rendered of a clearer white.

The oxygenated acid may be employed either in the aerial form, or diluted with water; and the latter appears to be the most convenient mode of applying it. The effect seems to result entirely from the action of the oxygen which the acid parts with to the cloth, and which has a power of destroying vegetable colours. Perhaps the fading of dyed stuffs on being exposed to the action of the light and air may be accounted for on the same principles. The acid which M. Berthollet employed in bleaching he found had parted with all its superabundant oxygen to the cloth, and was reduced to the state of the common muriatic acid. The soap-leys seem to act in two ways; by neutralizing any of the superfluous acid which might be imbibed, it saves the cloth from being corroded; and it also prevents the suffocating fumes of the oxygenated acid from being offensive or injurious. Possibly the detergent quality of the leys may have a further effect

effect in carrying off the colouring particles which are detached from the cloth by the action of the oxygen.

When one or two parts of pale concentrated nitrous acid are mixed with four of fuming muriatic acid, an effervescence soon takes place, and oxygenated muriatic acid is produced; at the same time that the mixture becomes of a red colour. The mixed acid is called *aqua regia*, which has the property of dissolving gold.

The SPARRY or fluor acid was discovered by Mr. Scheele, and takes its name from the substance from which it is obtained, and which is commonly known in England under the name of Derbyshire spar. This acid when pure assumes the form of gas. In this state it is heavier than atmospheric air, extinguishes flame, and destroys animal life; it has a penetrating smell, like that of marine acid, but more powerful; and its causticity is such that it almost instantly corrodes the skin. Heat dilates it, without producing any other change. The addition of atmospherical air has the effect of producing with it a white vapour, which is more or less abundant, in proportion as the atmosphere contains more or less of humidity.

If vitriolic acid is poured on the Derbyshire spar, which is a combination of this peculiar acid with calcareous earth, and a gentle heat applied, the acid is disengaged in an aerial form. It readily combines with water, and therefore the recipient should be half filled with that fluid. The first experiments which were made of the distillation of this acid in glass vessels, were attended with a striking appearance, which required considerable acuteness for its explanation. It was observed that as soon as the acid gas reached the surface of the water, a quantity of earthy matter was

was deposited. This was at first naturally attributed to the acid carrying over with it part of the calcareous stone from which it was distilled. Upon examination, however, it was found that the earth deposited in the water was siliceous, and this gave rise to an opinion that flint was only a composition of this acid with water. This hypothesis was soon overturned, by observing that the glass vessel in which the distillation was performed was always corroded, or in part dissolved. In this manner it was found that the fluoric acid has the singular property of dissolving glass. As only a moderate heat is required for the distillation of this acid, it is now usual to make use of leaden vessels for that purpose; which are not corroded by the acid. The basis of this acid is unknown; as we are not acquainted with any substance which can abstract its oxygen.

The fluoric acid has been successfully employed to make etchings on glass, in the same manner as nitrous acid is applied to copper. It combines readily with earth and alkalies, but scarcely, if it all, acts on gold, silver, lead, mercury, tin, antimony, bismuth, or cobalt, but it dissolves their calces. It acts directly on iron and zinc, with the production of inflammable gas; and it likewise dissolves copper in the metallic state, though less easily than when calcined.

If BORAX is dissolved to saturation in boiling water, and the vitriolic acid added in such quantity as to be perceptibly in excess, a substance will rise to the surface of the water in the form of white scales, which is proved to be a peculiar acid. Many chemists have supposed that this acid is an artificial product, formed by a combination of the salts made use of in its manufacture. This opinion, however, has been relinquished, since this acid has been found to exist in a

state of great purity in mineral waters, and since real borax may be formed by adding this scaly salt to the mineral alkali. The acid of borax requires about fifty times its weight of water for its solution. In a moderate heat it melts with less intumescence than borax itself; and the glassy substance, thus formed, is again soluble in water, having only lost its water of crystallization.

The acid of borax is used to fuse the flinty earths, with which it forms clear and almost colourless glasses; by the assistance of heat it dissolves the earth precipitated from what is called the liquor of flints, or flint dissolved in sparry acid. It unites with ponderous earth, magnesia, lime, and alkalis, and forms with these substances saline compounds. All these properties, and more especially its taste, the red colour it communicates to the tinctures of violets and turnsole, and its neutral combinations with alkalies, sufficiently indicate its acid nature; but it is the most feeble of all the acids, and is disengaged from its combinations even by the carbonic acid. The acid of borax is the substance called by Homberg sedative salt, from its supposed effects on the human body. It effervesces with a boiling hot, alkaline solution, but not with metals or absorbent earths, though it may be united with them. It has a weak attraction for inflammable substances, particularly spirits of wine, the flame of which it tinges green. From this circumstance it has been supposed, but without sufficient proof, to contain copper.

PHOSPHORIC acid is obtained by the combustion of the bones of adult animals, which are afterwards pounded, and passed through a fine silk sieve; a quantity of weak vitriolic acid is then poured upon the powder, but less than is sufficient for dissolving the whole. This acid unites with the calcareous earth of
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the bones, and forms selenite, and the phosphoric acid remains free in the liquor. The liquor is decanted off, and the residuum washed with boiling water; this water, which has been used to wash out the adhering acid, is mixed with what was before decanted off, and the whole is gradually evaporated. The dissolved selenite now crystallizes in the form of silky threads, which are removed; and by continuing the evaporation we procure the phosphoric acid, under the appearance of a white pellucid glass. When this is powdered, and mixed with one third of its weight of charcoal, we procure very pure phosphorus by sublimation. The phosphoric acid, however, as procured by the above process, is never so pure as that obtained by oxygenating pure phosphorus, either by combustion or by means of the nitrous acid.

The phosphoric acid may be rendered concrete with very little difficulty, by merely exhaling the moisture. It abounds in the animal kingdom, and is not unfrequent in the vegetable and mineral. In this last it is found united with lead and iron, as well as with calcareous earth.

The acid of AMBER is obtained from the substance of that name, by the simple application of heat. The operation must not be carried on too far, or by too strong a fire, as the oil of the amber is apt to rise with the acid. The acid is found in a concrete form in the neck of the subliming vessel; it is soluble in twenty-four times its weight of cold water, and in a much smaller quantity of hot water. It possesses the qualities of an acid in a very small degree, and only affects the blue vegetable colour very slightly.

C H A P. IV.

N E U T R A L S A L T S.

*The Union of an Acid and Alkali destroys the corrosive Quality of each.—
Neutral Salts do not communicate the saline Quality to other Bodies.—
Crystalline Form—how decomposed.*

NATURAL productions pass by gradations into each other; and I might have given an account of the primitive earths immediately after that of the alkalies, as these substances have several properties in common, particularly that of uniting with acids, and forming neutral compounds. Metals also are capable of being united with acids, and of forming with them saline substances. A lucid order will however be better preserved, by at present confining our attention to the consideration of such neutral bodies as are formed by the union of an acid and an alkali.

To a person unacquainted with chemistry, it is a striking circumstance that two acrid and corrosive substances should by their union form a compound very mild and inactive. Such however is the case, and what is still more remarkable, their previous acrimony, and tendency to combine, renders the neutral body proportionably more inoffensive. Thus an alkali united with vitriolic acid, may be received into the body with much less caution than when combined with the aerial or carbonic acid. The neutral salts in general have not so strong a taste as the simple, their tendency to combination and their solubility being less considerable; but the criterion, which more especially distinguishes them from the former, is, that they cannot,

not, like the simple salts, communicate the saline properties to other bodies. Their crystalline form is likewise a circumstance which very generally distinguishes the neutral from the simple salts. The volatility of the neutral salts is not in general so great as that of the simple salts.

Neutral salts may in many cases be decomposed by heat alone, but in general it is necessary to have recourse to elective attraction, or the addition of a third substance. When the decomposition is effected by heat alone, the more volatile part is forced off: but it seldom succeeds in this way, the ingredients commonly adhering so strongly that they rise together. It then becomes necessary to have recourse to elective attraction. Thus, if from a neutral salt we wish to obtain the acid pure, we apply another acid which has a greater attraction for the alkali. If our object is to obtain the alkali separate, we apply a substance which has a stronger attraction for the acid*.

* I would recommend to the reader, before he proceeds further in this part of the work, to look over again that part of the fourth chapter of the first book which relates to the attraction of combination or chemical attraction, Vol. I. p. 18 to 24.

C H A P. V.

VITRIOLIC SALTS.

Glauber's Salt ; how decomposed ; Solution of it left to cool crystallizes on being shaken.—Vitriolated Tartar.—Vitriolated Ammoniac.

THE first substances of this kind which challenge our attention, are Glauber's salt and vitriolated tartar, or as they are denominated in the new chemical nomenclature, sulphat of soda, and sulphat of pot ash. The former of these neutral salts is composed of the vitriolic acid, combined with the mineral alkali ; and the latter of the same acid with the vegetable alkali. They both have a saline bitterness. By heat their ingredients may be raised into vapour, but no one simple salt will separate them, as no acid has a stronger attraction for the alkali than the vitriolic, nor any alkali a stronger attraction for the vitriolic acid than the fixed. Dr. Stahl proposed the effecting of this separation as a problem. He knew how to solve it, and it was afterwards done by a double elective attraction. Another more curious method is this ; take Glauber's salt or vitriolated tartar, melt the salt in a hot crucible, and add to it first a quantity of charcoal, which has a stronger attraction for the oxygen of the vitriolic acid than the latter has for the alkali. These being exposed to heat, the charcoal in part disappears, and the mixture acquires a deep red colour. If the matter is poured out, we find it to be an *hepar sulphuris*, or liver of sulphur, the charcoal having carried off with it the oxygen in the form of carbonic acid gas.

GLAUBER'S SALT is more fusible than vitriolated tartar, melting in a moderate degree of red heat: The solution of Glauber's salt forms into columnary crystals, which

which have generally six sides, four principal, and two which seem accidental. Its crystals, containing a large quantity of water, are liable to have it abstracted from them by the atmosphere, when they fall to powder, or in chemical language *effloresce*. How much water Glauber's salt is capable of containing, is known by its requiring twice its weight of water to crystallize. The water should be added in a boiling state, and the mixture boiled a little afterwards; it may be set by in a quiet place, and will be found crystallized the next day, or will suddenly assume that state on being shaken. On crystallizing, a quantity of heat is perceived to be emitted by the substance passing from a fluid to a solid state, and consequently losing some of its latent heat.

Of Glauber's salt, all that is used at present is produced by art. It is said to be produced by nature in the waters of mineral springs, and of the sea. But the salt found in them is usually not Glauber's salt, but Epsom salt, consisting of the vitriolic acid and magnesia. Glauber's salt is obtained by uniting the vitriolic acid with the mineral alkali of common salt, as happens in the process for obtaining the muriatic acid.

VITRIOLATED TARTAR is distinguished from Glauber's salt, by a less degree of fusibility. It requires for its fusion the strongest fire. Its crystals are harder, but less bright, and do not contain so much water as those of Glauber's salt. Hence they are not liable either to spontaneous efflorescence, nor to watry fusion, but, like other salts, which contain little water, attract it strongly. This salt decrepitates* in the

* In decrepitation the crystals burst, and fall into powder, from the expansion of the water which they contain, by the heat. This occasions that crackling noise which common salt makes when thrown into the fire.

fire. Vitriolated tartar does not appear to be a fossil salt; it is found in the juices of vegetables, and remains in their ashes after they are burnt. What is used in dyeing and medicine, is obtained by art, most commonly by adding vitriolic acid to nitre, in order to dislodge the nitrous acid.

One hundred parts of vitriolated tartar contain, according to Bergman, about 52 parts of fixed vegetable alkali, 40 of vitriolic acid, and 8 of water of crystallization.

The vitriolic acid combined with the volatile alkali is called AMMONIACAL VITRIOL, or sulphat, of ammonia. Ammoniacal salts, it is proper to remark, are so called from *ammon*, an Arabic word for sand; or, as Pliny conjectures, from the temple of Jupiter Ammon, near which ammonia used to be found in great quantities, on account of the camels dung and urine brought thither. With respect to the general properties of ammoniacal salts, as their alkali is very volatile, they are unable to bear any great degree of heat without being converted into vapour, though much more than might be expected from their ingredients. They emit pungent fumes if a fixed alkali or lime is added to them, as these substances, having a stronger affinity with the acids, expel the volatile alkali.

When ammoniacal vitriol is very pure, it has the form of needles, which, on careful examination, are found to be flattened prisms of six sides, two of which are very broad, terminated by six-sided prisms irregularly formed; but the whole figure of the crystallization is subject to considerable varieties. This salt is sometimes in the form of quadrangular prisms, and is sometimes obtained in very thin plates.

Its taste is bitter and urinous; it is light, and very friable. It is scarcely changed by exposure to air;

it does not effloresce like Glauber's salt, but on the contrary slightly attracts the humidity of the air. It is very soluble in water, two parts of cold or one of hot water being sufficient to hold it in solution; it crystallizes by cooling; but the most perfect crystals are obtained by spontaneous evaporation. It likewise unites with ice, which it melts, producing at the same time an excessive degree of cold. It does not act on the earths, nor on magnesia; though this last, according to Bergman, seems to decompose it after a length of time.

If mild-fixed vegetable alkali, that is alkali combined with the carbonic acid gas, is distilled with ammoniacal vitriol, a double decomposition and combination take place. The vitriolic acid unites with the fixed vegetable alkali, and forms vitriolated tartar. The carbonic acid gas being at the same time volatilized, together with the volatile alkali, also in a state of gas, both unite, and form an ammoniacal salt, which crystallizes in the recipient.

Ammoniacal vitriol seems not to exist in a state of nature; nor is it used either in medicine or the arts.

C H A P. VI.

NITROUS SALTS.

Common Nitre; Phenomena attending its Deflagration with inflammable Substances.—Natural History of Nitre.—Cubic Nitre.—Union of nitrous Acid with various Earths.—Nitrous Ammoniac.

COMMON NITRE, or nitrat of pot-ash *, consists of the vegetable alkali and nitrous acid. Nitre was unknown to the ancients; the substance which they distinguished by that name was a fossil alkali, for we are told by Pliny that it was detergent, and used in making glass. It is uncertain when nitre was discovered, but we find it mentioned in the earliest chemical writers. Nitre melts in a very gentle heat, and in a greater degree of heat totally evaporates. Cold water dissolves one-sixth of its weight; and hot water about its own weight of this salt. Its crystals are more regular than those of any other salt (being prisms of six sides) having very little water in their composition, and therefore not liable to spontaneous evaporation. Its most extraordinary property is its deflagration with inflammable substances, which happens from the decomposition of its acid, by which a large quantity of oxygenous gas is set at liberty. To the production of this air is owing the rapid combustion of mixtures of nitre and inflammable substances, as evinced in † gunpowder. When nitre is melted by itself, no particular effect takes place; but if charcoal is added to it in its melted state, deflagration

* Commonly known under the name of salt-petre.

† The reader will do well to consult what has been said respecting gunpowder in Book II,

or detonation takes place. We are therefore not to consider nitre itself as an inflammable substance, but only as affording the pabulum of fire. If we continue to add charcoal, we find that the effect becomes less and less, till it entirely ceases. What remains in the crucible is different from nitre, it requires more heat to keep it fluid, and upon examining it we find it a pure vegetable fixed alkali. The charcoal disappears, because it is converted into carbonic acid gas by being united with oxygen; and the other component part of nitrous acid, the azote, by being deprived of its oxygen, is also volatilized and dispersed.

When the deflagration is performed with sulphur instead of charcoal, the consequences are considerably different. Like charcoal indeed, when sulphur is added in a certain quantity, it will produce no further deflagration; but when sulphur is used, the flame is insupportable to the eye, and the appearance of inflammation is greater though the noise is less. If the residuum is dissolved in water, it will readily crystallize, and is found to be vitriolated tartar. The reason that less explosion is produced by sulphur than charcoal is, that the former, when united with the oxygen of the nitre, becomes fixed; whereas charcoal united with the same principle is converted into gas, and escapes with violence. The formation of vitriolated tartar is owing to the production of vitriolic acid from the sulphur and the oxygen, which combines with the fixed vegetable alkali.

The detonation of nitre is a nice test of the inflammability of bodies, as there are many which are found to have this property when added to nitre in a state of fusion, which exhibit no signs of it on ordinary occasions.

Nitre exists in large quantities in nature, and is continually

continually formed in inhabited places; it is found in great quantities upon walls which are sheltered from the rain; and the Bishop of Llandaff collected a considerable portion from the decayed mortar of an old barn.

There appear to be three principal circumstances that promote its formation; the first is, the presence of chalk, or any other calcareous earth, as appears by its being collected from walls covered with plaster, or from the ruins of ancient edifices. This salt is likewise found perfectly pure in chalky earths. The late Duc de la Rochefoucault obtained it, in the proportion of one ounce in the pound, from the chalk of Roche Guyon.

The second circumstance necessary for the production of this salt, is the putrefaction, or spontaneous decomposition of vegetable and animal matters. It is a well known fact, that places which are moistened with animal liquids, or contain animal matters in a state of putrefaction, such as dunghills, stables, privies, &c. produce much nitre. This constant observation has been applied to the formation of artificial nitre-beds. Dry ditches are dug and covered with sheds open at the sides; these are filled with animal substances, such as dung, the excrements of quadrupeds, or birds, with the remains of vegetables. These matters are from time to time watered, especially with water charged with animal or vegetable matters capable of putrefaction, and they are turned up to renew their surfaces from time to time. When the putrefaction is in an advanced stage, a small portion of the matter is taken up and lixiviated, to ascertain whether it contains nitre; and when it is found sufficiently charged with that salt, the whole is lixiviated.

The third circumstance which in the opinion of some,

some, is supposed to favour the production of nitre, is the access of air; this is the cause of the formation of the nitre found on walls; and for this reason it is that nitre-beds require to be frequently turned over, in order that the air may touch them in all points. The necessity of the access of air is said to be still more evidently shewn by the nitre contained in chalk, as it is never found below a certain depth. When the three circumstances here treated of are united, the production of salt-petre is very abundant. Nitre-beds ought always to be constructed on these principles.

The theory of the formation of nitre has not been long known. Glauber, and many other chemists since his time, supposed nitre to exist ready formed in vegetables, from which they imagined it to pass into animal substances, and to become disengaged by putrefaction; but it was soon perceived, that vegetables do not contain a sufficient quantity of nitre to account for what is obtained from nitre beds. M. Thouvenel, whose dissertation on the formation of nitre was honoured with the prize of the academy, has made many experiments to discover its origin: he found, that the nitrous acid is formed by the combination of an elastic fluid, disengaged from animal matters in a state of putrefaction, and pure air. He has likewise discovered, that the nitrous acid, once formed, combines with calcareous earth, when any animal matters are made use of; and that the remains of vegetables are useful to afford the fixed alkali, which is the basis of common nitre. But M. Thouvenel did not determine the nature of the gas, which is disengaged from putrefying animal matters. It is to Mr. Cavendish that we are indebted for the proof that it is the same gas, which constitutes one of the principles of the atmosphere, under the name of azote, or phlogificated air,

or atmospheric mephitis. His experiment, wherein the nitrous acid was formed by the combination of this gas with vital air, by means of the electric spark, has been already mentioned.

CUBIC NITRE, or nitrat of soda, consists of the nitrous acid and the fixed mineral alkali. It resembles common nitre in all its striking qualities; almost its only difference is the form of its crystals, which is a paralelloiped. The crystals adhere so strongly, that they are scarcely ever found distinct and regular. For the deflagration of cubic nitre, charcoal is most proper; when performed with sulphur, Glauber's salt is produced.

Cubic nitre has not yet been found in nature, but is always produced by art. The shortest method is adding nitrous acid to fossil alkali. Its taste is cooling, and rather more bitter than that of common nitre. Fire decomposes it; but it decrepitates, and does not so easily melt as common nitre; like that salt, however, it gives out vital air during its decomposition. It is slightly deliquescent when exposed to air. It is more soluble in cold water than the common nitre, two parts of water, at the temperature of sixty degrees, dissolving one of the salt. It is scarcely more soluble in boiling water, and therefore cannot be had in regular crystals, except by slow evaporation.

Siliceous earth combines with the basis of this salt, and disengages the nitrous acid; clay likewise separates the acid, and affords a residue in the form of frit*, which is porous and opaque when a strong heat has been applied. Ponderous earth decomposes this salt, and disengages the mineral alkali. Magnesia and lime do not sensibly change it. The vegetable fixed

* The mixed materials for making glass.

alkali has a stronger attraction for its acid than the mineral. This fact is very easily shewn. If a heated solution of cubic nitre is divided into two parts, and the caustic vegetable fixed alkali added to one of them, it will afford prismatic crystals during its cooling; no crystals, however, will be observed in the other part because cubic nitre does not crystallize by mere cooling without evaporation.

The neutral salts hitherto examined produce no effect whatever on cubic nitre; if these salts are dissolved together in the same water, they crystallize separately, and each in its ordinary manner; the nitre and Glauber's salt by cooling; the vitriolated tartar and cubic nitre by evaporation. All these properties shew, that cubic nitre differs from common nitre.

NITROUS AMMONIAC, or nitrat of ammoniac, is composed of the nitrous acid and volatile alkali. It is more soluble and more fusible than the vitriolic ammoniac. When the heat is increased a little above what is necessary for its fluidity, it is converted into copious vapours. The degree of heat necessary for its fusion is a little above that of boiling water; and if more heat is suddenly employed, it has the singular property of undergoing deflagration, though no inflammable substance should be added to it, and even in a close vessel. This seems to depend on the decomposition of the volatile alkali.

M. Berthollet having exposed ammoniacal nitre to the action of heat in a pneumato-chemical and distilling apparatus, and having observed the phenomena of this operation more carefully than had been done before, remarks, that it is not a true detonation which takes place, but a sudden and instantaneous decomposition, in which part of the volatile alkali is entirely destroyed. The water obtained in the receiver contains a small part of
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the nitrous acid disengaged in proportion to the quantity of volatile alkali decomposed; and the latter gives out phlogisticated air or azotic gas. The liquid product of this operation being weighed, a greater quantity of water is found than existed in the ammoniacal nitre; and M. Berthollet concludes that this superabundant water is formed by the union of the inflammable gas, which is one of the principles of the volatile alkali, with the vital air of the nitrous acid. The azotic gas, or other principle of the volatile alkali, which is six times more in quantity than the inflammable gas, is disengaged and collected under the vessels of the pneumatic apparatus.

This salt dissolves readily in water, and in a very large quantity, but it has not so strong an attraction for water as to be deliquescent. It may be decomposed by the vitriolic acid, or either of the fixed alkalis. The nitrous ammoniac is contained in the juices of some plants, but it is usually prepared by artificial combination.

C H A P. VII.

M U R I A T I C S A L T S.

Sal Digestivus.—*Common Salt.*—*Rock Salt.*—*Natural History of Salt.*—*Saltiness of the Ocean.*—*Uses of common Salt in the Arts.*—*Sal Ammoniac.*—*Natural History of Sal Ammoniac.*

THE combinations of the muriatic acid with the alkalis are, 1st, SAL DIGESTIVUS, or muriat of pot-ash, which has also been called the febrifuge salt of Sylvius, and is a composition of the muriatic acid with the fixed vegetable alkali. Its taste is penetrating and bitter; its crystals cubical, but almost always confused and irregular. In the fire it decrepitates, that is, its crystals suddenly break and fly in pieces by the rarefaction of the water which enters into their composition. If the heat is then continued, and sufficiently strong, it melts, and is volatilized without decomposition. It is not much altered by exposure to the air; it is however slightly deliquescent. About three parts of cold water are required to hold one part of this salt in solution, and hot water does not dissolve a greater quantity.

Clay appears to decompose this salt in part, for marine acid is obtained by distilling it with the clays found in the vicinity of Paris. This operation, however, in fact affords only a small quantity of acid, and sand seems to have a similar effect. Ponderous earth seizes its acid, and separates the alkali, according to Bergman. Magnesia and lime do not at all change it. The vitriolic and nitrous acids disengage the muriatic acid with effervescence. This salt is found in a state of nature,

but never in considerable quantities; it is found in sea-water, and in the water of salt springs, and it exists, though rarely, in places where nitre is found; it is likewise met with in the ashes of vegetables, and in animal fluids. It is not employed in the arts, and its bitter taste prevents its being used for culinary purposes. In most of its properties, however, it is very similar to common salt.

2d. COMMON OR MARINE SALT is composed of the muriatic acid and the mineral fixed alkali, and is therefore the *muriat* of *soda* of the new nomenclature. This salt requires a full red heat for its fusion; soon after this it begins to evaporate in white fumes. It has a strong attraction for water, so as to deliquesce in a moist air. During evaporation, the crystals of this salt form at the top of the solution, contrary to those of other salts, which form at the bottom. When the evaporation is carried on quickly, it forms into thin irregular crusts, and this is the state in which we commonly have it. When the evaporation is slow, it assumes the cubic form, and the smallest crystals are the most regular; but if examined accurately, one of their sides will be found a little hollow. The larger crystals have a pyramidal hollow apex, with a broad base. This is owing to their superior surfaces being dry when floating in the water, while their inferior surfaces are moistened. Hence, as all dry bodies have a repulsion for water, and as their inferior surfaces have a tendency to sink, they are hollowed into little pits on the superior surfaces.

This salt contains little water of crystallization, and decrepitates in the fire. If frequently dissolved, evaporated, and dried, its quantity is more diminished than that of any other salt. By decomposition we obtain either its acid or its alkali. The old chemists used to
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obtain its acid by heat alone, but this is troublesome, and requires vessels capable of enduring great heat. It is most readily decomposed by the vitriolic acid, which has the strongest attraction for the alkali. The nitrous acid will also decompose it, but is more liable than the vitriolic acid to come over with the muriatic. Some water must be put into the retort with the vitriolic acid, otherwise the muriatic acid will come over in fumes so copiously as to burst the vessels. The quantity of the water should be about half that of the vitriolic acid; one half of which should be put into the receiver to condense the fumes of the muriatic acid, and the other half mixed with the vitriolic to prevent its too sudden action. Glauber's salt remains after this operation, and this is the usual way of preparing it. The way to decompose marine salt, so as to obtain its alkali, is, first to expel the muriatic acid by means of the nitrous; we thus obtain cubic nitre, which must be deflagrated to obtain the alkali. A better method, however, is to mix a solution of marine salt with caustic vegetable alkali; by evaporation muriat of pot-ash is obtained, and the remaining water contains the mineral alkali, pure and disengaged.

Common salt is the most useful of saline bodies; for though there are some which resist putrefaction equally well, there is none which is so friendly and agreeable to the human stomach. Its agreeable qualities are not indeed confined to man; most other animals indicate a great fondness for it. The rock salt, or sal gem, though only one form of common salt, does not melt so easily as the common crystals. The most remarkable mine of this salt is at Cracow, in Poland, where there is thought to be sufficient to supply the whole world many thousand years. In this

mine there are houses, chapels, and streets of rock salt, which, when illuminated, afford a beautiful prospect. This salt is also obtained from some springs. When found in the earth it is seldom cryftallized in any regular form; it has various degrees of whitenefs, and is often found coloured; in this latter ftate it is more particularly called fal gem, because it often has the appearance and transparency of gems.

The ocean differs in saltnefs in different climates. It is falter towards the equator than near the poles. This feems to arife from the different quantities of water which are evaporated, in proportion to thofe which fall in rain. One pound of fea water in the Baltic yields about a quarter of an ounce of falt; near Holland half an ounce; and in the British fea about two ounces. Boyle has alfo obferved, that in places of great depth the water is falteft at the bottom.

In the voyage made towards the north pole in 1773, it was found, that the fea-water at the Nore contained not quite one thirty-fixth of falt; at the back of Yarmouth sands, not quite one thirty fecond; off Flamborough Head, rather more than one twenty-ninth; off Scotland, rather lefs than one twenty-ninth; latitude 74° , at fea, one twenty-ninth; latitude 78° , rather lefs than one twenty-eighth; latitude 80° , near the ice, not quite one thirtieth; latitude $80\frac{1}{2}^{\circ}$, under the ice, not quite one twenty-eighth; latitude 68° , 46, rather more than one twenty-eighth; latitude 65° , at fea, rather lefs than one twenty-eighth. Dr. Hales got only one twenty-feventh from water taken up in the Mediterranean, and one twenty-ninth from water taken up at the Nore. Dr. Ruty fays, he procured one twenty-fifth from water taken up in latitude 65° ; one twenty-eighth from water taken up near Dublin; and one thirtieth from water taken up at Dungarvan; and Dr. Lucas, that he obtained one twenty-fifth from water taken

taken up near Harwich. From other observations, also it has appeared, that water from near Teneriff contained about one thirty-second of salt, and that some from Saint Jago contained fully one-fourth. Further experiments are needed to ascertain the saltiness of the sea in different latitudes with precision.

The salt commonly used for culinary purposes, and known by the name of bay-salt, is obtained from the water of the sea by evaporation. This evaporation is in some places performed by the heat of the sun, the water being let into shallow trenches, in order to expose as large a surface as possible. This method is practised in the southern provinces of France, and on a very large scale near Aveiro in Portugal. In the northern provinces, where the heat of the sun is not sufficiently great, artificial fires are employed. In some salt-works these two methods are united; and in England, and countries where salt rock is plentiful, that substance is dissolved in salt water, and then evaporated*. In very cold countries another method is employed

* “ A great quantity of rock salt is used at Northwich, in order to strengthen their brine springs, and a much greater quantity is sent coastwise to Liverpool, and other places, where it is used either for strengthening brine springs or sea-water; much of this rock salt was formerly exported to Holland, and it is still sent to Ireland for the same purpose. Rock salt, and the white salt which is at Northwich, chiefly made from rock salt, is exported free from the salt duty; and I was informed, that the quantity, which is annually exported from Northwich, is so great, that if it paid the duty, it would bring in to government, a sum not much short of four hundred thousands pounds a year. “ According to the best accounts I have been able to procure, the gross duty on salt made in South Britain, amounts annually to seven hundred thousand pounds (a).” The duty on salt made at Northwich is about seventy

(a) Camp. Sur. of Brit. Vol. II. p. 26.

employed to separate the salt from sea-water. The water is exposed in trenches on the sea-shore, where it forms

seventy thousand pounds a year, or a tenth part of the whole duty (*b*).

The Northwich rock salt is never used at our tables in its crude state; and its application to the pickling or curing of flesh or fish, or preserving any provisions, without its being previously refined into white salt, that is, without its being dissolved in water, and boiled down into what is called white salt, is prohibited under a penalty of 40*s.* for every pound of rock salt so applied. The pure transparent masses, however, of rock salt, might, probably, be used by us with our food, without any sort of danger or inconvenience; at least, we know that rock salt is so used, without being refined, both in Poland and in Spain. In the last of these countries, at Cordova in the province of Catalonia, there is a solid mountain of rock salt, between four and five hundred feet in height, and a league in circuit; its depth below the surface of the earth is not known (*c*). This prodigious mountain of salt, which has no mixture of other matter with it, is esteemed so singular an appearance, that it is thought to militate very much against the opinion of those, who would derive the origin of all the beds of rock salt, which are found under the surface of the earth, from the evaporation of salt water, left in subterraneous caverns, either at the deluge, or upon some more local commotions of the globe.

The quantity of rock salt which may be dissolved in a definite quantity, suppose a pint or 16 avoirdupoise ounces of water, is differently estimated by different authors. Boerhaave is of opinion that 16 ounces of water will not dissolve quite 5 ounces of rock salt (*d*); Spielmann thinks that they will dissolve $6\frac{2}{3}$ ounces (*e*);
Newmann

(*b*) Since I received this information, an additional duty of 10*d.* a bushel has been laid, in 1780, on salt. The whole duty now amounts to 4*s.* 2*d.* a bushel, the bushel weighing 56 lb. The makers of salt can afford, in most places, to sell their salt, exclusive of duty, from 8*d.* to 10*d.* a bushel.

(*c*) Hist. Nat. de l'Espag. p. 406.—See an account of similar mountains of rock salt, in Shaw's Travels, p. 229, and in Pliny's Hist. Nat. l. xxxi. c. 7.

(*d*) Chem. vol. I. p. 476.

(*e*) Inst. Chem. p. 48.

forms so thin a stratum, that the cold of the atmosphere acts powerfully in congealing it. As the frozen part consists

Newmann agrees with Spielmann (*f*); Eller says, that 7 ounces of fossile salt may be dissolved in 16 ounces of water (*g*); lastly, Hoffmann assures us, that 16 ounces of water will not dissolve above 6 ounces of common salt (*b*). I have tried this matter with distilled and with common water, and in various degrees of heat, and cannot but be of opinion, that Hoffmann's experiment approaches nearest to the truth; I never could dissolve quite 6 ounces of rock salt in 16 ounces of water. It is not wholly improbable, that different sorts of rock salt may differ somewhat with respect to their solubility in water.

‘If it be admitted, that 16 ounces of water can dissolve 6 ounces of salt and no more, then we may be certain, that no brine spring, in any part of the world, can yield 6 ounces of salt from a pint of the brine. For brine springs are, ordinarily, nothing but water in which fossile salt has been dissolved; but a pint of the strongest brine cannot contain so much salt as is contained in a pint of water, which has been saturated with 6 ounces of salt; for a pint of water, in which 6 ounces of salt have been dissolved, is increased a little in bulk, it will do more than fill a pint measure, and the salt left in the surplus will shew, how much the salt, contained in a pint of the strongest brine, falls short of 6 ounces. Or, we may consider the matter in the following manner, which will, perhaps, be more intelligible; 16 ounces of water, impregnated with 6 ounces of salt, constitute a saturated brine, weighing 22 ounces; if therefore we would know how much salt is contained in 16 ounces of such brine, by the rule of proportion we may argue, that if 22 ounces of brine contain 6 ounces of salt, 16 ounces of brine will contain $4\frac{4}{11}$ ounces of salt. Hence we may infer, that the strongest brine springs will not yield much above one quarter of their weight of salt (*i*).

‘ Dr.

(*f*) Newmann's Chem. by Lewis, p. 256.

(*g*) Obs. Phy. Chem. L. ii. Ob. xvi.

(*b*) Ber. Mem. 1750.

(*i*) ——— Several pits at Northwith, and at Barton in Lancashire, contain no less than six ounces of salt upon sixteen of brine, which is as large a proportion of salt as water will dissolve. *Newm. Chem.* p. 212, Lewis's note.—The author here is fallen, probably,

consists of mere water, the fluid which remains is consequently more concentrated. The operation is then completed by means of artificial heat.

Pure

Dr. Leigh, who first shewed the manner of refining rock salt, informs us, that some of the strongest springs at Northwich, gave seven or eight ounces of salt from a quart of brine; but a quart of brine weighs considerably more than 32 ounces, the weight of a quart of water: so that the Northwich springs, from this account, do not yield a quarter of their weight. At Middlewich there is said to be one salt spring, which is stronger than the rest, this spring yields a *full fourth* part of salt (*k*), and hence it is, probably, fully saturated. We have an account in Kircher's works, of some famous brine springs in Burgundy, from which we learn, that one hundred pounds weight of the strongest brine, gave twenty-five pounds, or just *one fourth* of its weight of white salt (*l*).

There are a great many brine springs in Cheshire, Worcestershire, Staffordshire, Hampshire, and in other parts of Great Britain, some of which are sufficiently rich in salt to be wrought with profit, others not. From what has been before advanced, the reader will readily comprehend that sixteen tons of the strongest brine consist of twelve tons of water, and of four tons of salt; and that, in order to obtain these four tons of salt, the twelve tons of water must be, by some means or other, evaporated, so as to leave the salt in a concrete form. Suppose there should be a brine, which in sixteen tons should contain fifteen tons of water, and only one ton of salt; yet it may chance, that such a weak brine may be wrought with more profit than the strongest; for the profit arising from the boiling of brine into salt, depends as much upon the price of the fuel used in boiling it, as upon the quantity of salt which it yields. Thus the sea-water, which surrounds the coasts of Great Britain, is said to hold seldom more than one thirtieth, or less than one fiftieth part of common salt; but fuel is so cheap at Newcastle, that they can evaporate thirty or forty tons of water,

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into a little mistake, by confounding a pound of water with a pound of brine; for if a pound or 16 ounces of water will only dissolve 6 ounces of salt, a pound of the brine, thus formed, will only hold $4\frac{4}{11}$ ounces of salt.

(*k*) Philos. Trans. N^o 53.

(*l*) Kerch. Mun. Sub. Tom. II. Cap. XI.

Pure clay has very little action on marine salt. Ponderous earth decomposes it, but lime and magnesia produce no effect. Common salt is used to vitrify the surface of some kinds of pottery. This is done by throwing a certain quantity of it into the furnace, where it is volatilized, and applies itself to the surface of the pottery. This is the kind of glazing used in the making of white English pottery. Common salt is also used in making glass, to render the glass whiter and clearer. It is also employed as a flux to facilitate the precipitation of metals from the scorixæ, and to prevent their calcination from the contact of the atmosphere.

3d. Common SAL AMMONIAC is the muriat of ammoniac of the French chemists, and consists of the muriatic acid united to the volatile alkali. This salt is converted into vapour before it melts, but may be brought into fusion by being combined with other substances, or even uncombined, if properly confined. When thrown into the fire, it increases the flame, and tinges it with a blue colour, especially the flame of charcoal. When the air is very moist, this salt deliquesces. It is very remarkable for producing a great degree of cold when mixed with water.

in order to obtain one ton of salt, and yet gain as much clear profit as those do, who, in counties less favourably situated for fuel, boil down the strongest brine.

The advantage resulting from strengthening weak brine or sea water, by means of rock salt, is very obvious. Suppose that the sea water at Liverpool, where large quantities of rock salt are refined, would yield one ton of salt from forty-eight tons of water, then must a quantity of fuel sufficient to evaporate forty-seven tons of water be used in order to obtain one ton of salt. But if as much rock salt be put into the forty-eight tons of sea water, as can be dissolved in it, then will the sea water resemble a brine fully saturated, each sixteen tons of which will give four tons of salt, and the whole quantity yielded by the evaporation of forty-seven tons of water, will be twelve tons of salt.

If we wish to obtain the acid of sal ammoniac, we may expel it by means of the vitriolic acid, but the fumes cannot be condensed without great difficulty. For obtaining its alkali, the chemists generally employ the vegetable, as it is the cheapest. The quantity of vegetable alkali used is generally equal, but perhaps ought a little to exceed, that of the sal ammoniac; the water is in general equal in weight to the alkali, and a volatile alkali sufficiently strong is obtained. The product is different, according to the mildness, or causticity of the fixed alkali. When a mild fixed alkali is used, so much volatile alkali rises, that Du Hamel and others thought part of the fixed alkali was volatilized, and rose along with it. This however is found to be owing to the carbonic acid, which made part of the weight of the fixed alkali, being transferred to the volatile alkali.

The sal ammoniac of commerce is in the form of cakes. It is prepared at Cairo from the foot of camels dung, which is burned there instead of wood. This foot is put into round bottles a foot and a half in diameter, terminated by a neck two inches high; each bottle contains about forty pounds of this foot, and affords nearly six pounds of the salt. These vessels are exposed to the heat of a furnace which acts on their bottom, while the upper part, being cooler, suffers the salt to be condensed there. When the operation, which occupies three days, is finished, the bottles are broken and the salt taken out; it receives the form of the upper part of the subliming vessel, and the cakes are therefore convex and unequal, with a protuberance on one side from the neck of the subliming vessel.

Pomet has described a kind of sal ammoniac in loaves, similar to those of sugar with the point cut off, and which are imported into France by the way of
Holland,

Holland. This kind is made in the East Indies. 'Sal ammoniac is, however, now made in large quantities in Britain. The volatile alkali is obtained in an impure liquid state from soot, or bones, or any other substance which affords it; to this the vitriolic acid is added, and the vitriolic ammoniac thus produced is decomposed by common salt, by a double affinity, or elective attraction; the vitriolic acid combining with the mineral alkali, and the marine acid with the volatile alkali. The liquor therefore contains Glauber's salt and sal ammoniac, which are separated by crystallization; and the sal ammoniac is sublimed into cakes for sale. Lord Dundonald extracts volatile alkali from pit-coal; but whether it can be afforded cheaper for the general purposes of commerce, than that of the above process, is not, I believe, yet ascertained.*'

The taste of sal ammoniac is penetrating, acrid, and urinous. The form of its crystals is a hexahedral pyramid. Cubical crystals are sometimes, though rarely, formed in the middle of the concave and hollow parts of the loaves which are produced by sublimation.

This salt possesses a singular property, namely a kind of ductility, so that it rebounds under the hammer, and may be bended; a circumstance which renders it difficult to pulverise it.

Sal ammoniac is not decomposed by clay, and by magnesia very imperfectly. Lime, and likewise ponderous earth, separate the volatile alkali, even without the assistance of heat. If sal ammoniac is triturated with quick-lime, the strong smell of alkaline gas is immediately perceived.

* Fourcroy's Chemistry. Note of the Translator.

C H A P. VIII.

COMBINATIONS OF THE OTHER MINERAL ACIDS.

Sparry Tartar.—Sparry Soda.—Borax; its Properties; its Use in the Arts.—Combinations of neutral Salts with Metals.

THE combinations of the other mineral acids with the alkalies, have in general been very imperfectly examined, and I shall therefore be very brief in treating of them.

The SPARRY TARTAR, or fluat of pot-ash of the French chemists, is composed of the acid of spar united to the vegetable alkali. It is always in a gelatinous form, and has so strong an attraction for water, that it cannot be crystallized. According to Scheele, it is acrid, caustic, and deliquescent, when dried and melted; he compares it in this state to the liquor of flints. It appears, that the fire disengages the sparry acid, and that the siliceous earth taken up by the acid melts into a soluble earth by means of the fixed alkali. This salt has not been applied to any use. Of the sparry soda still less is known; and the same may be affirmed of the sparry ammoniac.

The combinations of the acid of borax have not attracted much more attention, except the substance from which this acid derives its name. BORAX, the bora, of suda of M. Lavoisier, is composed of a peculiar acid united to the mineral alkali. The form in which it is exposed to sale is that of crystals, very transparent, and containing a large proportion of water. When a small quantity of borax is heated so as to dissolve in its own water, it boils in a white foam; and when the water is dissipated, the salt is found to
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have lost much of its weight. By increase of heat, it undergoes a proper fusion, and assumes the appearance of glass; but is distinguished from that substance, by dissolving and crystallizing again.

Borax may be decomposed by means of the muriatic acid. It appears surprizing, but the fact is certain, that a quantity of acid of borax, though so weak an acid in its more obvious properties, will dislodge, when heat is applied, both the nitrous and muriatic acids, and unite itself to their alkali. The reason seems to be, that the attraction of different substances for the same body is different in different degrees of heat. This again is to be attributed to a double elective attraction, in consequence of the addition of the matter of heat. The cohesion of the nitrous and muriatic acids to their bases is so much weakened by their affinity with heat, or in other words, their tendency to assume the gaseous form, that the attraction of the boracic acid, which is more fixed, becomes superior, and displaces them.

Borax, as imported from the East Indies, is very impure. When purified, it has a very regular form. Its crystals are six-sided prisms, two of the sides being commonly larger than the others, terminated by trihedral pyramids. Its crystallization is, however subject to considerable varieties. It is styptic, and acts strongly on the tongue, and like alkalies it converts the syrup of violets to a green. Borax, exposed to the air, loses a small part of its water of crystallization, and slightly effloresces. It is soluble in twelve parts of cold and six of hot water. Its crystals may therefore be obtained by cooling; but the finest and most regular are formed by suffering the cold saturated solution to evaporate spontaneously in the ordinary temperature of the atmosphere.

Borax is exceedingly useful in many manufactures. It is employed as an excellent flux in the art of glass-making, as well as in assays. It is advantageously employed in soldering, which it assists by promoting the fusion of the solder, by softening the surfaces of the metals, and by defending them from the action of the air.

Very little is known of the combinations of the acid of borax with the vegetable and volatile alkalies.

The phosphoric acid, and the acid of amber, are capable of combination with the alkalies; but the results of these combinations are so little known, that I shall pass them over in silence, and hasten to the consideration of the earthy and stony substances.

Some saline, earthy, and metallic substances, have such a relation to each other, that they are separated with great difficulty, and adhere after repeated solutions and crystallizations. This circumstance has given rise to another division of salts, which are denominated triple. as they do not, however, appear of sufficient consequence to be treated of under a separate section, I shall merely enumerate them at the conclusion of the present. The most remarkable examples of this kind are, mineral alkali with calcareous earth; common salt with magnesia; vitriolated magnesia with iron; alum with iron; vitriolated copper with iron; vitriolated copper with iron and zinc; vitriolated iron with copper; vitriolated iron with zinc; vitriolated iron with nickel.

C H A P. IX.

E A R T H S I N G E N E R A L.

Different Kinds of Earth.—New Earths discovered.—Definition of Earths.—Exceptions.—Other general Properties of Earths.—Calcareous Earth.—Magnesia.—Barytes.—Clay.—Flint.

IT is now generally agreed among chemists and mineralogists, that all the earthy and stony substances which compose the solid parts of this globe, are chiefly resolvable into five simple and original kinds of earth; namely, lime or calcareous earth, magnesia, barytes or ponderous earth, argill or clay, and silica or flint; to these late discoveries have added three other earths, the stronthian, the jargonic, and the adamantine; but these are found in very small quantities, and doubts are yet entertained whether they are any thing more than varieties or compounds of the five principal earths.

These substances agree in the following properties, which may be considered as the characteristics of all earthy substances. They are nearly insoluble in water, are uninflamable, have not the metallic splendour, and their specific gravity, compared with that of water, is not more than five to one. This definition, however, like that of salts, is not so precise as to be beyond the reach of criticism; because there are some earths perfectly soluble in water, though but in small proportions, and there are many in the internal parts of the earth which afford the strongest evidence that they have been in a state of solution. But the definition, though not strictly accurate, is proper in a general sense. There is great difference of solubility between earths and salts, for a few grains of earth

earth are sufficient to saturate* a large quantity of water. There are two other circumstances not included in the definition, which make part of the idea of an earthy substance; 1st, a great degree of fixedness; 2dly, a disposition to form a glassy concretion when melted with certain other substances.

Lime, properly so called, is obtained by expelling the carbonic acid from calcareous substances by means of heat. *Calcareous earth* is in a tolerably pure state in common quick-lime; but if it is required perfectly free from foreign admixture, it may be obtained by the following process: If pounded chalk is several times boiled in distilled water, the remainder will consist almost entirely of calcareous earth, combined with the carbonic acid. If distilled vinegar is added to the powder thus obtained, it will form a saline combination with the lime only, to the exclusion of all extraneous matter. To a solution of this, decanted from the impurities, mild volatile alkali being added, the alkali will unite with the vinegar, while the calcareous earth seizes the carbonic acid of the alkali, and falls to the bottom in the state of a perfectly pure chalk. The carbonic acid may be driven off by heat, and calcareous earth is thus obtained in its most simple state.

The relative weight of quick-lime to that of slaked lime is as 1,000 to 1,287. Every pound can imbibe four ounces four drams and fifty-three grains of water.

Calcareous earth is soluble in the nitrous and muriatic acids, and forms deliquescent salts. It is precipitated from its solutions by means of vitriolic acid, with which it forms a nearly insoluble compound, called selenite, (or plaster of Paris.) Pure calcareous

* See note *, p. 1.

earth, or lime, is soluble in a small proportion in water, with which it contracts great heat. It is infusible without addition. It attracts the carbonic acid from the fixed alkalies, and by itself becoming mild renders them caustic. Its specific gravity is 2,723.

Magnesia does not burn into a caustic substance like quick-lime, though it is deprived of its carbonic acid by the application of heat. It is soluble in several acids, and forms with the vitriolic the sal catharticus amarus, or Epsom salt. When mixed with water, it shews a very small degree of heat, but without any effervescence. It requires 7,692 times its weight of water for its solution. It is not precipitated from other acids by the vitriolic, as calcareous earth is. Its specific gravity is 2,155.

Barytes is by far the most ponderous of the earths, from which circumstance it derives its name.

With vitriolic acid it forms the ponderous spar, which is insoluble in water; and its combinations with the nitrous and muriatic acids are also not very soluble, but with the acetous acid (or vinegar) it becomes deliquescent. Combined with carbonic acid, it is soluble in 1550 times its weight of water, when pure in 900 times. The specimens of barytes naturally combined with carbonic acid are rare; it is more commonly found united with the vitriolic acid. From this the earth may be separated by the following process: Pound the ponderous spar, and mix it with twice its weight of fixed alkali; expose this mixture to a strong red heat for about two hours. The acid quits the earth to unite with the alkali, forming a neutral salt, which may be washed away. The earth remains combined with carbonic acid, which may be dispelled by heat. The specific gravity of this earth, when pure, is 3,773.

Argill, or *clay*, is soluble in the vitriolic, nitrous, and muriatic acids, and forms alum with the first of these. If concrete volatile alkali*, or any other of the alkalis, is added to a solution of pure alum, the alkali and acid unite, while the clay falls to the bottom, united with only a small quantity of fixed air. The fluid must be abstracted by decantation, and the precipitate washed with distilled water, and dried. Pure clay does not become caustic by burning, but is contracted in size, and becomes very hard. The specific gravity of this earth is only 1,669.

The principal natural specimens of argillaceous earth are boles, clays, marles, slates, and mica. In none of these, however, except the flag-stone, does the argill amount to half the weight of the whole substance. Silica abounds very much in common clays. Baked clays constitute all the varieties of bricks, pottery, and porcelain. If baked in a strong heat, they give fire with steel.

Silica, or *flint*, is soluble in only one of the acids, the fluoric, yet during its precipitation, it is capable of combining with most of the mineral acids. In its indurated state, it is always sufficiently hard to scratch and strike fire with steel. After being burnt, it does not fall to powder as the calcareous earth does. It produces no effervescence with acids. It may be dissolved by the fixed alkalies, both in the dry and wet way. When alkali and flint are exposed to the heat of a glass-house furnace, if the alkali is only half the weight of the silica, it produces a diaphanous and hard glass, but when the alkali is in double or triple the proportion, the glass deliquesces of itself, by attracting the humidity of the atmosphere, and forms what is

* The volatile salts in a solid state.

called liquor of flints. This earth is perfectly dissolved in that wonderful boiling water-spout, above sixty feet high, at Geyser in Iceland, where by cooling it forms a hard siliceous mass. Pure siliceous earth is obtained by fusing* clear quartz with four times its weight of fixed alkali, dissolving the whole in distilled water, and precipitating the earth by an acid. Its specific gravity is 2,650.

M. Bergman has formed perfect siliceous crystals by dissolving siliceous earth in the sparry acid, and suffering it to crystallize slowly. It is probable that nature forms them in a long course of time from a solution or diffusion of this earth in water.

Of the newly discovered earths I shall treat in a separate chapter, though it may be premised, that they are rather of importance in order to complete the nomenclature of the mineral kingdom, than from their quantity or their properties.

Though the simple earths are all infusible alone, yet they may readily be fused by mixture with each other. The calcareous earth is found to act as a menstruum in dissolving the other earths by heat; and when it has once acted on any earth, a compound menstruum is formed, which acts still more efficaciously in dissolving other earths. Hence it is, that any three of the simple earths may be fused into glass, provided calcareous earth is one of the number.

Thus far it appeared necessary to premise concerning the general properties of the simple earths in their separate state; but as their combinations are various, and their uses in this last state very important, it will be proper to treat of each on a more ample scale than the limits of a single chapter would admit.

* Melting by heat.

C H A P. X.

CALCAREOUS EARTHS.

Chalk.—Limestone.—Marble.—Marle.—Calcareous Spar.—Iceland Crystals.—Petrifications.—Parts of Animals found in Marle, &c.—Gypsoms.—Great Varieties.—Alabaster.—Fibrous Stone.—Mineral Glass.—Selenite.—Gypseous Spar.—Plaster of Paris; how prepared.—Fusible or Derbyshire Spar.—Spars, how formed.—Beautiful Appearances in different Caverns.—Metallic Combinations with calcareous Earth.

CALCAREOUS earth is sometimes found in the form of powder, but more frequently in that of a concrete substance called chalk, which differs with respect to the fineness of its particles and firmness of texture.

1. Chalk consists of calcareous earth or lime, united with carbonic acid, and an union of the same principles also constitutes limestone and marble. These substances only differ from common chalk in their degree of purity, or in the manner of their aggregation, admitting of more or less polish. The different coloured veins in marble are produced by the admixture of other substances, (most commonly iron) unequally distributed through the mass.

2. Strata of marble also contain calcareous earth, more or less blended with a considerable proportion of clay and sand.

3. Calcareous earth is often found projecting into the interstices and crevices of rocks in a crystallized state, and is then called calcareous spar. It is more or less transparent, and shivers into flat fragments of a rhomboidal figure. One variety is called Iceland crystals.

tals. They engaged the attention of Sir Isaac Newton, by their remarkable quality of refracting the rays of light without separating them into colours, so as to make a line drawn on paper appear double, when viewed through them. The English lead-mines are full of spars; their shape is in general a firm column, terminated at each end with a pyramid. Of these calcareous spars there are many varieties.

4. Calcareous earth appears in the form of animal and vegetable substances, petrified into stone by being exposed to petrifying waters. These fill up the pores of the substance with calcareous earth, and incrust them. Hence we may conclude, that this earth is soluble in water, and is deposited in certain circumstances. The quantity of earth, however, contained in the water is very small, and therefore the petrifications are formed slowly. Those organic bodies, which resist putrefaction most, are frequently found petrified, such as bones, shells, and the harder kinds of wood; on the contrary, the soft parts of animals, which are very subject to putrify, are scarcely ever found petrified. Mr. Kirwan remarks, that petrifications are most commonly found in strata of marle, chalk, lime-stone, or clay; seldom in sand-stone, still more rarely in gypsum, but never in gneiss, granite, basaltes or shoerl; they sometimes occur among pyrites and ores of iron, copper, and silver, and almost always consist of the species of earth, stone, or other mineral, which immediately surrounds them. Those of shells are generally found nearest the surface of the earth, those of fish deeper, and those of wood deepest. A very remarkable circumstance is, that petrifications are found in climates where their originals could not have existed. From the gradual and insensible concretion

of this kind of matter from dropping waters, are formed the large pendulous columns hanging like icicles from the roofs and sides of caves. The most remarkable are in the Peak of Derbyshire. Sometimes they are found in the arches of old bridges, and arise from the water oozing through and carrying particles of lime with it. This earth so concreted is called stalactites, stone-icicles, or drop-stone.

5. The shells of all crustaceous animals, from the coarsest to the pearl which lines the shell of the oyster, are all made up of this calcareous earth with a small quantity of animal gluten. Egg-shells are of the same nature, and those marine bodies which, from their hardness and vegetable appearance, are called stony plants, such as are all the species of coral, &c.

Marles, which have been already mentioned as containing calcareous earth, are generally divided into three kinds. First, shell-marle; second, clay-marle; third, stone-marle. The first is found in beds of considerable extent, and consists of the remains of sea and land shells; that which contains the sea shells is commonly found in the greatest quantity. Of this kind is that of Paris, mentioned by M. Reaumur, which is about ten feet deep, and of great extent, consisting of oyster and other sea shells; and some very large beds may be found in the neighbourhood of Woolwich. The relics of land shells are those of snails; they have probably been carried by the current of some water, and deposited at one place, and the water being drained off, the shells remained behind. Beds of fresh-water shells are also found. Clay-marle is a calcareous matter, which when exposed to the air crumbles to dust; it is to be distinguished from common clay, by effervescing with acids, from the calcareous earth it contains,

contains. Stone-marle differs from clay-marle only in being much harder; but it differs from ordinary stone by breaking to pieces when exposed to the air.

It has been supposed by some respectable writers, that all these species of calcareous earth derive their origin from shells. Some marbles are evidently formed of shells, and those of Derbyshire exhibit this appearance in a remarkable manner. Coral is universally allowed to be the work of small animals of the polypus kind. The strata of limestone being also found so frequently united with shells and other marine substances, has induced the philosophers to whom I allude to believe, that the stone itself is altogether composed of shells, which at first mouldered into paste, and were afterwards pressed and concreted together. In one of the quarries of Italy, the bones of small fishes are found; and some rocks in the midland counties of England are almost wholly composed of the kind of shells called *entrochi*. The animals which produce the coral are here seldom to be found; but in other parts, as in Jamaica, the bottom of the sea is entirely covered over with coral, and harbours are sometimes stopped up with it. Sir Hans Sloane mentions a Spanish plate-ship, which was wrecked, and remained at the bottom of the sea twenty-five years, being then fished for, the treasure, as well as the timber, &c. were covered with coraline concretions. Hence, this constant growth at the bottom of the sea may in time produce beds and strata of this kind of earth, which, according to circumstances, may be converted into marle, limestone, marble, &c. Calcareous earths, united with carbonic acid, may be known under all forms, by effervescence with the mineral acids.

6. If vitriolic acid is poured on chalk, the carbonic acid is expelled, while the vitriolic unites with the

calcareous earth, and constitutes a substance which has very little solubility. This is GYPSUM, selenite, or plaster of Paris, which exists in considerable quantities in nature. Gypsums are found in solid masses, very soft, and easily scraped with a knife. They are distinguished from the combinations of calcareous earth with carbonic acid, by not effervescing with acids; and from other earthy bodies, by being by heat changed into a white powder, which when mixed with a large proportion of water, suddenly concretes into a stony mass. They are most commonly found in the strata of clay, sometimes in those of sand, under the appearance of a whitish coloured mass, but the small pieces are transparent, and sometimes have a red tinge. They are often composed of small shining particles, like the grains of sugar, and when under this appearance they are particularly called gypsum. When hard, so as to admit of being cut into toys and figures they are called alabaster. The second form under which they are found, is that of a fibrous structure of oblique crystals, which are parallel to themselves, but which cross the mass from the upper to the under surface. In this state they are called *fibrariæ* or fibrous stone by Dr. Hill. These differ much in size and regularity of concretion. The third species is composed of clear transparent plates, like glass, in close contact with each other, but which may be separated. They split with a knife into fine plates, very flexible, though they cannot be bent without producing flaws. They are called *glacies marina*, and sometimes *Muscovy glass*, but improperly, as that is a different substance.

The fourth species is in the form of separate oblong crystals, which are called *selenites*; some are long and regular, like crystals of salt. The fifth species of gyp-
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seous spar is of a platey texture. Gypseous spar varies in compactness and transparency, is sometimes white, sometimes reddish, and is mixed with a greater or less quantity of other matter: sometimes we meet with it in crystals. The ores of metals are often found in this spar.

Sixthly, gypsum is often met with in waters of springs in a dissolved state; for we find by experiment, that it is soluble in water, though but in small quantity. When the water is evaporated, it is deposited in crystals very small, and which appear like a white powder; but by the microscope are found to be oblong regular concretions.

Margraff first shewed that all these species were composed of calcareous earth and vitriolic acid. He took a quantity of gypseous earth in a subtile powder, and boiled it for some time in a solution of fixed vegetable alkali; and upon examination, he found the calcareous earth at the bottom in an uncombined state, and in the solution a vitriolated tartar. He also composed an artificial gypsum of calcareous earth and the vitriolic acid, which had all the properties of a natural gypsum. From knowing the composition of these substances, we may sufficiently understand their properties, particularly that of being converted by a moderate heat into plaster of Paris. If the purer kinds are reduced to fine powder, and put into an iron vessel, by the time the vessel is heated the powder grows light, and is thrown into motion like a boiling fluid. There are also a variety of other earthy powders, which when moist give the same appearance; for the vapour rising up, makes its way through the powder, keeps it afloat, and agitates it like a liquid in a boiling state. This appearance continues till most of the water is evaporated. After this the powder becomes heavy,
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and lies at the bottom of the vessel as before heating. It is then prepared for plaster of Paris, for if a quantity of it is put into so much water as gives it the consistence of cream, it will soon become solid, and ring like a vessel of earthen-ware, or metal. It loses its transparency by heat, and becomes white. The softer kinds are best for the plaster of Paris.

The explanation of all these phenomena is not difficult, when we consider the nature of gypsum, which being a saline compound, has all the qualities of a salt. In its natural state it is crystallized in consequence of its containing a quantity of water. Heat expels the water; which being again added, is attracted by the gypsum, and occasions a crystallization.

A more violent heat produces very little change, as the vitriolic acid adheres very closely to the earth. If these substances, however, are mixed in powder with a quantity of charcoal-dust, the whole of the acid may be dissipated, and the calcareous earth only left behind, and thus a particular phosphorus is formed. In this experiment the charcoal attracts the oxygen of the acid, which is by that loss rendered volatile, and is dispersed in fumes.

7. Calcareous earth is also found saturated with muriatic acid in sea-water and in salt-pits.

8. Calcareous earth, united with the fluoric acid, forms the fusible spar or fluor, which is commonly known by the name of DERBYSHIRE SPAR. The texture of this compound is either sparry, or irregularly shattered or cracked. It is either transparent or opaque; and the specimens are of a cubic, rhomboidal, polygonal, or irregular figure. The coloured spars have the property of emitting light when laid on a hot iron, or otherwise heated; but they lose this property by being made red hot. The green spars are
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the most phosphorescent, but none of them exhibit this quality except when well warmed. They are scarcely harder than common calcareous spars, and therefore do not strike fire with steel. They do not melt by themselves; but very much promote the fusion of other stones, particularly the calcareous. They do not effervesce with acids, either before or after being submitted to the action of fire.

Mr. Whitehurst explains in the following manner the formation of sparry and stalactitical productions. When water impregnated with the sparry acid proceeds slowly through different strata of earths and minerals, it becomes charged with a variety of these substances in solution; and as it exudes gradually on the surface of caverns and fissures, the aqueous particles evaporate, and the sparry matter crystallizes in various forms, including in its own substance the heterogeneous matters with which it is charged.

If the quantity of water thus impregnated, which exudes through the pores of the earth or stone, is not more than will easily evaporate in the ordinary heat of the atmosphere, a sparry crust is formed. If the quantity of water exuded exceeds the quantity evaporated, stalactites are produced in one instance, and tubes in another.

If a drop of water hangs from the roof, almost dropping, the aqueous particles evaporate from the surface sooner than from its interior parts. A crystallization therefore takes place on the surface, while the center remains fluid: the water thus detained is continually increasing, and the tube gradually extends downwards. By this process, tubes are frequently formed of two feet in length, and one tenth of an inch in diameter. The appearance of caverns ornamented with these splendid productions exceeds that

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of the most laboured works of art: transparent columns, adorned with the most beautiful and vivid colours, disposed sometimes in the form of a honeycomb, sometimes in a more irregular arrangement: mirrors, reflecting the images of objects, tinged with a light shade of the most delicate colours, ravish the eye of the beholder. The pillars appear of various forms and sizes; sometimes arranged like a regular colonnade, and sometimes disposed with all the delightful irregularity of nature. The stalactites hang like icicles from the lofty roofs of these stupendous caverns, and are reflected back by the polished and glittering floors. Some of the most striking caverns of this kind are the grotto of Antiparos*, Poole's Hole, and Peak Hole, in Derbyshire.

9. Calcareous

* The following is an account of this famous grotto, communicated by Magni, an Italian traveller, to the celebrated Kircher. — Having been informed (says he) by the natives of Paros, that in the little island of Antiparos, which lies about two miles from the former, a gigantic statue was to be seen at the mouth of a cavern in that place, it was resolved that we (the French consul and himself) should pay it a visit. In pursuance of this resolution, after we had landed on the island, and walked about four miles through the midst of beautiful plains, and sloping woodlands, we at length came to a little hill, on the side of which yawned a most horrid cavern, that with its gloom at first struck us with terror, and almost repressed curiosity. Recovering the first surprise, however, we entered boldly; and had not proceeded above twenty paces, when the supposed statue of the giant presented itself to our view. We quickly perceived, that what the ignorant natives had been terrified at as a giant, was nothing more than a sparry concretion, formed by the water dropping from the roof of the cave, and by degrees hardening into a figure that their fears had formed into a monster. Incited by this extraordinary appearance, we were induced to proceed still farther, in quest of new adventures in this subterranean abode. As we proceeded, new wonders offered themselves: the spars, formed into trees and shrubs, presented

9. Calcareous earth is found saturated with what was thought a particular acid, which has been called the tungstenic

presented a kind of petrified grove; some white, some green; and all receding in due perspective. They struck us with the more amazement, as we knew them to be mere productions of nature, who, hitherto in solitude, had, in her playful moments, dressed the scene, as if for her own amusement.

‘ But we had as yet seen but a few of the wonders of the place; and we were introduced only into the portico of this amazing temple. In one corner of this half illuminated recess, there appeared an opening of about three feet wide, which seemed to lead to a place totally dark, and that one of the natives assured us contained nothing more than a reservoir of water. Upon this we tried, by throwing down some stones, which rumbling along the sides of the descent for some time, the sound seemed at last quashed in a bed of water. In order, however, to be more certain, we sent in a Levantine mariner, who by the promise of a good reward, with a flambeaux in his hand, ventured into this narrow aperture. After continuing within it for about a quarter of an hour, he returned, bringing some beautiful pieces of white spar in his hand, which art could neither imitate nor equal. Upon being informed by him that the place was full of these beautiful incrustations, I ventured in once more with him, for about fifty paces, anxiously and cautiously descending by a steep and dangerous way. Finding, however, that we came to a precipice which led into a spacious amphitheatre, if I may so call it, still deeper than any other part, we returned, and being provided with a ladder, flambeaux, and other things to expedite our descent, our whole company, man by man, ventured into the same opening, and descending one after another, we at last saw ourselves all together in the most magnificent part of the cavern.

‘ Our candles being now all lighted up, and the whole place completely illuminated; never could the eye be presented with a more glittering, or a more magnificent scene. The roof all hung with solid icicles, transparent as glass, yet solid as marble. The eye could scarce reach the lofty and noble ceiling; the sides were regularly formed with spars; and the whole presented the idea of a magnificent theatre, illuminated with an immense profusion of lights. The floor consisted of solid marble; and in several places, magnificent columns, thrones, altars, and other objects appeared,

tungstenic acid, though it is certainly no other than the metallic salt of that name. This combination forms the TUNGSTEIN of the Swedes. This stone is remarkably heavy, and resembles fluor spar in the form of its fragments. It becomes yellow in acids, and is found united with petroleum (or mineral pitch) in the proportion of ninety-five of the former to four of the latter. In this state it forms the swine-stone, which is of a dark colour, and becomes fetid by friction.

10. Calcareous earth is also found united with three of the metals, iron, copper, and lead; of each of which there are several varieties. When united with copper, it is called mountain blue; when united with

as if nature had designed to mock the curiosities of art. Our voices, upon speaking or singing, were redoubled to an astonishing loudness; and upon the firing of a gun, the noise and reverberations were almost deafening. In the midst of this grand amphitheatre rose a concretion of about fifteen feet high, that, in some measure, resembled an altar; from which, taking the hint, we caused mas to be celebrated there. The beautiful columns that shot up round the altar, appeared like candlesticks; and many other natural objects represented the customary ornaments of this sacrament.

Below this spacious grotto, there seemed another cavern; down which I ventured with my former mariner, and descended about fifty paces by means of a rope. I at last arrived at a small spot of level ground, where the bottom appeared different from that of the amphitheatre, being composed of soft clay, yielding to the pressure, and in which I thrust a stick to about six feet deep. In this, however, as above, numbers of the most beautiful crystals were formed; one of which, particularly, resembled a table. Upon our egress from this amazing cavern, we perceived a Greek inscription upon a rock at the mouth, but so obliterated by time, that we could not read it. It seemed to import that one Antipater, in the time of Alexander, had come thither; but whether he penetrated into the depths of the caverns, he does not think fit to inform us.—*Kircher de Mund. Sub. 112.*

calx of copper, it is denominated Armenian stone. Gypseous earth combined with calx of copper, is called turquoise and malachites. The purest malachite, according to Kirwan, contains seventy-five parts of copper and twenty five of aerial or carbonic acid; calcareous earth is therefore not an essential ingredient. It is of a green colour, and is sometimes cut and polished as a gem.

C H A P. XI.

M A G N E S I A N E A R T H S.

Magnesia, how obtained.—Epsom Salt.—Scap Rock.—French Chalk.—Serpentine Stone.—Mica.—Talk.—Muscovy Glass.—Asbestos.—Mineral Cloth.—Mountain Leather.—Mountain Flax.—Mountain Wood.

TO obtain MAGNESIA, the mother water of nitre, or of common salt, is placed in a large vessel, and diluted with a considerable quantity of common water. Fixed alkali dissolved in water is then added, and the mixture just made to boil. By this process the magnesia falls to the bottom of the vessel in the form of a powder, which is purified by repeated affusions of water. Magnesia, in its mild state, consists of forty parts magnesian earth, forty-eight carbonic acid, and twelve water. The crystalized aerated magnesia contains half its weight of carbonic acid, one fourth magnesian earth, and one fourth water.

Magnesia combined with vitriolic acid constitutes EPSOM SALT, which in many respects resembles Glauber's salt; it may be distinguished, however, by an easy experiment; for if a fixed alkali is added to a solution of Epsom salt, a precipitation is produced, which is not a consequence of adding an alkali to a solution of Glauber's salt. Even the volatile alkali, if mild, is capable of separating magnesia from its acid, by means of a double attraction; the alkali unites with the vitriolic acid, and part of the earth falls to the bottom, combined with carbonic acid.

Magnesia enters into the composition of some earthy substances; the stones usually treated of under this

head consist of magnesia united with flint; but the latter usually predominates. Most of them are soapy to the touch, and so soft that they may be cut into various utensils.—Of these the following are the most remarkable:

1. *Steatites, lapis ollaris, or SOAP ROCK*, is of various colours, but chiefly of different shades of green. It does not become ductile in water, and is fused with difficulty. One variety of it is in the form of six-sided prisms, another is lamellated.

2. *Smectis, or FRENCH CHALK*, is found pretty plentifully in Cornwall. Its colour is either white, yellow, or red and white; some specimens have the appearance of Castile soap.

3. *SERPENTINE STONE* is of different shades of green. The structure of this stone is fibrous, and it might therefore be confounded with another earthy matter, called asbestos, if its fibres did not adhere so closely together, as to escape observation, when the stone is cut and polished. Of the serpentine stone there are many varieties, and it is found spotted or streaked with a great diversity of colours. What is commonly called serpentine stone, is a true lapis ollaris; but being variegated like the skins of some serpents, is distinguished by another name. Great quantities of this stone are found in Italy and Switzerland, where it is often worked into the shape of dishes and other vessels. It is harder than steatites, but not so hard as to give fire with steel; and less smooth to the touch, but is susceptible of a good polish; it looks like marble, and is often in thin pieces semitransparent. The greener sorts of this stone have been called nephritic; their colour arises from manganese. But the term lapis nephriticus is commonly applied to jade.

4. *Micaceous earths, or TALKS*, may be defined

earthy or stony bodies, the texture and composition of which consists of thin flexible particles, divisible into plates or leaves, having a shining surface. These plates, by being exposed to heat, separate into smaller ones, but their flexibility is much diminished. By a strong heat they curl or crumple, but it is very difficult to reduce them to perfect fusion without addition. The plates of mica, when of the purest kind, are transparent, and there is one variety, the plates of which, from their near resemblance to glass, are called Muscovy glass. Micæ, however, are often tinged with a variety of colours, or are more or less opaque. Sometimes they have a lustre resembling that of metallic substances. Sometimes they are in the form of shining powder, like that which is used in bronzing figures. This appearance has often imposed upon miners, who have thought they met with gold and silver, whereas there is never any metal in these substances but iron. They are found also mixed with other stones, as the granite, which frequently contains a great quantity of talk. Freestone also contains more or less; its horizontal layers have between them a thin stratum of talk where the stone more easily separates. It is also found in some kinds of slate, which, when exposed to the air, moulder into talky powder. The transparent Muscovy glass is used for windows, and for those lanterns which are employed in powder magazines, as this substance is not so liable to break as glass, and is unassailable by fire. The twisted, or crumpled mica, which is found at Hardal in Jemland, is there manufactured into kettles and other vessels, as also for hearths of chimnies; and the powder which falls in the working may be mixed with common salt for the distillation of the muriatic acid. The shining appearance of the micaceous earths has obtained them the

names of daze, glimmer, or glift. Talk differs from other micas in its laminæ or filaments being much tenderer and more brittle, but both have the metallic lustre.

5. The ASBESTOS, or amianthus, is a fossil agreeing with talk in having a regular structure, in being flexible, but differing in being composed of fibres instead of plates. When long exposed to air, it dissolves into a sort of downy matter, which has some degree of toughness, but the fibres cannot be unravelled. Cloth and paper have been made of this substance, which resist the fire. Asbestos, however, though unaffailable by common fires, has submitted to the power of strong burning mirrors, and has undergone vitrification. The ancients are said to have manufactured cloths of this fossil, in which they wrapped their dead when they burned them, that the ashes might be preserved. Several moderns have succeeded in making this cloth; the chief contrivances which are necessary are to mix the mineral fibres with a large proportion of flax, and to use oil freely; these matters are afterwards consumed by exposing the cloth to a red heat. Although the cloth of asbestos when soiled is restored to its whiteness by burning, yet it does lose some part of its weight, as has been ascertained by accurate experiments. The varieties of this curious genus of fossils are mountain leather or cork; mountain flax, to which the name of amianthus is particularly applied; common or unripe asbestos, and mountain wood. These substances all consist nearly of the same component parts, and differ chiefly in colour, solidity, or in the form and direction of their fibres. Some specimens of the amianthus are so light as to float in water. When the fibres are parallel, it is

called mountain leather; when twisted, mountain cork.

The mountain cork or leather contains in the hundred from 56 to 62 parts of siliceous earth, from 22 to 26 of mild magnesia, from 7 to 14 of mild calcareous earth, 1.7 of clay, and 10.6 of iron. These afford a white slag by fusion. The specimens which are of a yellowish *brown* colour are impure, and melt pretty easily into a black slag. There is also a species of a light green colour, somewhat more brittle, and contaminated with iron. This last is soluble by heat into a semitransparent glass.

C H A P. XII.

P O N D E R O U S E A R T H S.

Barytes a scarce Mineral; found in two States.—Cristatum.—Ponderous Spar.—Cawk.—Liver Stone.

BARYTES is found in two states, combined either with the carbonic or vitriolic acids. 1st. When united with the former acid, it resembles alum, but is hard and striated, as if composed of radiating fibres coming from a center. This mineral has only been found native in a lead mine at Anglezark in Lancashire. It is sometimes of a greenish colour; sometimes jagged, when it is called *cristatum*, from its resemblance to a cock's comb. These prominences are found accreted to balls of the same substance. Later investigations have however classed this as a sulphat of Barytes.

2. Ponderous earth is more frequently united with vitriolic acid, and in this state it is found in all the Derbyshire and Cumberland lead mines, and in several coal pits throughout England. These stones are found of various appearances, pale yellow, blackish, with coarse scales, or with fine sparkling scales. They are either transparent or opaque. The transparent **PONDEROUS SPAR** is usually in the form of a six-sided very flat prism, ending in a four-sided pyramid; but, like all other crystals, liable to be varied by the circumstances attending their formation. The opaque specimens, called **CAWK** by the miners, are of a white, grey, or fawn-colour; frequently of no regular figure, but often in the peculiar figure of a number of small

convex lenses united together. These varieties are all remarkably heavy, in general exceeding four times the weight of water, and by this circumstance the presence of barytes may commonly be discovered. The stones composed of vitriolic acid and barytes may be known by their smelling like liver of sulphur when rubbed. From this property they are called *lapis hepaticus*, and *leberstein* (liver-stone) by the Germans.

C H A P. XIII.

ARGILLACEOUS EARTHS.

General Account of Clays or Argils.—Alum; its Composition.—Natural History of Alum.—Action of this Substance on other Bodies.—Uses of Alum in the Arts.—Lac Lunæ.—Porcelain Clay.—Manner of making different Kinds of Pottery.—Stone Ware.—Yellow, or Queen's Ware.—China.—Lithomarga.—Terra Lemnia.—Bole.—Zeolite.—Lapis Lazuli.—Tripoli.—Brick Clay.—Slate.

THE argil, or earth of clay, is one of those substances which abound most in nature. There are immense strata of clays, and they make a part of every rich soil. The idea commonly entertained of clay, is that of a natural substance, the purest kinds of which are firm, and have a sort of fatness or unctuousity, and which by being rubbed by the finger receive a polish. When dry, they imbibe moisture, so that when applied to the tongue it adheres to them. From their attraction for water, they are always found moist in a natural state. If more water is added, they form a ductile paste, which, when thoroughly burnt and dried, becomes hard, stony, and impenetrable to water. On the regular contraction which clay undergoes from the application of different degrees of heat, depends the construction of a thermometer for measuring intense degrees of heat, and invented by Mr. Wedgwood*.

As clays when wrought together become impenetrable to water, they are made use of to retain water in ponds, &c. This is the reason that when cattle are allowed to tread a clayey soil in wet weather, the

* See vol. i. p. 115.

plants die that grew there; for the clay being previously mixed with the water, and being then compressed by the feet of the cattle, the ground is rendered too tough for the vegetables to spring up through it, especially when the clay thus trodden together is afterwards dried by the heat of the sun. Clays differ much in consistency. Some melt in the mouth, others are gritty, and get between the teeth. They are white, blue, grey, red, yellow, or black. Some are much less viscid than others. Some resist a very violent heat without undergoing any change; but most of them, in very intense heat, melt into a vitrified mass. Some of them effervesce with acids, others not. All these varieties have but one species of earth for their basis, and are nothing more than mixtures of pure clay with heterogeneous substances. Thus we often find strata, which contain a large mixture of sandy and gritty particles. All clays which are sandy, are so from sand, or calcareous earth: when mixed with the latter, they effervesce. The variety of their colour depends on an admixture of iron; though sometimes of inflammable matter. The clay becoming white in the fire, is the surest sign of its purity. We can actually extract iron from most of these clays, especially those which burn to a red colour, which colour is always assumed by the calces or rust of iron. When they effervesce with acids, they class with marles. Clay, united with vitriolic acid, forms that common and well known substance called ALUM.

The *Στυπτηρια* of the Greeks, and the alumen of the Romans, was a native substance, and differed much from the salt of which I am now treating. The varieties mentioned by Dioscorides refer to stalactites, which contained very little if any alum, and that completely enveloped by a vitreous matter. The
descriptions

descriptions of Pliny are still more difficult to be understood, as he had not seen the substance which he describes, but merely transcribed from others. The factitious salt which is now called alum, was first discovered in the eastern countries, but when, where, or by what means, is unknown. On account of its similar astringency, and its use in the arts of tanning and dying, the new salt has retained the old name.

Among the most early works for the preparation of alum, was that of Roccho, a city of Lycia, now called Edeffa, hence the appellation Roch alum (now commonly mistaken for rock alum). In the neighbourhood of Constantinople, and other parts near Smyrna, were many alum-works. The Italians hired and made use of these, but about the fifteenth century introduced the art into their own country.

Bartholomew Perdix, or Pernix, a merchant of Genoa, who had often been at Roccho, discovered the matrix of alum in the island of Ischia, about the year 1459, and established a manufactory there; at the same time John de Castro made the same discovery at Tolfa, by means of the *illex aquifolium*, which he had also observed to grow in the adjacent mountains of Turkey; and his opinion was confirmed by the taste of the stones. The attempts of the Genoese at Viterbium and Volaterre succeeded extremely well; inso-much that an edict of Pope Pius II. prohibited the use of oriental alum.

Manufactories were established in Spain, Germany, England, Sweden, &c. in the course of the sixteenth century.

The proportion of the principles may be ascertained in the following manner: the water is expelled by a gentle heat; the remaining mass grows opaque, swells, foams, and at length grows quiet, spongy, and friable; the

the quantity of earthy basis is easily determined by precipitation with fixed or volatile alkali.

Mr. Pott first observed that when clay is mixed with vitriolic acid, and boiled a considerable time, the solution affords alum, though he obtained but little in this way. Margraff found that the vitriolic acid dissolves one half or more of the purest clay; from the solution he obtained much alum, but always found it necessary to add a certain portion of alkaline salt before the alum would appear; and he could never obtain it without adding a greater quantity of vitriolic acid than was necessary to compose the alum. The other half, which did not dissolve, he concludes to be a very fine sand, or an earth of the stony kind. The shortest way is to add a small quantity of fixed or volatile alkali to the solution, which immediately becomes muddy, the alkali attracting some of the superfluous acid, a powder precipitates, consisting of the crystals of alum.

The alum, however, which is employed in the arts, is not prepared in this way. Nature produces but a very small quantity of actual alum, and this is mixed with heterogeneous matters, or efflorescences, in various forms, upon ores during calcination, but rarely occurs crystallized. In this latter state, it is reported to be found in Egypt, Sardinia, Spain, Bohemia, and other places; it is sometimes generated in the aluminous schist of Lapland and West Gothland, by a spontaneous decomposition of the ore; besides it is found (but rarely) in mineral springs. Alum is mostly prepared from certain fossils, or ores of alum, as they are called. These ores are generally found in strata, which appear like indurated clays, of a dark black colour, and have a sulphureous smell. When exposed to the air for some time, they grow hot, swell, and crumble
down

down into a powder, emit sulphureous fumes, and sometimes take fire. Some do not undergo this change merely from exposure to the air, but must be first burnt and washed, and then exposed to the air a good while before alum can be obtained. After they have been crumbled down in this manner, they are steeped in water; an alkali is then added, and the alum crystallizes and subsides.

These ores are evidently natural mixtures of clay and sulphur. By exposure to air, according to the old system of chemistry, it was supposed that the clay acted on the sulphur in such a manner as to make it part with its phlogiston, whence they explained the production of heat. This fact, however, is now much better explained, according to the new system, by supposing that the oxygenous gas of the atmosphere is decomposed; and while the oxygen is absorbed by the sulphur (with which it forms vitriolic acid) the heat is set at liberty, and becomes sensible.

After a proper quantity of alkali has been added to the solution, it is crystallized in the common manner, that is by evaporation. The crystals are at first tolerably distinct, but of no considerable size. A great quantity of them being heaped together until they undergo a watery fusion, they unite into a mass, which is called roch alum, and in this form it is exposed to sale.

That accurate and attentive observer, Bishop Watson, in his *Chemical Essays*, relates, that being one day engaged, in evaporating something or other from a saucer made of Staffordshire yellow ware, he was surprised to see a white substance bubbling through a crack in the saucer; upon tasting it, he found it to be a salt, and, upon further examination, discovered that it was a perfect alum. The fire, he observes, was a
very

very hot one, and it was made of coal cinders; the faucer was placed on the bar of the grate, and the alum, he conceives, was formed from the sulphureous acid of the cinders uniting itself with the clay, which enters into the composition of the yellow ware. He was informed that the vapour which, in some places, escapes from the coal-pits which are on fire in Staffordshire, forms an alum whenever it meets with an argillaceous earth. This, he remarks, is conformable to the manner of making alum on the Solfatara, near Naples, where they place little heaps of argillaceous earths or stones over the crevices from which the sulphureous vapour issues, in order that they may collect a greater quantity of alum.

This salt contains much water, hence it undergoes what chemists call the watry fusion; after this there remains a substance called burnt alum, which contains the earth and vitriolic acid, with little or no water; this, if the heat is increased, does not melt, nor by heat alone can we separate the whole of the acid, though some of it rises; but the addition of any inflammable matter disposes it to rise in fumes, which are very sulphureous. One hundred parts of crystallized alum contain thirty-eight of vitriolic acid, eighteen of clay, and forty-four of water.

The sensible qualities of alum shew it to be the opposite to borax, which is composed of the fixed alkali and a very weak acid; on the contrary, alum is the strongest acid, combined with an earth which attracts it very weakly; so that the qualities of the acid are very little altered, for if we apply a solution of alum to the infusion of litmus, it changes it to a red. The solution has also a manifest acidity, combined with another taste which approaches to sweetness. If an alkali is added, the earth is immediately precipitated,
and

and this effect is not only produced by the fixed and volatile alkalies, but by magnesia and calcareous earth. Alum is often obtained from the liquor of the compound of iron and vitriolic acid.

The earth of alum will combine in excess to the salt when already formed. M. Beaumé boiled a solution of alum with the earth precipitated from another portion of alum, by means of fixed alkali; the earth was dissolved with effervescence, the filtrated solution had no longer the taste of alum, but that of a hard water, did not redden the tincture of turnsole, but converted syrup of violets to a green. By spontaneous evaporation it afforded crystals, scaly and soft to the touch like mica; M. Beaumé compares them to selenite. It is not easy to compose alum by adding vitriolic acid to this saturated salt, the mixture becoming acid, but not styptic. However, after spontaneous evaporation for three months, the solution afforded crystals of alum mixed with some micaceous scales, similar to those afforded by alum saturated with its earth.

Alum, heated with combustible matters, forms a substance which takes fire on exposure to air, and is called the pyrophorus of Homberg. This chemist, who published an account of the pyrophorus, in the year 1711, made experiments on human excrement, for the purpose of obtaining a colourless oil possessing the property of fixing mercury into fine silver: the inquiry produced many discoveries; the residue of this animal substance, distilled with alum, took fire on exposure to the air. Homberg repeated this experiment a number of times, and always with success. Lemery the younger, in the years 1714 and 1715, published two memoirs, in which he affirms, that pyrophorus may be made with a great number of vegetable

vegetable and animal substances heated with alum. But he did not succeed in his attempts to form it with some other vitriolic salts. These two chemists, who supposed alum to be a combination of the vitriolic acid and calcareous earth, imagined that the latter being converted into lime attracted the humidity of the air, and produced a degree of heat sufficient to set fire to the sulphur formed by the vitriolic acid and inflammable substances.

Alum is one of the most useful salts in the arts. It is added to tallow to make candles hard. Wood sufficiently soaked in alum does not easily take fire: the same is true of paper impregnated with it, which for that reason is very proper to keep gun-powder, as it also excludes the moisture of the air. This paper is also useful in whitening silver, and in silvering brass without heat. Alum is useful added to milk which does not easily separate its butter.

It is particularly useful in dying, in preparing the matters to be dyed; for by cleansing and opening the pores upon the surface by a gentle corrosion, it both renders the substance fit for receiving the colouring particles (by which the alum is generally decomposed) and at the same time makes the colour fixed. It constitutes the basis of crayons, which generally consist of the earth of alum, finely powdered and tinged for that purpose, with different colouring matters.

The argillaceous fossils are referred to the following heads:

I. ARGILLA AERATA, to which the fanciful name of *lac lunæ* has been applied. This was supposed to be a particular species of calcareous earth, till M. Sreber found that it was a combination of argil with the carbonic acid. It effervesces with acids,
and

and contains a very small proportion of calcareous earth, and sometimes of gypsum. It is generally found in small cakes of the hardness of chalk, like which it marks white. Its colour is snow white, and when examined by the microscope it is found to consist of small transparent crystals. It effervesces with acids.

II. PORCELAIN CLAY, *argilla apyra*, the *kaolin* of the Chinese. This is very refractory, and is with great difficulty brought into perfect fusion. After it has been submitted to the action of heat, it is of a solid texture, and is so hard as to strike fire with steel. It is found of an excellent quality in Japan, and likewise in different parts of Europe. In Sweden it is met with in coal-pits, between the strata of coal. Common pipe-clay belongs to this division, and differs from porcelain clay only in being less pure, which prevents its burning to a good colour.

The essential ingredient in all kinds of pottery is clay or argillaceous earth, because these earths are capable of being kneaded, and easily receiving any form, and of acquiring much solidity and hardness by exposure to fire. Pottery is, in general, covered with a glazing, or is made to undergo a vitrification at the surface, without which it would be pervious to fluids. Ordinary pottery is glazed with glass of lead mixed with metallic calces, or with fusible metallic earths. A fine kind of pottery is made of white clays, or such as whiten in the fire; the surface of which is vitrified by throwing into the furnace, when the ware is sufficiently baked, some common salt and saltpetre. The English stone ware is composed of tobacco-pipe-clay and ground flints. The use of the flints is to give strength to the ware, so that it may preserve its form during
the

the baking. In making this stone-ware great pains are taken to employ only the finer particles of the clay and flint. With this view the clay is much beaten in water, by which the finer parts being mixed with the fluid are suspended, while the coarser sink to the bottom of the vessel. The thick liquid, consisting of water and the finer particles of the clay, is farther purified by passing it through hair and lawn sieves of different degrees of fineness. After this the liquid is mixed, in various proportions for different wares, with another liquor, of about the same density, and consisting of flints calcined, ground, and suspended in water. The mixture is then dried in a kiln, and afterwards, being beaten to a proper temper, it becomes fit for being formed at the wheel into dishes, plates, bowls, &c. When the ware has been exposed to heat for about forty-eight hours, it is glazed by means of common salt. This is thrown into the furnace through holes in the upper part of it, and being converted into a thick vapour by the heat, is applied to the surface of the heated ware, and causes it to vitrify. This curious method of glazing earthen ware was introduced into England by two Dutchmen, near a century ago. It appears to be produced by a combination of the alkali of the salt with the siliceous earth of the pottery. The yellow or queen's ware is made of the same materials as the flint ware, but in different proportions. The glazing is also different; it is made by mixing together in water, till it becomes as thick as cream, one hundred and twelve pounds of ground white lead, twenty-four pounds of ground flint, and six pounds of ground flint glass. The ware, before it is glazed, is baked in the fire, by which it acquires the property of strongly imbibing moisture; it is then dipped in this composition, and suddenly taken out. It is afterwards

wards exposed a second time to the fire, by which means the glaze it has imbibed is melted, and a thin glassy coat is formed upon its surface, which is more or less yellow, according as a greater or less proportion of lead has been used.

Porcelain, or china, is a semivitrified earthen ware of an intermediate nature between common wares and glass. The first specimens of this beautiful manufacture came from China and Japan. Chinese porcelain is said to be composed of two ingredients, one of which is a hard stone or rock called *petuntse*, which they carefully grind to a very fine powder; and the other, called by them *kaolin*, is a white earthy substance, which they mix intimately with the ground *petuntse*. Reaumur examined both these matters; and having exposed them separately to a violent fire, he discovered that the *petuntse* had fused without addition; but that the *kaolin* had given no sign of fusibility; from which it appeared that the former was of a flinty nature, and the latter argillaceous. He afterwards mixed these matters, and formed cakes of them, which, by being baked, were converted into porcelain similar to that of China. Macquer thinks that the first European porcelains were made in Saxony and in France; and afterwards in England, Germany, and Italy. Manufactories have since been established in almost all the countries of Europe, in many of which porcelain is made very little if at all inferior to the Chinese.

III. Lithomarga, or STONE-MARROW, when dry, feels as slippery as soap, but is not wholly diffusible in water. When mixed with water, it falls in pieces, so as to assume the appearance of curds. In the fire it melts into a frothy slag. In the mass it breaks into

irregular scaly pieces. This is the fuller's earth used in the dressing of cloths. To this species also belongs the terra lemnia; this is of a brownish colour and shining texture, and falls to pieces in water with a crackling noise. The terra lemnia is so called from the island of Lemnos, now Statimane, in the Ægean sea, whence it is procured. It is likewise called the Turkish earth, on account of its being impressed with the seal of the grand signior.

IV. BOLE is a fine and dense clay of various colours, containing a large quantity of iron. It is not easily softened in water when indurated, as the porcelain and common clays, but either falls to pieces in the form of fine grains, or repels the water, and cannot be made ductile. In the fire it grows black, and is then attracted by the loadstone. The soft boles are of various colours, as red, yellow, green, grey, and blueish grey. The red kind is that used in medicine, under the name of Armenian bole; an indurated kind of which affords the material for red pencils. An indurated bole is frequently found in coal-pits, between the seams of coal, and is called coal slate. It is met with frequently in pieces like nuts of various sizes; which when broken exhibit impressions of plants, as the nodules of copper-slate from Ilmenaus contain representations of fish. A species of bole is found with scaly particles, the *bornblende* of the Swedes. It is distinguished from mica, by the scales being less shining, thicker, and rectangular. It is frequently mixed with pyrites; it is of two kinds, black and greenish. The former, when rubbed fine, affords a green powder, and is either of a lamellated or granular texture. The greenish kind is of a granular texture, or striated.

V ZEOLITE is in general of a crystalline form, composed of imperfect pyramids turned towards a common center. Their form is sometimes globular; but seldom prismatic. The lapis lazuli belongs to the zeolites. These fossils are harder than fluors, but may be scratched by steel. The siliceous earth predominates much in them. The lapis lazuli contains silver and iron, which gives the blue colour. Zeolite melts *per se* with ebullition into a white frothy slag, which in the moment of fusion affords a phosphoric light. The lapis lazuli first becomes brown when melted, and then produces a clear glass with blue clouds. By scorification with lead, one hundred weight of it has afforded two ounces of silver.

VI. TRIPOLI seems to be of a volcanic origin. It is an earth consisting of very fine particles, and is known by its quality of rubbing or wearing hard bodies, which gives them a polish. Other fine clays, however, have the same property when a little burnt. The tripoli grows somewhat harder in the fire, and is fused with great difficulty. When crude it imbibes water, but is not soluble in it. It tastes like chalk, and is rough or sandy between the teeth, though no sand can be separated from it. That which has been just described is of a yellow colour, and is sold by druggists. This kind of tripoli has been lately discovered in Scotland. Another variety, called the rotten-stone, is found in Derbyshire. It is in common use in England for all sorts of finer grinding and polishing, and is also sometimes used by lapidaries for cutting of stones.

VII. Common or BRICK CLAY is found of various colours, as red, pale red, grey, and blue. It acquires

a red colour, more or less deep, in the fire, and melts pretty easily into a greenish glass. It consists of a mixture of pure clay, siliceous and martial (or iron) earths, containing also a small quantity of vitriolic acid. The clay is also found mixed with calcareous earth, when it constitutes marle. It is also found in an indurated state, either pure or mixed with inflammable substances, and vitriolic acid, in which case it forms the ores of alum.

VIII. Argillaceous fossil stones, to which the denomination of SCHISTI properly belongs. The most remarkable stones comprehended under this division are the blueish purple schistus, or common roof slate; the dark blue schistus, or writing slate; the pyritaceous schistus; the bituminous schistus; the argillaceous grit, which is also called sand-stone, and free-stone; the killas; the flag-stone, and the toad-stone.

The method of splitting the slate, used for the roofing of houses, is the following: they expose it in blocks to be well wetted and soaked by the rain; when the frost comes upon it afterwards, it rarifies the water, and cracks and opens all the joints of the stone, so that when the frost has completed its work it lies in loose flakes or shivers. Thus the elements perform with ease what no manual art could have easily accomplished.

C H A P. XIV.

SILICEOUS EARTHS.

*General Arrangement of Flinty Substances.—Gems.—Diamond.—Ruby.—Sapphire.—Topaz.—Emerald.—Hyacinth.—Amethyst.—Garnet.—Tourmalin.—Opal.—Composition and Properties of precious Stones.—Quartz.—Rock Crystals.—Pebbles.—Flints.—Lapis Nephriticus.—Cat's-Eye.—Hydrophanes.—Explanation of the Phenomena of the Hydrophanous Stone.—Moon-Stone.—Chalcedony.—Onyx.—Carne-
 lion.—Sardonyx.—Agate.—Common Flint.—Chert.—Sand and Gravel.—Jasper.—Feldt Spar.—Labrador Stone.—Schirl and Whetstone.—Art of making Glafs.—Prince Rupert's Drop and Philosophical Phial.—Curious Phenomena.*

THE siliceous earths are chiefly distinguished by their hardness, by which they strike fire with steel, and their property of forming good glafs with alkali. They may be divided into, 1, Gems, or precious stones; 2, Quartz; 3, Flints; 4, Jaspers; 5, Feldt spars,

I. GEMS.—The diamond is the hardest of all bodies, and the most valuable of all the gems; it is however not an earthy but an inflammable substance, and therefore will be fully treated of under that head*. It is mentioned on the present occasion only, that the catalogue of gems may not appear incomplete.

2. The ruby has been confounded with the diamond, on account of its hardness and lustre, but some late experiments shew that it is essentially different. According to Cronstadt, there are four principal kinds of rubies:—1. The ruby of a deep colour inclining to

* See Chap. 44.

purple. 2. The spinell ruby, of a ponceau red, that is, of a bright corn-poppay-flower colour. 3. The balafs-ruby, pale red inclining to violet. 4. The rubicell, of a reddish-colour.

3. The sapphire is transparent, and of a blue colour, and is said to be next to the diamond in hardness. They are sometimes of a milky appearance.

4. The topaz is chiefly of different shades of yellow, but is sometimes greenish. When of a sea-green colour it is called aqua-marine; when more green, the beryl; when yellowish green, the chrysolite.

5. Emerald, the chief colour of which is green, is the softest of the precious stones, and when heated is phosphorescent like the fluors.

6. The jacinth or hyacinth, is of a fine reddish yellow colour, and sometimes brown; these gems are formed in prisms, pointed at both ends.

7. The amethyst is a gem of a violet colour, or great brilliancy, and as hard as the best kinds of rubies and sapphires, from which it only differs in its colour. This is called the oriental amethyst, and is very rare; when it approaches to the purple, or rose colour, it is more esteemed than when it inclines to the blue.

The amethysts called occidental, are of the same nature as rock crystals, and have the same gradations of colour. Crystals within the geodes, or hollow agate-balls, are very often found of an amethyst colour, and some are very fine.

8. The garnet, when transparent and of a fine colour, is reckoned among the gems; but it varies more than any, both with respect to its form and colour, some being of a deep and dark red, some yellow and purple, and some brown, blackish, and quite opaque. The regular shape of the garnet is the dodecagon, with rhomboidal faces, and its chief variation is, the double

eight-

eight-sided pyramid, terminating by four faces on each end. In general their lustre is less than that of other gems, as well as their hardness, which yields to the file, though they sometimes strike fire with steel. Their colour proceeds from the iron which they contain; and, according to M. de Saussure, even the finest oriental garnets attract the magnetic needle at a small distance. The Syrian garnet is the finest, and most esteemed: it is of a fine red, inclining to a purple colour, very diaphanous, but less brilliant than the oriental amethyst.

9. The tourmalin has lately been brought much into notice by its remarkable property of becoming electrical, in consequence of the simple application of heat. If it is immersed in hot water, in which process no friction can be supposed to happen, after it is removed it gives signs of contrary electricity at the two opposite ends of its prismatic form.

The oriental tourmalins are found in the island of Ceylon: they are transparent, of a dark brown yellow. From Brasil they are for the most part green; but there are also some red, blue, and yellow. From Tyrol they are obtained of so dark a green, as to appear opaque. They are also found in the mountains of Old Castile in Spain.

10. The opal is a most beautiful stone, from the changeable appearance of its colours by refraction and reflection. There are two kinds; one of which, the opal of Nonnius, appears olive-coloured by reflection, and then appears to be opaque; but when held against the light, it is found to be transparent, and then appears of a fine red colour. The white opal, of a glass-like complexion, throws out green, yellow, purple, and blueish rays; but it is of a reddish, or rather flame-colour, when held against the light.

The precious stones are chiefly composed of the argillaceous and siliceous earths; of which the former predominates. Some diamonds also are thought to contain a portion of earth, but these cannot properly be accounted diamonds.

On dissolving the very subtile powder of the gems in a double weight of vitriolic acid highly concentrated, the residuum, after evaporation, being washed with warm water, yields a metallic colouring substance, and a small portion of lime. The metallic part, precipitated by what was in the old chemical nomenclature called a phlogisticated alkaline lixivium, yields a beautiful Prussian blue; hence we conclude that the red colour of the ruby, as well as the blue of the sapphire, the yellow of the topaz, the tawny of the hyacinth, and the green of the emerald, are to be attributed to iron*.

Bergman obtained by analysis, from one hundred parts of the following precious stones:

	Clay.	Flint.	Lime.	Iron.
Emerald,	— 60	— 24	— 8	— 6
Sapphire,	— 58	— 35	— 5	— 2
Topaz,	— 46	— 39	— 8	— 6
Hyacinth,	— 40	— 25	— 20	— 13
Ruby,	— 40	— 39	— 9	— 10

From the above it may be collected, that the gems agree in this respect, that they all consist of the same principles;—and that of these the argillaceous earth forms the greatest part, then the siliceous, next the calcareous, and least of all the iron †. The gems, except the emerald and hyacinth, resist the most in-

* Bergman's Dissertations, p. 15.

† Chemical Essays, Diss. 15.

tense fire; yet we know that the ruby has been softened in the focus of a burning mirror*.

These stones all assume different forms of crystallization, and as this affects the arrangement of their minute parts, it doubtless is not without effect on their external appearance. Their value depends on their hardness and transparency. The degrees of hardness are—1, diamond; 2, ruby; 3, sapphire; 4, topaz; 5, hyacinth; 6, emerald.

The garnet differs from all the above, in the siliceous earth being more prevalent than the argillaceous.

II. QUARTZ has less transparency and hardness than the precious stones. The fracture of quartzose stones is vitreous, or like glass, and they strike fire with steel. Heat causes them to lose their hardness and transparency, and reduces them to a white opaque earth. They are generally cracked throughout, and break irregularly, and into sharp fragments. Melted with alkali they give a more solid and fixed glass than any others of the siliceous order. When there is no interruption to their natural accretion, their substance always crystallizes into hexagonal prisms, pointed at one or both ends. These occur in clefts, fissures, and small veins in rocks. Quartzose stones very often contain metals.

No very remarkable stones belong to this genus. The varieties are Fat quartz, which is very glossy; it is either colourless, or is tinged with white, blue, or violet. Dry quartz, transparent, white, or pale green. Sparry quartz, pale yellow, or pale blue. Crystallized quartz is either opaque or transparent: the transpa-

* *Chemical Essays, Diss. 15.*

rent and dark-brown kind is called smoky-topaz; the yellow, blue, green, and red, false gems; and the colourless, rock crystals; when milky, milk crystals, and pebbles. Quartz is also found combined with iron and copper; with the former it constitutes a black calx, with the latter a red calx.

III. FLINTS are more uniformly solid, and not so much cracked in the mass, as quartz; and are more pellucid than jasper. They are better for making glass than the jasper, but not so good as quartz, and seem in most respects to be of an intermediate nature between these stones. Flint often shews evident marks of having been in a soft and tough state, like glue or jelly.

The several varieties of flints have obtained more distinct names, from the variety of their colours, than from any real difference in their substance; but these are still proper to be retained, as the only names by which jewellers and others are used to distinguish them.

1. Jade, lapis nephriticus. This stone feels unctuous to the touch, but is so hard as to strike fire with steel, and is also semipellucid. These latter circumstances sufficiently denote its flinty nature; though its unctuousity has induced some mineralogists to think that it ought rather to be referred to the argillaceous or magnesian orders. It is not hardened by the heat of the furnace, but it melts by the solar heat, in the focus of a burning mirror, into a green glass. That called by the name of circumcision-stone, which comes from the Amazon river, melts more easily by the concentrated rays of the sun into a brown opaque glass. The colour of these stones is either milky, or different shades of green. Those of a grey, olive, or yellowish colour,

colour, are the vulgar lapis nephriticus; which name they have obtained, from a supposed property of curing nephritic pains, when applied externally to the loins. Their semipellucid appearance, hardness, and specific gravity, are characters by which the lapis nephriticus may be distinguished from other stones.

2. The cat's eye is a very scarce stone. It is opaque, and reflects green and yellow rays, in a manner somewhat similar to the eye of the animal from which its name is derived. It is found in Siberia.

3. The hydrophanes, or oculus mundi. The character which distinguishes this from all other stones is its property of becoming transparent in consequence of being immersed in water. This happens from its imbibing that fluid, as it becomes again opaque by being dried.

This circumstance may be illustrated by a comparison with some other natural phenomena. The appearance of clouds serves to shew that particles of water, copiously mixed with those of air, prevent the transmission of light, and render the mass more or less opaque, although the particles of each, separately taken, are pellucid. The cause of this is to be sought for in the difference of the refracting power; for, by means of that, the rays are turned from their original course at every particle, a circumstance which is very injurious to transparency. A common experiment will still more clearly elucidate this point. The most transparent glass, when reduced to powder, becomes opaque, because the air which now occupies the interstices reflects the light much more copiously than the particles of glass. But upon pouring on water, which displaces the air, and which differs less from the glass in its refracting power, a certain degree of transparency is restored. On this principle depends the nature

ture of the hydrophanous stone, which is opake when dry, but gradually acquires transparency by lying in water. This stone agrees nearly in specific gravity with water, at least is not more distant from it than glass. Its particles are transparent, but it is uniformly perforated by invisible foramina, so that the air and water are admitted, but not readily. When dry, therefore, on account of the great difference of the mediums between the particles of the stone and those of the air, it is opake; but when the water is gradually imbibed, it grows by degrees pellucid, beginning at the surface, and proceeding towards the center. That the hydrophanes absorbs moisture and emits air, which is a fluid of much less density, appears from the weight it acquires, and the small bubbles which cover its surface during the time it is acquiring its transparency.

4. Moon-stone, or rainbow-stone, reflects light of pearl and carnation colours. Its fracture is foliated, and its colour pale blue and milky.

5. Chalcedony, or white agate.—This stone is usually cut with a convex surface, and receives a good polish. Its degree of hardness is intermediate, between that of the onyx and the true agate. It is semitransparent, and its colour is usually very similar to that of milk diluted with water.

6. The onyx is the hardest of flints. Its usual colour is that of the human nails. It is either marked with white lines only, or with black and white together. Heat deprives it of colour, and, if suddenly applied, cracks it.

7. The carnelion derives its name from its resemblance to the colour of flesh. It is either quite red or of different shades of red, with brown and yellow.

8. The sardonyx is a mixture of the chalcedony and carnelion,

carnelion, sometimes disposed in strata, and sometimes confusedly blended and mixed together. Its colours are therefore a mixture of white and red, sometimes in stripes, sometimes irregularly notched.

9. *Agate*. This name is given to flints that are variegated with different colours promiscuously blended together, and they are esteemed in proportion to the mixture and perfection of their colours.

10. *Common flint or pebble*, is in reality of the same nature with *agate*, but wanting the beautiful and various colours of the substances that bear that name. Chalk and white lime-stone are usually the matrices of flints, in which they are imbedded in the form of nodules, consisting of nuclei involved in a crust.

11. *Chert* is less hard and transparent than the common flint. It is not in general found in loose and single, irregular nodules, but forms veins in rocks. Cherts are found of a flesh-colour, white, pale yellow, and greenish, and seem to be of an intermediate nature between the flints and jaspers.

Sand and gravel may be considered as flinty matters, torn away from the rocks in which they originally existed, and afterwards worn and smoothed by the attrition occasioned by the motion of water. Sand and gravel, however, consist of all the variety of stony matters which existed in the masses from which they proceeded, and are therefore found of many different colours and properties.

IV. The name of *JASPERS* is given to all the opaque siliceous stones, which in their texture resemble dried clay. The principal circumstance, besides their appearance, which distinguishes them from the other siliceous orders, is their more easily melting in the fire. They in general contain much iron. They are
very

very hard, and admit a good polish; and they are variegated with different colours. They are seldom ranged in strata, but form considerable masses and veins in rocks. They are also found in small round masses. The principal species of jaspers are the following—the white, grey, yellow, red, brown, green, veined, spotted, flowered, and green with red points, or blood-stone. Toys, and more especially cups and saucers, are made of jasper. Many antique sculptures are on stones of this nature.

V. The most common kind of FELDT-SPAR is formed of rhombic laminæ, and has therefore obtained the name of rhombic quartz. It gives fire with steel, whence it has been called *spathum scintillans*. It is harder than the schisti, and is fusible. It is found in loose masses, two inches long, or mixed with sand, clay, &c. or bedded in granite. It is used in making china at Dresden. Its colours are white, red, brown, pale, yellow, or greenish.

The Labrador-stone is generally classed with the feldt-spars. It admits of a very fine polish, and when in that state reflects a variety of beautiful colours. The stone itself is of different shades of grey.

VI. SHIRL or COCKLE, of different shades of green; and the various species of whetstones, are also commonly referred to the siliceous order, though the latter are generally in some measure compound.

The uses of the flinty substances are various, and have been partly intimated; but there is one art, in which their use is too conspicuous to be passed over in silence.

The art of making glass depends on the fusion of
earthy

earthy substances, of which the flinty earth is the best, and for that reason is called vitrifiable. But as earths cannot easily be fused without mixture, it is necessary to add certain substances which may promote the vitrification. In the making of ordinary glass, two parts of sand, or other siliceous matter, are mixed with about one of fixed alkali. If the glass is not required to be transparent, impure alkali, not freed from the ashes, is employed; but in making the finer and most transparent kinds of glass, care is taken to purify both the earth and the alkali. One of the chief points to be observed in the making of glass is to heat the mixture gradually, so that the elastic fluids may escape before the materials cohere, as the ingredients are otherwise apt to be so swelled by the disengagement of air as to be lost by flowing over the sides of the vessel in which they are heated. In order to prevent this, due proportions of sand and alkali are mixed together, and exposed, during a considerable time, to a red heat, not intense enough to melt them. By this calcination the inflammable matters, which would have impaired the colour of the glass, are consumed, and the air expelled. This first mixture of the materials of glass, after being treated in this manner, is called the *fritt*.

The due degree of heat is an essential point in making of glass: it ought not only to be very strong, but also maintained during a long time. In great manufactories the glass is kept fused during ten or twelve hours before it is taken out of the pots. The ingredients are thus more completely melted, and more thoroughly mixed, and the appearance of threads or veins is in some measure prevented, which proceed from the different density of different portions of the glass, and which therefore act differently on the rays

of light. The imperfections of glasses are most sensibly felt in the construction of optical instruments.

Good glass, although kept in fusion for a long time in a great heat, is never perfectly liquid. It is always somewhat thick, and when taken out may be drawn into fine threads. The great ductility and flexibility of red hot glass fits it for being reduced into any form. In general the glass is taken out of the pots in which it is fused by means of an iron tube. When a sufficient quantity of the glass is collected at the extremity of the tube, the workman begins to blow through it, and thus inflates the glass. He occasionally rolls it, in order to form it into a cylinder, a cone, &c. and if it becomes too cold, he heats it by holding it before the mouth of the furnace. Glass, in its tough state, may be cut with shears, bended with pincers, pressed into moulds, and wrought, in a variety of methods dependent on these properties, into the vast variety of forms which it is made to assume. Glass vessels as soon as made, are carried to an oven, in which they are gradually cooled; for without this process, which is called *annealing*, they would either break in the cooling, or be liable afterwards to be broken by the slightest force.

The principal defects of glass are colours, veins, and bubbles. The colours which generally injure the common alkaline glass are shades of green, blue, and olive. These are most effectually removed by the addition of a small quantity of manganese. The cause of the veins has been already explained, and that of the bubbles depends on the imperfect expulsion of air.

The addition of calx of lead to glass renders it much more dense, and less liable to be broken. Artificial gems are only the best kinds of glass, coloured with different metals; but the modes of applying the several metals

metals to this use will be mentioned when treating of them.

There are two toys made of unannealed glass, which, though commonly used for the amusement of children, exhibit phenomena which justly interest the curiosity of the philosopher. When a drop of melted glass is suffered to fall into water, it assumes an oval form, with a tail or neck resembling the retort of a chemist. This is called Prince Rupert's drop, and possesses the singular property, that if the smallest portion is broken off, the whole drop flies into powder with a kind of explosion, and a considerable shock is communicated to the hand that grasps it*. The other is called the philosophical phial, which is a small cylindrical vessel of glass, open at the upper end, and rounded at the bottom. It is generally made of glass so thick that it will bear a smart blow against a hard body without breaking, but if a small pebble or piece of flint is let fall into it, it immediately cracks and flies in pieces. This vessel is formed upon similar principles with Prince Rupert's drop, it consists of glass suddenly cooled, and, I suspect, by immersion in water.

Various explanations have been offered of these facts. The most generally received is founded on the assumption that the dimensions of bodies which are suddenly cooled remain larger than if the cooling had been more gradual. The dimensions, therefore, of the smooth external surface of these glasses, which are suddenly cooled, are supposed to be larger than is adapted to the accurate envelopement of the internal

- * Honour is like that glassy bubble,
That gives philosophers such trouble;
The one part crack'd, the whole will fly,
And wits are crack'd to find out why.

HWDIBRAS?

part, which is necessarily cooled in a more gradual manner; if, therefore, by a crack or rasure, a solution of the continuity takes place in the external surface, the sudden action of the parts which remained in a state of tension, to recover that of perfect cohesion, is supposed to effect the destruction of the mass.

This explanation I confess has not appeared to me satisfactory, and I have been inclined to suspect that the phenomenon arises either from a quantity of air being included in the substance of the glass, which rushes suddenly out, on the surface which includes it being broken; or that by the sudden cooling the pores of the glass are sealed up by the fine smooth surface, and contain little or no air; so that on the continuity of that surface being interrupted, the air suddenly rushing into all the pores of the glass may effect its dissolution. That the whole effect depends on destroying the continuity of the surface, I have sufficiently proved; for unless the flint or pebble which is let fall into the philosophical phial is large and angular enough to scratch the surface of the glass, it will not break. To ascertain whether the fracture of these toys depends or not upon the air, a few experiments might be made on Prince Rupert's drops in a vacuum; when, if it proceeds from air included in the drop, the explosion will be more violent, or the drop would perhaps spontaneously burst; and if from the contrary cause, it will not break at all in vacuo.

C H A P. XV.

OF THE STRONTHIAN, JARGONIC, AND ADAMANTINE EARTHS.

The Scottish or Stronthian Earth discovered by Dr. Crawford.—Of the Jargonio Earth.—Adamantine Earth.—All of these scarce Minerals.

THE SCOTTISH or STRONTHIAN earth was long unnoticed, and was confounded with the calcareous genus, to which it bears a near resemblance. It was first brought under the consideration of the learned by the late Dr. Crawford. It has hitherto been only found in a mild state, united with fixed air, which (like limestone) it loses by a strong heat, when it forms a kind of lime. This lime, however, is more soluble in water than that produced from common calcareous earth, and is specifically heavier. It decomposes vitriolated tartar, but is itself decomposed by barytic lime. It also decomposes solutions of common gypsum, and of nitrated or muriated calx.

Vitriolic acid dropped into this lime water produces an immediate precipitation, which it does not in common lime water. The earth itself is found in large light or whitish green masses. Its specific gravity is from 3.4. to 3.644.

Of the JARGONIC earth, the only species yet known is the stone called the Jargon of Ceylon, which is generally of a grey or greenish olive colour. The crystallization presents either right-angled quadrangular prisms surmounted by pyramids, or octohedrals. The external lustre is casual, but the internal is strong, inclining to the metallic. Its specific gravity is 4.416. In its qualities it more resembles argil, than any other

kind of earth. It is incapable of uniting with fixed air.

The ADAMANTINE earth is also a late discovery, and was found in a stone called adamantine or diamond spar, in which it constituted about one fourth of the weight. It is insoluble in acids, and infusible by alkalis; in this last property therefore it differs from silica, and in the former from all the other earths. Its specific gravity is said to exceed 3,000.

These earths are all of them scarce, and form a subject rather interesting to the curious, than important to the general reader. The Stronthian is said to be the most abundant, and yet even this seems scarcely to have been subjected to a sufficient analysis to ascertain its nature and properties; nor will it be a matter of surprize, if on further examination these new earths should be found to be only compounds derived from some of the five principal earths, since the more the works of nature are explored, the more of simplicity is discovered, and the genuine effect of science is rather to diminish than enlarge the technical vocabulary.

C H A P. XVI.

COMPOUND EARTHS.

Definition of this Genus.—Various compound Stones.

IN a strict sense all earths and stones, as they exist in nature, may be denominated compound, as there are none which are wholly simple. By compound earths, however, is here meant such as are formed of two or more kinds of stony matter, and which in general constitute a mass of an heterogeneous appearance. In treating of these substances, the arrangement of M. Daubenton appears the most perfect and commodious.

Mixed Stones,

OF TWO GENERA.

Quartz and scintillating spar	-	Granitin.
Quartz and schirl	- - -	Granitello.
Quartz and steatites	- - -	Quartzose steatites.
Quartz and mica	- - -	Micaceous quartz.
Transparent quartz and mica	-	Micaceous crystal.
Quartz in grit and gem stone	-	{ 1 Garnet on grit stone. 2 Garnet in grit stone.
Quartz in grit and mica	- - -	Micaceous grit.
Quartz in grit and calcareous matter	- - -	{ 1 Crystallized grit. 2 Grit in stalactites.
Quartz in sand and opaque stone	-	{ sandy and siliceous breccias.

Quartz in sand and schistus	-	{	scintillating schistus hornstone. trap.
Quartz in sand and zeolite	-		scintillating zeolite.
Scintillating spar and paste, cement, of schirl	- - -	}	ophites.
Semi-transparent stone, with stone	- - - -	{	jaspered agate, or agatized jasper.
Schirl and mica	- -	{	micaceous spathose schirl.
Schistus and mica	- -		micaceous schistus.
Schistus and marble	- -		Florence marble.
Serpentine and marble	-	{	1 Green Egyptian marble. 2 sea-green marble. 3 green antique marble. 4 green marble of Suza. 5 green marble of Varalta.
Ponderous spar and calca- reous matter	- -	}	alkaline ponderous spar.

OF THREE GENERA.

Quartz in sand, schistus, and mica	-		Rough whet-stone.
Quartz, gem, and mica	- -		garnet rock.
Quartzose paste, scintillating spar in large fragments, and schirl	- -	}	porphyry.
Quartzose paste, scintillating spar in large fragments, and schirl	- -	}	serpentine. hard ser- pentine.
Quartz, schirl, and steatites	-		tuberculous rock.
Quartz, scintillating spar, and schirl	- - -	}	granite.

OF FOUR GENERA.

Quartz, scintillating spar, schirl and mica	- - - -	}	granite.
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OF SEVERAL GENERA, MORE OR LESS IN NUMBER, UNITED IN BRECCIAS. } universal breccias.

DOUBLE BRECCIAS.

- Varieties. { 1 Fragments of porphyry, with a paste of porphyry.
 2 Fragments of granite, with a paste of schirl.

C H A P. XVII.

VOLCANIC PRODUCTS.

Lava.—Different Kinds.—Progress of a River of Lava—Compound Parts of Lava.—Pumice Stone.—Basaltes.—Trapp.—Terra Puzzolana.

I. **L**AVA is of very various appearance, according to its composition, and its more or less perfect vitrification. The materials of which lavas consist, are the common substances to be found every where in the earth, namely, stones, metallic ores, clay, sand, &c.; and as there is room for great variety in the combinations of these substances, the melted masses formed by them must in different circumstances be very various. Some lavas are very compact, and receive a beautiful polish, exhibiting great variety of colours and forms. Others are extremely porous, and mixed with scorixæ or dross. On the different consistence of lavas depends their capacity for being converted into mould, capable of supporting vegetables. Some lavas have a tendency to crumble into dust immediately on issuing from the crater; others are a perfect glass, and are calculated to resist for a long time every approach towards dissolution.

Lava, when first thrown out from the crater of a volcano, is an imperfect liquid mass, and flows down the side of the mountain with considerable rapidity. From loss of heat, however, its surface is soon converted into a tough and black crust, which, as it becomes thicker, gradually impedes the progress of the fluid lava which is contained within it. This crust is frequently broken, when the stream of lava resembles
a river

a river with masses of ice floating on its surface. Fluid lava sometimes flows for a considerable distance, under the tenacious scum, and again appears beyond it in all its splendor. In the night time the course of the lava appears like flame, in consequence of the bitumen, which is mixed with the lava, and which is supposed to be the principal cause of its fluidity. In the day-time its course is marked by a thick white smoke.

Mr. Kirwan divides lavas into three kinds, the cellular, the compact, and the vitreous. All lavas are more or less magnetic, give fire with steel, are of a granular texture, and melt without the addition of other substances. The cellular lavas are such as have undergone only the first and lowest degree of fusion, being just softened and heated sufficiently to expel the fixed air contained in the matter from which they are formed, which seems to be argillaceous slate; hence they abound in small cavities occasioned by the expansion of that air. The specific gravity of some lavas from these cavities is so small, that they float for some time on water. From this circumstance they have sometimes been mistaken for pumice-stone; but they differ from it, because their texture is never filamentous. The perfectly vitrified lavas must have been exposed to an immense heat, as they are very difficultly fused without addition. M. Saussure has ingeniously imitated all the different kinds of lavas, by different degrees of fusion of the earthy substances from which they are formed. M. Bergman analyzed a specimen of the perfect kind, and found an hundred parts to consist of forty-nine of siliceous earth, thirty-five of argillaceous, four of calcareous earth, and twelve of iron.

The beds of lava are deepest and narrowest near the
crater,

crater, and broader and shallower as they advance, unless some valley intervenes. Pumice-stones lie at a still greater distance; and from these observations, says Mr. Kirwan, extinguished volcanoes may be traced. The quantities of matter thrown out of volcanoes at one eruption, are often so great as to cover a space of country of many miles, and to be many years in cooling.

II. PUMICE-STONE is a volcanic ejection, but is frequently found at a distance from its origin. Its colours are grey, white, and reddish brown. It is hard, rough, porous, consists of slender fibres parallel to each other, is very light, and with difficulty gives fire with steel. It seems to have been originally an asbestos decomposed by the action of fire. One hundred parts contain from six to fifteen of magnesia, with a small portion of calcareous earth; the remainder is chiefly silex. Pumice-stone swims on water. It is used to smooth rough surfaces, and, in a state of powder, in various branches of manufacture, chiefly for polishing.

III. BASALTES is a stone of a dark grey colour, covered with a ferruginous crust, and generally crystallized in opaque triangular or polyangular columns. When it is amorphous*, and breaks into large, thick, square pieces, it is called *trapp*. When heated red hot, and quenched in water, it becomes by degrees of a reddish brown. It melts without mixture into a perfect slag. One hundred parts contain fifty-two siliceous, fifteen argillaceous, three calcareous, two of magnesian earth, and twenty-five of iron. Basaltes

* Not of a regular form.

sometimes is found in large columns with convex and concave articulations, so as to resemble an artificial structure: of this kind are the basaltic pillars in Ireland, called the Giant's Causeway.

Basaltes has always, till very lately, been considered as a volcanic product; and in corroboration of this opinion it is asserted that glass, in cooling, has been known to assume the regular basaltic form. Sir William Hamilton remarked, both in Sicily and Naples, that such lavas as have run into the sea are either formed into regular basaltes, or have a great tendency to that form. Mr. Kirwan, however, in the last edition of his *Elements of Mineralogy*, takes considerable pains to controvert the common opinion. His principal arguments to prove that basaltes are formed by water, and not by fire, are the closeness of their textures, since they are quite free from the cavities which are numerous in all other volcanic products, and their containing mild calcareous earth, which could not have been the case if they had been subjected to such a degree of heat as to have reduced them to a state of fusion. Basaltes also contain zeolites in some instances, which must have lost the water combined with them, if they had been subjected to much heat. In basaltes there is no appearance of vitrification, which they must have had if they had crystallized from a state of fusion. Basaltes are also frequently found, not only at a distance from volcanoes, but mixed and surrounded with strata, which have evidently derived their origin from water. For instance, their substance sometimes passes gradually into argillites and sandstones. Mr. Kirwan seems at a loss to account for the peculiar shape of basaltes; but this is equally difficult on the principles of either theory. He mentions an instance, however, of a stone cracking into pieces
of

of a similar figure. On the whole, Mr. Kirwan thinks it much more probable that basaltés furnish the materials of volcanic products, than that they themselves are of volcanic origin.

IV. *TERRA PUZZOLANA* or *Terras*, is a volcanic production, of a grey, brown, yellowish or blackish colour, loose, granular, or dusty and rough, porous and spongy, resembling a clay hardened in the fire, and then reduced to a gross powder. Its most distinguishing property is, that when mixed with about one-third of its weight of lime and water, it hardens very suddenly, and forms a cement which is more durable in water than any other. Its indurating power seems to arise from the dry state of the half-baked argillaceous particles, which causes them to imbibe water very rapidly, and thus the desiccation of the calcareous earth is accelerated. It is found not only in Italy, but also in France, in the provinces of Auvergne and Limoges, and also in England and elsewhere. According to Bergman's analysis, one hundred parts contain from fifty five to sixty of siliceous earth, nineteen or twenty of argillaceous, five or six of calcareous, and from fifteen to twenty of iron.

C H A P. XVIII.

M E T A L S.

Uses of Metals.—Their Properties.—Weight, Opacity, Malleability, Ductility, Fusibility.—Mix with each other.—Their Inflammability.—Calcination.—Entire and Semi-metals.—Perfect and imperfect.—Natural History of Metals.—Working of Mines.—Assaying.—Smelting.—Union with Acids.—Action of other Substances on Metals.

METALLIC substances are valuable for their durability, their capacity of assuming and retaining all sorts of forms and impressions; the closeness of their texture, which renders them capable of polish; the firm cohesion of their particles, which renders them highly proper for utensils, where great strength is required to be combined with moderate bulk. Several of the metals are also highly useful as medicines.

The first and most obvious property of metals is their remarkable weight, in which they exceed all other bodies. By this circumstance they are distinguished from earths; the lightest of metals, which is tin, being seven times the weight of water, whereas the heaviest earth is only between four and five times the weight of that fluid.

Metallic substances are by far the most opaque of all bodies. The most opaque stone divided into thin plates, has more or less of transparency, whereas gold is the only metal which admits of being reduced to such a degree of thinness as to afford the smallest perceptible transmission of light. Gold in leaf, which is about $\frac{1}{100000}$ part of an inch in thickness, transmits light of a lively green colour; but silver and brass leaf are

are perfectly opake. The opacity of metallic bodies renders them exceedingly proper for reflecting the rays of light, as no bodies possess this property in so eminent a degree. Thus we observe that glass reflects objects very imperfectly, unless coated with metal, as in looking-glasses. The capacity of reflecting light depends on the degree of polish and the whiteness of surface, consequently white metallic substances reflect a greater quantity of light, and are more brilliant, than those which are coloured.

A property which seems to belong exclusively to metals, and yet not to all of them, is malleability. This consists in a capacity of having their substance extended, and their surface increased, either in breadth or length, without being liable to fracture. The capacity, however, of being extended in length and breadth is not exactly the same, for metals which admit of extension under the hammer cannot always be drawn into wire, which property is distinguished from the other by the term ductility. Beating always reduces metals to a state of rigidity and brittleness. To remedy this, the metals are generally heated red hot, and cooled again slowly; in this case their malleability will be increased, and this is called annealing them. Crammer says, that if gold is annealed in this manner the leaf will be opake, and that the transmission of light through ordinary gold leaf depends on small cracks and flaws in the metal. If this assertion is true, it will in a great measure establish the perfect opacity of metallic substances. Metals, when hammered, give out a degree of heat, and at the same time become brittle; and the only method of restoring their malleability is to expose them to the action of heat, and to suffer as much of this as possible to fix itself in their substance, by cooling them gradually.

From

From these facts it is probable that the malleability of metals, as well as fluidity and elasticity in general, depends on the particles of bodies being kept at a distance by the presence of latent heat.

Metals are of all bodies the best conductors of electricity.

Metals are fusible by heat, and one of them (mercury) is well known to exist in a state of fusion in the ordinary temperature of the atmosphere. The particles of metals have a remarkably strong attraction for each other, which is evinced by small portions of metal, when in a state of fusion, having a tendency to assume a globular form.

Most metals will uniformly mix in all proportions with each other; the specific gravities, however, of these compounds is scarcely ever such, as would be mathematically deduced from the specific gravities of the metals employed, on the supposition of their junction by simple contact. Mixtures of metals are more fusible than might be expected from the degree of fusibility of their component parts, and are therefore conveniently used as solders.

It is found that metals which, after having been fused, are suffered to cool gradually, evince a tendency to assume a regular figure, and to crystallize in general in an octahedral form.

Metals, in their splendid or *reguline** state, have a considerable attraction for oxygen, and are in this re-

* This is the state in which metals usually appear when wrought. The state of a calx or ore is essentially different, they then appear like coloured earthy substances.

The name *regulus* was given by the fanciful alchemists to the metallic button, found in the bottom of the crucible after an assay, from the idea that this button contained gold, which they called the *king* of metals.

spect nearly allied to the inflammable substances. Iron burns with a bright flame when heated to a certain degree, and immersed in vital air; and a mixture of tin and nitre produces a violent deflagration. Zinc, when heated and acted on only by common atmospheric air, burns with a bright and vivid flame like phosphorus. It is remarkable that mixtures of metals calcine more easily than the metals in a separate state. Thus a mixture of lead and tin, neither of which, when separate, afford heat and light, in their mixture produce both, and the calcination is remarkably rapid. From the addition of oxygen the weight of the calx is greater than that of the quantity of the metal from which it was produced. In some metals, however, the attraction for oxygen is so weak (as is the case with the finer metals) that it is only by particular processes that they can be combined with it. Metals united with oxygen lose their splendor, malleability, and texture, and are denominated calces.

According to the old chemical theory, the calx of a metal was deemed a simple substance, and was called the earth or basis of a metal; and it was supposed that this earth, united with phlogiston, constituted the metal in its perfect state. It is now, however, very satisfactorily proved, that the metallic state is the more simple, and that the calx is a combination of the metal with oxygen. Metals are reduced from the calciform to the reguline or metallic state, by heating them in contact with substances which have a stronger attraction for oxygen than themselves, as charcoal, tallow, &c.

Metals which are malleable are called entire metals; and those which are brittle, semi-metals. Metals are also distinguished into perfect and imperfect. The perfect are such as are not calcined by being heated in contact

contact with air, and are three in number, silver, gold, and platina: the other metals are calcined in those circumstances, and are called imperfect. It will easily be understood that these differences merely indicate different degrees of attraction for oxygen; and as in this respect, as well as in regard to malleability, there are numerous gradations among the metals, it will be necessary to treat separately of each metal as a distinct substance. I shall begin with such metals as have most resemblance to the earths, and are therefore called semi-metals, and conclude with those which have the metallic properties in the highest perfection.

Those metallic bodies with which we are at present acquainted, and which we can reduce to the metallic or reguline state, are the following seventeen:

1. Arsenic.	} Semi-metals.	10. Iron.	} Perf. Met. Imperfect Metals.
2. Molybdena.		11. Tin.	
3. Tungstein.		12. Lead.	
4. Manganese.		13. Copper.	
5. Nickel.		14. Mercury.	
6. Cobalt.		15. Silver.	
7. Bismuth.		16. Gold.	
8. Antimony.		17. Platina.	
9. Zinc.			

Of these the nine first are called semi-metals; from defect of malleability; the five following imperfect metals, from their being calcineable by heat and air; and the three last, perfect, from their capacity of resisting the action of heat and air without change.

It is necessary, however, to remark, that to the above list of nine, late discoveries have added four new semi-metals, viz. uranite, sylvanite, titanite, and menachanite, of which I shall afterwards treat in a distinct chapter.

Metals exist in a state of nature in four different forms.

1. They are found in a native state of purity, with all the metallic properties. Gold is always found in this state; silver, copper, mercury, bismuth, and arsenic often; iron seldom; and lead, zinc, and regulus of antimony still more rarely.

2. Metals are found in the state of earth or calx, without the metallic aspect, and often resembling ochres.

3. The common state, however, in which metals are found is that of ores. In this state they are either combined with sulphur or with some metal, the most common of which is arsenic*.

4. The last state in which metals are found, is that of a combination with saline substances, and almost always acids. The vitriolic acid is most frequently found combined with metals, viz. zinc, lead, copper, and iron. The carbonic acid is also a common mineralizer, and the arsenical and phosphoric acids have likewise been discovered in combination with metals.

Metallic substances are more commonly found in mountains than in plains, and almost always in such mountains as form continued chains. It is in the stratified mountains that metals most abound, where the inclination of the strata, in consequence of the convulsions of nature, brings a variety of substances into view, which must otherwise have been for ever concealed beneath the reach of human investigation. There are entire mountains which consist of iron ore, but in general the metallic part of a mountain is very inconsiderable in proportion to the whole. The ores sometimes run parallel to the stony strata; the layer on which the ore is placed is called the bed or floor

* In this and the following state they are said, in technical language, to be *mineralized*; that is combined with some other mineral substance.

of the mine; the other which covers it, is called the roof. Sometimes, however, the metallic strata, which are always more irregular than the other strata of which the mountain is composed, intersect the bodies which surround them in a variety of directions. The metallic ores are accompanied with stony matters, which seem to have been formed at the same time. These stones are usually quartz and spar; they are called the rider or matrix* of the metal, and must neither be confounded with the mineralizing substance which is intimately combined with the metal, nor with the general mass of stone, of which the mountain containing the metal is composed. It is observed that the vegetables which grow on metalliferous mountains are dry, the trees small, sinuous, and deformed, and the sands often exhibit metallic colours. Mineral metallic springs are usually found in the vicinity; by the examination of which, and of the sands over which they flow, a tolerably accurate judgment may be formed of the metallic contents of the neighbouring strata. When metallic veins appear at the surface of the earth, the ground may be broken into with great probability of advantage, and the boring instrument, by bringing up the substances which compose the internal parts of the mountain, together with the metallic minerals, serves to shew their quality, as well as the resistance which may be expected in digging.

Before a metallic vein is wrought with a view to profit, it is necessary to ascertain the proportion of metal contained in it, and this is called assaying. In these small trials the fusibility of the mass is increased by the addition of three times the quantity of the black flux, which is made by burning together two parts of

* So called from its frequently inclosing the ore. The sparry matters are also sometimes called by mineralogists *gangues*.

tartar with one of nitre. The alkali of this compound increases the fusibility of the stony matter mixed with the ore, and consequently affords the metal an opportunity of separating from it; while the charcoal contained in it, and which proceeds from the impurity of the tartar, abstracts the oxygen of the ore, and reduces the metal to a reguline form.

When the operation has been properly performed, the metal, or regulus, is found in the form of a button at the bottom of the mass, and being weighed shews the proportion of metal contained in the ore.

This method is used in reducing small quantities, as in assaying of ores, but would be too expensive in large operations. In this latter case it is customary to mix the ores or calces with the fuel, but to let as little air as possible pass through it, as this would tend to re-calcine the metal. To prevent this effect, a particular sort of furnace is employed, in which charcoal is chiefly used.

It frequently happens that the same minerals contain the perfect metals mixed with the imperfect; these are separated both in the small and large way by heating the mixed mass in contact with air. By this operation the imperfect metal is reduced to a calx, and leaves the perfect metal in a state of purity. If the remaining metallic matter is still a compound, and contains two of the perfect metals, these are separated by exposing them, with as large a surface as possible, to the action of a menstruum, which has the property of dissolving one of them without the other.

There is also a method of assaying in the humid way, by submitting the ores to the action of different acids; but this is not so practicable as the other.

In the extraction of metals in the large way, the ore is pounded, washed, roasted, smelted, and refined. By pounding, the stony matters are separated from the metallic, and the whole being then washed on inclined planes

planes or tables, the stony matter being lighter is washed away, while the metallic remains behind. The roasting or burning is intended to expel the volatile matters. Ores which contain much sulphur must be roasted in the open air, but such as contain but little may be roasted in the furnaces which afterwards serve to fuse them. Some ores are fusible alone, others require to be mixed with different fluxes. The methods of refining metals are extremely various, and depend on particular chemical affinities, which will be mentioned under the head of each metal.

The salts, and of them the acids in particular, have great effect on metals. Metals unite with acids into compounds, many of which crystallize. The corrosiveness of the acid is abated by its union with the metal, but not in so great a degree as by its union with the alkalis or earths. Neither is the point of saturation so well marked in the union of an acid with a metal as with an alkali. The same acid may, in many cases, be united to the same metal in different proportions; when the acid is in excess the mass is deliquescent, when it is deficient it seems to produce little other effect on the metal than to destroy its texture, and reduce it to a friable and earthlike state.

Every metal, however, is not disposed to unite with every acid, though some unite with all; others with only one acid. The order also in which the acids attract the metals is different from that in which they attract the alkalis. Metals attract the muriatic acid most strongly, next the vitriolic, and last the nitrous. Metals which dissolve in the same acid differ very much in the force with which they adhere to it, so that they may be employed to precipitate one another. Thus, if we add to the solution of silver in aqua-fortis, quicksilver, it precipitates the silver; copper, the quicksilver;

quicksilver; iron or lead, the copper; and zinc, which precipitates these, may itself be precipitated by an alkali.

The solution of metals in the acids is attended with the escape of an elastic vapour, and an effervescence*. This appearance is proved to arise from a decomposition either of the acid or the water, and the elastic fluid differs in different cases, according to the source from which it derives its origin; when it arises from the decomposition of water, it is hydrogen or inflammable gas; when from that of the nitrous acid, nitrous gas, &c. Before the metal can be dissolved, it is necessary that it should be oxygenated; and therefore when its attraction is sufficiently strong, it decomposes the acid or the water, by abstracting their oxygen. It has been already remarked, that the muriatic acid has the strongest attraction for metals, and the nitrous less than either that or the vitriolic. From merely observing the action of these acids on metals, however, a different conclusion might be drawn, for the nitrous acid acts with violence and rapidity in comparison with the other two; and the muriatic, when in its purest state, has the least action of the three. This seeming inconsistency depends on the different degrees of attraction which the bases of the different acids have for oxygen. The reason, therefore, why some metals cannot be dissolved in particular acids, is, that they have not a sufficiently strong attraction for oxygen to decompose the acid. If we separate a metal from an acid by any substance which is not capable of depriving it of oxygen, we always

* This was formerly adduced among the proofs for the existence of phlogiston, which, united with a small quantity of the water or acid, was supposed to constitute this elastic fluid, at the same time that the metal, by its loss, was deprived of its splendour, &c.

obtain it in a calcined state. Thus gold, if precipitated from its solution in aqua regia by an alkali, is a calx; but if precipitated by any of the inflammable substances, as aromatic oils or spirits of wine, or by another metal, it appears in the metallic form. If metals are calcined previous to being united with acids, they produce no escape of gas, because being already furnished with oxygen, they have no tendency to decompose the acid.

Light appears to alter the colour and brilliancy of some metallic matters, independently of the action of air; for when exposed to light in transparent vessels well closed, they become tarnished, and lose their metallic brilliancy.

Heat applied to metals produces no other effects than expansion and fusion, if the air is completely excluded, unless carried to such a degree as to volatilize them; but even in that case, when the heat ceases to act, they return to their original state. Metals, on being converted into vapour, boil like other fluids, and even gold and silver are capable of this state when acted on by a large concave mirror.

Most of the combustible bodies act on metals. Inflammable gas gives them a deeper colour, and is capable of reducing some of them to the metallic state. Sulphur, and its combinations with alkalies, called hepars, act powerfully on metals.

From what is hitherto known of metals, there is every reason to believe that they are simple substances.

C H A P. XIX.

A R S E N I C.

Natural History of Arsenic.—Mode of reducing it to the metallic Form.—White Enamel.—Orpiment.—Realgar.—Its Use in Medicine.—A dreadful Poison; how to detect it in the Body.—A Remedy for the Poison of Arsenic.

ARSENIC is often found native, in black heavy masses, but not very brilliant. It has sometimes the metallic lustre, and reflects the colours of the rainbow; in its fracture it is more brilliant than at its surface, and seems composed of a great number of small scales. Native arsenic is very easily known, when it has the metallic brilliancy and scaly texture. It is, however, more frequently found in the form of a powder, or, in chemical language, of flowers*, or mixed with certain earths. Cobalt ores contain much arsenic, and that which is commonly sold is brought chiefly from the cobalt-works in Saxony. The ore is thrown into a furnace, resembling a baker's oven, with a flue or horizontal chimney, nearly two hundred yards long, into which the fumes pass, and are condensed in the form of a grey or blackish powder. This is refined by a second sublimation in close vessels, with a little pot-ash to detain the impurities. As the heat is considerable, it melts the flowers into those white crystalline masses which are met with in commerce.

The regulus is obtained from this substance, which

* Flowers, in the old chemical language, means those matters which by heat are raised into the neck of a retort in the form of very fine powder, as flowers of sulphur, &c.—It was, probably, originally *flour*.

is a calx of arsenic, by heating it with one-tenth of its weight of charcoal, or of any unctuous matter. The mixture is put into a tall vessel, and a gradual and gentle heat applied to the lower part of it, while the upper is kept cool by the air. The arsenic, when nearly ret hot, parts with its oxygen, and rises to the upper part of the vessel, where it is condensed in the metallic form. To give it, however, its perfect metallic splendour and opacity, the sublimation must be repeated.

The regulus of arsenic is of a bright yellowish white colour, very ponderous and friable, and subject to tarnish and become black on exposure to air. If heat is applied to the regulus in contact with air, it is volatilized before it melts, and is at the same time imperfectly calcined. The fumes are dangerous, and have a strong and offensive smell, resembling that of garlic,

The white calx of arsenic is so far in a saline state as to be soluble in eighty times its weight of cold, or fifteen times that of boiling water. When distilled with the nitrous acid, it decomposes that fluid by depriving it of part of its oxygen. The arsenic, by this addition of oxygen, is reduced to the state of an acid less volatile than either the regulus or calx, but retaining the form of a white concrete substance. The oxygenated muriatic gas likewise reduces arsenic to the state of an acid.

Arsenic readily melts with other substances so as to form glass, and even promotes their fusion. At first it always renders the glass milky, but by a continuation of heat the arsenic evaporates, and the glass becomes quite transparent. It is an ingredient in the white enamel dial-plates; and it forms those white spirals which are common in the stalks of wine-glasses.

Sulphur unites readily with arsenic into a compound more fusible than the arsenic itself. Orpiment is a combination of arsenic and sulphur, of a yellow colour. It is found naturally in the earth, generally of an irregular form, and composed of shining flexible laminæ. Its specific gravity, according to Kirwan, is 5,315, who also asserts that it contains one-tenth part of its weight of sulphur. The same author mentions, that realgar, or the red combination of arsenic and sulphur, contains sixteen parts of sulphur in the hundred, and is of the specific gravity of 3,225. Chaptal, however, observes that the difference between realgar and orpiment does not consist in the proportions of sulphur, nothing more being necessary in order to convert orpiment into realgar, than exposure to a strong heat. The violent action of arsenic on the animal machine is much abated by combination with sulphur. Common white arsenic has sometimes been successfully used in doses of one-twelfth or one-sixteenth of a grain. Received, however, in any considerable quantity into the body, it produces dryness of the mouth, heat in the throat, excruciating pains in the bowels, attended sometimes with vomiting of blood, cold sweats, &c. On dissection, the bowels are found inflated and corroded. Many black and livid spots appear on the stomach and small intestines, sometimes gangrenous. But these signs are not altogether to be depended on. Some of the arsenic is frequently found, and may be easily distinguished. The powder is heavy, and easily separates from the lighter contents of the bowels, by washing with water; the arsenic always falling to the bottom. A very little of this is sufficient to give the smell of garlic, and tinge copper white, if heat is applied to it.

It was formerly usual to give mucilaginous drinks, or milk or mild oils, to persons poisoned by arsenic.

But

But Navier, a physician of Chalons, who has made experiments to ascertain the best remedies against the poison of arsenic, has discovered a substance which combines with it in the humid way, and destroys, in a great measure, its causticity. This substance is the calcareous or alkaline liver of sulphur, which is still better adapted to the intention, when it holds a small quantity of iron in solution. When this martial hepar is poured into a solution of arsenic, it is decomposed without emitting any smell, because the arsenic combines with the sulphur, and forms orpiment, and at the same time unites with the iron. Navier prescribes a dram of the liver of sulphur in a pint of water, of which he directs a glass to be taken at a time; or five or six grains of dry liver of sulphur may be given in pills, a glass of warm water being given after each pill. When the first symptoms are dissipated, he recommends the sulphureous mineral springs. Navier likewise approves the use of milk, because it dissolves the arsenic as well as water, but he condemns the use of oils, which have not that property.

Arsenic shews a strong disposition to unite with all the metals except platina. By a mixture of it in its ordinary state with copper, a metal is produced resembling silver. It generally gives metals a white colour, and renders them brittle.

C H A P. XX.

M O L Y B D E N A.

Short Account of this Semi metal.—May be reduced to an Acid.—A scarce Mineral.

THIS is a mineral substance, which has till lately been confounded with plumbago, but is now found to be a combination of a particular metallic substance with sulphur. It is of a blackish colour, and consists of shining laminæ, which have a degree of flexibility, so as to be very difficultly reduced to powder.

Molybdena reduced to its metallic form resembles lead in colour and specific gravity, but is very brittle, easily calcined and volatilized, and will not mix with lead when in fusion.

It differs from all other semi-metallic substances by being nearly infusible in our furnaces; it is probably the impossibility of reducing it to the form of a round button, which induced Klaproth to suppose that he had never brought it to its metallic state. By Mr. Pelletier's account, however, it was evidently reduced, and Mr. Hielm produced a still purer and more perfect regulus. In a red heat it calcines. When in its reguline state it gives no colour to borax.—Molybdena, in this state, is called by Mr. Kirwan molybdenite.

Molybdena is capable of being oxygenated so far as to become an acid, in which state it is a concrete body, white and pulverulent, resembling chalk. This acid,

acid, heated with sulphur in a particular manner, is capable of being converted into a substance in every respect the same as native molybdena.

This mineral is scarce. It is distinguished from black lead by a more shining, scaly appearance; and it marks paper with a more brilliant stroke.

C H A P. XXI.

T U N G S T E I N.

*The Ore of Tungstein confounded with that of Tin.—Where found.—
Mode of reducing it to the reguline or metallic State.*

TUNGSTEIN or wolfram is a particular metal, the ore of which has frequently been confounded with that of tin. The specific gravity of this ore is to water as six to one; in its form of crystallization it resembles the garnet, and varies in colour, from a pearl white to yellow and reddish; it is found in several parts of Saxony and Bohemia. The mineral called wolfram, which is frequent in the mines of Cornwall, is likewise an ore of this metal; in all these ores the metal is oxydated; and in some of them it appears to be oxygenated to the state of an acid, being combined with lime into a true tungstat of lime*.

The calx of this metal cannot be obtained free from the bodies with which it is united, without a particular process, which consists in the alternate application of volatile alkali and marine acid, and the subsequent addition of the nitrous acid, as long as red fumes are produced. This calx or imperfect acid has the colour of brimstone, and is scarcely soluble in water. By being submitted in a crucible with charcoal, to a strong heat, a regulus of tungstein, called tungstenite by late mineralogists, may be obtained, which is a brown mass, consisting of a congeries of metallic globules internally of a steel grey, and which again becomes yellow by calcina-

* Lavoisier's Chemistry.

tion. The regulus is not acted on by the vitriolic and marine acids; the nitrous acid, however, and aqua-regia, act on it, and by oxygenating it reduce it to its calciform state.

M. Lavoisier recommends the following process for obtaining the calx of tungstein: Mix one part of ore of tungstein with four parts of mild vegetable alkali, and melt the mixture in a crucible, which ought to be of platina; then powder, and pour on twelve parts of boiling water; add pale nitrous acid, and the tungstenic acid precipitates in a concrete form. Afterwards, to insure the complete oxygenation of the metal, add more pale nitrous acid, and evaporate to dryness, repeating this operation as long as red fumes are produced from the acid.

In the state of yellow calx it has the following properties: it is perfectly insipid and insoluble in water; if triturated in water it simply diffuses through it like an emulsion, and takes some months to deposit from it. If volatile alkali is poured on it, it whitens, which instantly distinguishes it from the yellow calx of uranite, which will shortly be mentioned.

C H A P. XXII.

M A N G A N E S E.

Natural History of Manganese.—Its Effects on Glass.—Regulus or Metal.—Black Wad.—Manganese contained in Vegetables.—Uses in the Arts.

THIS metal is almost always found in the state of calces, which vary much in colour and appearance; they are white, blue, yellow, red, dark green, and black, according as they are united with more or less oxygen, or contaminated with foreign substances. The darker coloured the ores, the more oxygen they may be supposed to contain, as any process which deprives them of this principle always renders them paler. Manganese is also found crystallized in a variety of forms. Many naturalists, judging by their colour, and the ochry* crust with which they are often surrounded, have ranked the calces of manganese among the iron ores. The black calx of manganese gives a violet, purplish, and sometimes a reddish tinge to transparent glass; but when added in a small quantity to that which has a blueish or greenish cast; it produces only a slight duskiness, without a predominancy of any colour.

The regulus of manganese is very difficultly obtained. Its colour is a dusky white, but its masses are irregular and uneven from imperfect fusion. Its fracture is bright and shining, but it soon tarnishes and becomes blackish on exposure to air. When pulverised it is always magnetic, though it has not this property in the mass. If exposed to air, particularly

* Ochre being an iron ore.

in moist weather, it soon crumbles into a blackish brown powder, which is somewhat heavier than the regulus from which it was produced.

The calces of manganese retain their oxygen so weakly, that part of it may be expelled by the application of a strong heat. They also part with their oxygen to unctuous oils. If half a pound of that ore of manganese called black wad is well dried before the fire, afterwards suffered to cool for about an hour, and then mixed with two ounces of linseed-oil, small clots will be formed, and in little more than half an hour the whole will gradually grow hot, and at last burst into flame.

Manganese seems to be contained in the ashes of most vegetables, and to it the blue or greenish colour of calcined vegetable alkali is owing. If three parts of alkali of tartar, one of sifted ashes, and one-third of nitre, are melted together, they form a dark green mass, which being dissolved in water, affords a beautiful green solution; this being filtered on the addition of a few drops of vitriolic acid becomes red, and after a few days a brown powder is separated, which has all the properties of manganese.

The vitriolic, nitrous, and marine acids dissolve the regulus of manganese in the usual ways. The black calx is nearly insoluble in the acids, unless it is deprived of part of its oxygen by the addition of some inflammable or metallic substance. The marine acid, however, digested with the black calx of manganese, dissolves it without addition, in proportion as it loses some part of its oxygen. The oxygen uniting with part of the muriatic acid, renders it volatile, and converts it into oxygenated muriatic acid. The permanent solubility of the black calx of manganese in the acids, depends on the acid, or some substance mixed with the

acid, abstracting part of its oxygen. The manganese separated from its solution in acids by alkalies, is in the form of the white or imperfect calx, which, however, becomes black by being heated in contact with air.

In the dry way the calx of manganese combines with such earths and saline substances as are capable of undergoing fusion in a strong heat. The violet colour which it communicates to glass is liable to be destroyed by combustible substances. From this circumstance we may conclude, that the property of colouring glass depends on the calciform state of this metal, and that it is lost when any body abstracts its oxygen and reduces it to a regulus.

Manganese in its metallic form will not unite with sulphur, but melts readily with most of the metals. Gold and iron are rendered more fusible by a due addition of manganese, and the latter metal is rendered more ductile.

Manganese has hitherto been used chiefly by glass-makers and potters; but the important discoveries of the effect of oxygenated muriatic acid, prepared by means of manganese, in bleaching, will no doubt extend its utility to several other manufactories.

C H A P. XXIII.

N I C K E L.

Natural History of Nickel.—Metal how obtained.—Detonates with Nitre.—Has a strong Repulsion for Silver, and Attraction for Sulphur.—A useless Mineral.

THIS metal derives its name from the mineral in which it is contained. It is found united with sulphur and arsenic. Its ores have a coppery red colour, are almost always covered with a greenish grey efflorescence, and have been mistaken for ores of copper. The ores of nickel often contain cobalt and iron. Most of the sulphur and arsenic may be driven off by long continued roasting, and the occasional addition of charcoal, which prevents the arsenic from being rendered more fixed by calcination; and the green calx which remains may be fused by the strongest heat of a smith's forge, together with two or three times its weight of black flux. By these means a regulus may be obtained, which, however, is very far from being pure, as it contains much arsenic, cobalt, and iron. In this state it is of a white colour with a tinge of red, and has a granulated texture. When this metal is rendered more pure by treatment with sulphur, charcoal, volatile alkali, and nitre, it becomes extremely infusible, loses somewhat of its reddish tinge, and acquires a considerable degree of malleability. Nickel may be freed from sulphur and arsenic, but it cannot be accurately purified from cobalt and iron, for it is considerably attracted by the magnet, and gives signs of containing cobalt, after the utmost pains have been taken to obtain it in a pure state. It affords

a blue solution with volatile alkali, and in nitrous acid its solution is of a full green.

From its magnetic property, nickel has been considered as a modification of iron; and by its producing a blue colour with volatile alkali, it has been supposed to be an alloy of copper with various metallic substances. Chemists, however, are now very generally agreed in considering nickel as a distinct metallic substance.

M. Sage affirms, that when four parts of oil of vitriol are distilled with one part of the regulus of nickel in powder, the sulphureous acid passes over; the residue is greyish, and, being dissolved in distilled water, produces the most beautiful green colour. The crystals obtained from this solution are foliated, and of the colour of an emerald. According to M. Arvidson, the vitriolic acid forms a green salt, in decahedral crystals, with the calx of nickel.

This calx is easily soluble in the nitrous acid, and crystallizes in rhombic cubes. According to M. Sage, all the other solutions of nickel, or its calx, either in the muriatic acid or in vegetable acids, are more or less green. It has been said, that the nickel contained in cobalt occasions the substance known under that name to produce a green colour with acids. Nickel differs from cobalt in not being separated from acids by the addition of any other metal.

Nickel detonates* with nitre; this detonation afforded M. Arvidson a method of discovering the presence of cobalt, which no other proof has rendered sensible. Nitre has likewise the property of augmenting the intensity of the hyacinthine colour, communicated to glass by the calx of nickel. The calx of

* Inflames, and explodes suddenly.

nickel, fused with borax, likewise produces a hyacinthine colour. The calces of nickel are of a green colour.

The most remarkable properties of the regulus of nickel are, a repulsion for silver, and a strong attraction for sulphur. It has so strong an affinity for sulphur, as to attract it from most other metals.

Nickel combines by fusion with sulphur into a hard mineral of a yellow colour, with small brilliant plates, which, when strongly heated in contact with air, deflagrates and emits very luminous sparks, similar to those afforded by iron when forged. Cronstedt informs us that this metal is soluble in liver of sulphur, and forms a compound resembling the ores of copper. The sulphur can only be separated from nickel by repeated fusions and calcinations.

Cronstedt affirms that nickel forms, with bismuth, a brittle and scaly regulus. Nickel has not yet been applied to any use.

C H A P. XXIV.

C O B A L T.

Natural History of Cobalt.—Analogy between this Metal and the blue colouring Matter of Vegetables.—Mode of assaying it.—Mines of Cobalt.—Smalt, or Powder Blue.—Uses of Cobalt in the Arts.—Curious sympathetic Ink.—Changeable Landscape.—Union with other Metals.

C O B A L T has never been found native, that is, in a metallic state, but is almost always calcined or united with arsenic, the arsenical acid, sulphur, iron, vitriolic acid, &c. Minerals containing cobalt are frequently of a pink colour, which arises from the presence of arsenical acid, and this colour is destroyed by fire, in proportion as the acid is dissipated. When united with vitriolic acid, it also is sometimes reddish: the effect of acids on cobalt points out an analogy between it and the blue colouring matter of vegetables.

To assay cobalt ores, the operations of pounding, washing, and roasting, must be all employed. The cobalt remains in a state of black calx, more or less deep with respect to colour; this is mixed with black flux and a small quantity of decrepitated sea-salt; the fusion is performed in a forge heat in a covered crucible, which must be slightly agitated, to precipitate the metal as soon as the fusion is complete. The metallic button is sometimes found to consist of two distinct substances, cobalt being uppermost, and bismuth beneath; a stroke of the hammer readily separates them.

The

The regulus of cobalt is of a whitish grey or steel colour, hard, brittle, of a dull close-grained fracture, and moderate specific gravity. It has about the same degree of fusibility as copper; does not easily become calcined; and its calx is of so deep a blue colour as to appear black. Cobalt exposed to heat does not melt till it is well ignited. It appears to be very fixed in the fire, and it is not known whether it can be volatilized in close vessels. If it is suffered to cool slowly, it crystallizes in needle-formed prisms, placed one on another, and united in bundles. Cobalt, melted and exposed to the air, becomes covered with a dull pellicle, which is a calcination analogous to the rusting of iron.

The richest mines of cobalt are in Saxony. The ore which is worked there in the large way contains a considerable quantity of arsenic, which is driven off by heat, but is collected in long channels of wood, and preserved for sale, as was intimated before. After the ore has been kept some time in the furnace, there remains a dark friable substance, which is the cobalt in the form of a calx, and called *zaffre*. This is mixed with the ordinary ingredients of glass, and melted with a violent heat, so as to produce the common blue powder called *smalt*, which is a pounded glass. Some of this is mixed with flints and alkaline salts, and then sold under the name of *sapphire* to the manufacturers of porcelain and common Delft ware, for tinging their glazing blue.

Powder blue, or azure, is obtained by grinding *smalt* in mills, and afterwards washing it in water. This last operation is performed in a cask filled with water, and pierced with three openings at different heights. The water of the uppermost cock carries

out the finest blue. The larger particles fall more speedily, and the azure brought out by the water of the three cocks forms the different degrees of fineness, known by the names of azure of the first, second, and third fires. Powder and stone blue, used by laundresses, is a preparation made by the Dutch from the coarse smalt.

A small quantity of the calx of cobalt tinges glass of different shades, according to the quantity used. One grain of cobalt to seven thousand of the glass, renders it very blue: hence the pastes in imitation of sapphire are produced. Stained flint glass is made by sixteen parts of sand, eight or ten of pearl ash, and metals in different proportions.

Cobalt dissolves readily in aqua-fortis, both in its metallic state and in that of a calx. If we take a solution of its calx in that fluid, and add a quantity of water to it, and then let it stand a while, it turns red, and on evaporation forms crystals of the same colour, and by this it may be distinguished from all other metals. This solution forms a red sympathetic ink, which appears on the paper by heat, and again disappears by cold.

Aqua regia dissolves cobalt more easily than the muriatic, but not so easily as the nitrous, acid. This solution is a celebrated sympathetic ink. If it is diluted with a sufficient quantity of water to prevent its action on paper, and then used to write with, the letters are invisible as soon as the clear solution becomes dry; but if the paper is held to the fire for a short time, they appear of a fine green colour; which again disappears by removing it, and suffering it to cool. If held to the fire too long, the green colour becomes permanent. From these two inks a very curious changeable landscape may be made. The
trunks

trunks of trees, houses, &c. may be painted with common colours, so as to represent winter. The verdure, the fruits, and the flowers, may be depicted in different shades of the two inks. On approaching the fire the landscape will gradually be changed from a winter to a summer scene. The trees will begin to shoot out their foliage, and the flowers and the fruits will, by degrees, assume the appearance of maturity. The vivid parts will again fade, on being removed from the heat, and the landscape resume the wintry aspect.

It was formerly thought that the green colour produced by heat in the sympathetic ink of cobalt, arose from the metallic salt being crystallized, and afterwards attracting a sufficient quantity of water from the cold air to dissolve it, and cause it to disappear; but it is proved, that the marine salt of cobalt, dissolved in water, assumes the same colour when exposed to a certain degree of heat.

The vitriolic acid in a concentrated state does not dissolve cobalt without the assistance of heat, when the acid is decomposed, and comes over in sulphureous fumes. The cobalt is in part calcined, and in part converted into a crystalline salt soluble in water, and which may be precipitated by lime and by alkalies, in the form of a rose-coloured powder or calx. Diluted vitriolic acid acts upon the calx of cobalt, and forms the same salt.

Cobalt unites with all the metals except silver, lead, quicksilver, and bismuth, but does not produce any remarkable or useful compound with any. It is separated from acids by zinc in the form of a dark-coloured powder, but not by iron.

A mixture of nickel with the calx of cobalt very much injures the colour which the latter communicates

cates to glass. The following process is one of the best for separating them when the cobalt is in considerable quantity: Saturate a solution of the roasted ore in nitrous acid, and drop it into liquid volatile alkali. The cobalt then is instantly re-dissolved, and assumes a garnet colour; when filtered a grey powder remains on the filter, which is the nickel. The cobalt may be precipitated by any acid,

C H A P. XXV.

B I S M U T H.

External Qualities of Bismuth.—A powerful Dissolver of Earths.—Pearl White, a pernicious Cosmetic.—Curious Experiment.—A metallic Composition, which melts in boiling Water.—Various Uses of Bismuth in the Arts.

BISMUTH is extremely brittle, so that it may be easily separated, and even reduced to powder by the hammer. When broken it exhibits at the place of fracture large shining plates, disposed in a variety of directions. It is considerably ponderous, and is of a yellowish white colour; when in thin plates it is in some degree sonorous. It is very fusible, and melts at a temperature not exceeding 460° of Fahrenheit.

Bismuth is scarcely altered by exposure to air and light. In closed vessels it sublimes without alteration; it crystallizes the most easily of any metallic substance. If bismuth is kept in fusion in contact with air, its surface becomes covered with a pellicle, which changes into an earth-like matter of a greenish grey or brown, named calx of bismuth. Nineteen drachms of bismuth, calcined in a capsule of glass, afforded M. Baumé twenty drachms thirty-four grains of calx. Bismuth heated to redness burns with a small blue flame, scarcely sensible. Its calx evaporates in the form of a yellowish smoke, which condenses on the surface of cold bodies, into a powder of the same colour, called flowers of bismuth. This powder owes its volatilization only to the rapidity with which the bismuth burns; for if it is exposed in close vessels to fire, it melts

into a greenish glass without subliming. Geoffroy the younger observed, that the flowers of bismuth, which rise the last, are of a beautiful yellow, resembling orpiment.

The grey or brown calx, the yellow flowers, and the glass, are nothing more than combinations of this metal with the basis of vital air, which are not reducible without the addition of some substance that attracts the oxygen.

Calx of bismuth is one of the most powerful dissolvers or liquefiers of earthy bodies, or of the calces of other metals, and gives a yellowish tinge to glasses, into the composition of which it enters. Bismuth is also readily calcined by nitre, but without detonation. The alkalies have little effect on bismuth; when applied, however, in a caustic state, they dissolve part of the metal.

The vitriolic and muriatic acids do not act on bismuth, unless assisted by heat. The nitrous acid, however, dissolves it with great rapidity, and during the solution copiously emits dense red vapours. This is one of those solutions from which the calx is most easily separated by water. On being dropped into water a bright powder is deposited, called magistery of bismuth. This is supposed to be the same with the substance called *pearl white*, well known as a cosmetic; for when rubbed on the skin it gives it a white shining colour. But in reality all these metallic substances ultimately darken the skin, for a calx when long exposed to the air, and the exhalations of animal bodies, parts with its oxygen to the inflammable matter, and assumes a dark colour. Bismuth, moreover, possesses many properties in common with lead, and there are some instances in which the external use of this metal has produced the worst effects.

Solutions of bismuth are particularly affected by
fetid

fetid odours, which proceed from putrefying substances. This seems chiefly to depend on the sulphureous particles which are exhaled in those processes, and is illustrated by a striking experiment. If characters are written with a solution of bismuth on the first page of a book of fifty leaves, and the last page is impregnated with a small quantity of the liquid liver of sulphur, a short time afterwards the hepatic vapour, carried by the air which circulates between all the leaves, arrives at the other extremity of the book, and converts the colourless characters marked on the first page into a deep brown. It is affirmed that the hepatic gas passes through the paper; but it is sufficiently proved that the air carries the gas in this manner from one leaf to another, since the effect does not take place when the leaves are glued together. This experiment evinces, in the clearest manner, the impermanency of the beautifying effect of the calces of bismuth.

The nitrous solution of bismuth is without colour, and when well saturated affords crystals without evaporation. But by evaporation and cooling these crystals may always be obtained. The nitre of bismuth detonates feebly, and with reddish scintillations; after which it melts and inflates, leaving a calx of a greenish yellow colour. This salt exposed to the air loses its transparency, at the same time that the water of crystallization is dissipated.

The acetous acid dissolves bismuth slowly, and in small quantities.

Inflammable gas alters the colour of bismuth, and gives it a violet tinge. Sulphur unites with bismuth, especially with its calx; in which state it resembles crude antimony. It unites with all the metals, except zinc and regulus of cobalt, and takes away their malleability.

leability and ductility, and increases their disposition to calcine; it also increases their fusibility, hence its use in soldering lead and tin. If added to a mixture of lead and tin, in certain proportions, it produces a metallic compound, which retains the state of fluidity in the heat of boiling water.

Bismuth is chiefly useful for mixing with tin to produce pewter, rendering it harder, and better to be cast into molds. It is also used in making printers' types; for by giving a greater tenuity to the fused mass, it fits it for receiving a neater impression. An amalgam for foiling glass globules is made of ten parts of mercury, two of bismuth, and one of lead and tin. It may be substituted instead of lead in the art of cupelling the perfect metals, because, like that metal, it has the property of flowing into a glass which is absorbed by the cupels.

Bismuth is often found native. It is also found united with arsenic, sulphur, iron, and sometimes in a calciform state. The sulphureous ore of bismuth is of a whitish grey, inclining to blue; it has the brilliancy and colour of lead ore or galena, and almost always exhibits square facets, but it is never found in fragments truly cubical. It is very rare, and is found at Bastnas, in Sweden, and at Schneeberg, in Saxony.

C H A P. XXVI.

A N T I M O N Y.

Natural History of Antimony.—Regulus.—Snow of Antimony.—Calcination of Antimony.—Combinations with Acids.—Butter of Antimony.—Antimonial Wine.—Uses of Antimony in Medicine.—Flores Antimonii.—Glass of Antimony.—Crocus of Antimony.—Sulphur of Antimony.—Tartar Emetic.—James's Powder.

THE substance, which is commonly known by the name of antimony, is a combination of that metal with sulphur. This mineral is of a blackish grey, in brittle plates or needles, of various magnitudes, joined together in different forms. It is sometimes mixed with other metals, particularly lead and iron, and is very common in Hungary, and in some of the provinces of France. From this ore the regulus of antimony is separated by fusion. The antimony then forms a mass of metal at the bottom of the vessel, while the other matter becomes a scoria above it.

The appearance of antimony is bright, approaching, when very fine, to that of silver. It is very brittle, and it is composed of oblong plates or laminæ. When melted it forms a smooth mass like other metals, but upon breaking it, we find the plated appearance on the inside. The plated appearance depends on the crystallization, which begins at the part that first congeals. The regulus of antimony, which is prepared for commercial purposes, is cast into flat and circular pieces, which have a crystallization on their surface, in the form of the leaves of fern.

In fusibility antimony holds a middle rank, requiring

quiring a perceptible degree of red heat before it becomes fluid. In the same degree it emits vapours copiously if fresh air is admitted, which always promotes the volatility of metals. If these fumes are condensed, they form a white powder. In particular circumstances they crystallize. They are, indeed, a perfect metallic calx, to which the names of argentine, and snow of antimony, have been applied. This substance is so highly charged with the oxygenous principle, as to be soluble in water, and to approach to the nature of an acid.

To calcine antimony by heat and air alone, let the metal be powdered, then lay it on a broad shallow vessel, and apply heat not sufficient to convert it into fumes. This operation cannot be well performed, unless the antimony is in a state of minute division, so as to present a large surface to the air. The process must be conducted with caution at the beginning, on account of the fusibility of this compound of sulphur and antimony; but in proportion as the sulphur is dissipated, the remainder becomes more refractory, and the fire may be raised to such a degree as to make the vessel in which the antimony is contained red hot. The surface of the metal becomes at first tarnished, and soon afterwards it is changed into an earthy powder of a dusky colour, which, by continuance of the process, becomes white. These calces have a different degree of fusibility according to the degree of calcination. When little calcined a strong heat converts them into a glass of an opaque or black colour. When further calcined more heat is required, and the glass is a deep yellow. When calcined to whiteness, the most violent heat will not melt them without the addition of borax, and the mass is then of a pale yellow. Here we observe the effect of the presence of oxygen
in

in rendering this calx less fusible, and depriving it of colour. These calces may be reduced, but most readily when little calcined, by adding an equal quantity of black flux, or one-fourth of charcoal or soap.

The fossil fixed alkali brings antimony nearest to the state of the perfect metals. For this discovery we are indebted to Margraff, who melted two ounces of regulus of antimony with one of fossil alkali. He repeated the fusion eight times, and every time he used fresh alkali; but the three or four last times he did not use quite an ounce of alkali, but employed a mixture of alkali and flint. Every time it was thus melted the regulus lost some of its weight, and the alkali, having dissolved part of it, was tinged green. The remaining metal was always whiter and brighter, and acquired a small degree of toughness. The texture was much finer than before, and it would easily amalgamise with mercury. The weight of the regulus was reduced to about one half by eight operations. With the vegetable fixed alkali the effect was similar, but not so remarkable.

The regulus of antimony is calcined with great rapidity by the nitrous acid, but the muriatic and vitriolic scarcely act on it, unless assisted by heat. By the union of antimony with all these acids, saline compounds are produced, which are deliquescent, and which are decomposed by water, or the simple application of heat. The oxygenated muriatic acid and aqua regia dissolve the regulus of antimony with great facility.

But besides these methods of assisting the action of the muriatic acid on antimony, there is another process for combining the muriatic acid with the regulus. A quantity of mercurial sublimate in powder being

mixed with the regulus of antimony, the acid acts upon the antimony immediately, so as to render the mixing of them dangerous, from the corrosive fumes which arise. The common way is to powder them and mix them, and heat being applied, the muriatic acid of the sublimate attracts the antimony, and rises with it in the form of a very volatile compound, which condenses in the neck of the retort, of a consistence between solid and fluid, and is hence called butter of antimony. It is very caustic, and is used to consume the callous lips of ulcers, but is too violent to be used internally. If it is subjected to a second operation, it comes over fluid. The same process is employed to combine other metals with the muriatic acid. When butter of antimony is thrown into pure water, an abundant white precipitate or calx falls down, which is a violent emetic, and is known by the name of powder of algaroth.

The vegetable acids also act upon antimony weakly when applied to it in its metallic state, but much more strongly when it is slightly calcined. A solution of this kind was formerly used under the name of antimonial wine. A quantity of the regulus was cast in the form of a cup, which was occasionally filled with wine, and having stood a day or two, it became emetic. The quantity of antimony dissolved was very small, but was discoverable on adding an alkali, and precipitating it.

To give crude antimony any action as a medicine, it is necessary to destroy a part of the sulphur, and also in some measure to calcine it. The more sulphur it retains, the less active it is. If we calcine it too much we also destroy its effects; for in the state of a white calx it has little or no medical efficacy. The flores antimonii is a preparation in which the an-

timony

timony is nearly deprived of sulphur, and at the same time furnished with some oxygen. It is extremely violent in its effects; a very minute quantity producing convulsions and vomiting. Antimony indeed may be reduced to such a state as to affect the body in smaller quantities even than arsenic.

When antimony is combined with sulphur, and urged with a strong heat, it assumes the appearance of glass. The glass of antimony, though not much employed as a medicine, is very useful as a preliminary to the most valuable preparations. Few of the metals, indeed, have so much attracted the attention of chemists as antimony, and its preparations have been accordingly very numerous. To avoid, therefore, unnecessary prolixity, it will be proper to confine the reader's attention to those which have been found most useful.

By deflagrating antimony with nitre, the metal is calcined, as well as when exposed to heat in contact with air. The *antimonium calcinatum* of the London Pharmacopœia is prepared by throwing a mixture of eight ounces of antimony; with two pounds of nitre, into a crucible heated to a white heat. The white matter is burnt for half an hour, and, when cold, is powdered and washed with distilled water. This preparation is so inert, that it has been doubted whether it is capable of any action whatever on the human body.

When the antimony and nitre are in equal quantities, they form a more active composition. The mixture burns with violence, and ought to be injected, in small quantities at a time, into the heated crucible. After the combustion there remains a mixed matter, partly of a dark red, and partly whitish. Upon melting, it separates into a heavier part of a deep red, and

a saline part above of a paler colour. The former is the object of the operation, and is called crocus of antimony. The College direct a small quantity of sea salt to be used in this preparation, which promotes fusion, and probably increases the activity of the composition.

Fixed alkalies have a great degree of activity with crude antimony, on account of their attraction for the sulphur. The easiest mode of combining them is fusion. The first effect of the alkali is to combine with the sulphur, and form a liver of sulphur, which by a continuance of heat seems to dissolve the regulus of antimony. This compound is readily dissolved by boiling water, and if we add to the solution an acid, the metallic matter and sulphur are deposited of a yellow colour. This substance, however, which is called sulphur antimonii præcipitatum, may be obtained in an easier manner, by boiling crude antimony in a solution of alkali, and then precipitating the sulphurated antimony with the vitriolic acid.

The antimonium tartarifatam, or *tartar emetic*, may be obtained either by the use of the crocus or the glass of antimony. The former is, however, preferred by the London College, who adopt the following process: Take of crocus of antimony powdered one pound and a half, crystals of tartar two pounds, distilled water two gallons; boil them in a glass vessel about a quarter of an hour; filter the liquor through paper, and set it by to crystallize. Tartar emetic consists of the acid of tartar united to vegetable alkali and antimony partially calcined.

The pulvis antimonialis of the pharmacopœia, which is thought to be nearly the same as James's powders, is prepared by exposing equal parts of antimony and hartshorn shavings to a moderate heat, with a free access of air. With respect to the peculiar merits

merits of James's powders, they have never been proved either in theory or practice. The circumstances upon which the effects of antimonial preparations depend are well known, and though we cannot with certainty ascertain the process of Dr James, there is no reason to think that it is preferable to that of the pharmacopœia, in the preparation of the pulvis antimonialis. The love of mystery, however, has always had an influence over mankind, and there is no reason to believe that the period for its cessation is at hand.

The regulus of antimony is employed in the manufacture of printers types, and in making shot.

C H A P. XXVII.

Z I N C.

General Description of this Metal—Philosopher's Wool—Union with Acids.—White Vitriol.—Detonation of Zinc with Nitre.—Combination with Metals.—Pewter.—Its Use in Fire-works.—Natural History of Zinc.—Calamine.—Black Jack.—Brass, how made.—Tutty.—Pinchbeck.

THIS metal is in some degree malleable, and therefore holds a middle place between the semi-metals and metals, though it is usually referred to the former division. Its appearance is blue and brilliant, and when broken it is found to be crystallized in narrow plates. It melts when red hot; if heated in close vessels to a vivid red or white heat, the whole of it rises in vapour, and may again be condensed without any change. When heated, however, in contact with air, it burns rapidly with a white flame and crackling noise, and is converted into a white, soft, and flocculent substance, called flowers of zinc, or *lana philosophorum*. If the zinc is burnt in a deep crucible, this calx attaches itself to the upper part of it, though some part is always lost even in the deepest vessel, which will admit the air with sufficient freedom to maintain the combustion. If a gentle heat is applied no light is produced, and the surface of the zinc becomes gradually covered by a grey calx, which changes to white, by being afterwards heated in contact with air. Zinc is so apt to undergo this change that it is difficult to melt small pieces of it into a mass, for in the moment after they arrive at the melting point

point they are covered with a skin, which prevents their union. The calx of zinc is not very easily reduced to a reguline state, as the heat necessary for this effect is apt to volatilize the metallic product.

Zinc is readily acted on by all the acids, and no metal shews a greater attraction for them. It produces with them metallic salts, in which the acid is more neutralized than in the other metallic compounds of the same description. The acids do not deposit the zinc when they are diluted with water.

The concentrated vitriolic acid does not act on zinc, unless assisted by heat, and it then gives out sulphureous fumes. It is dissolved, however, with rapidity, and without the assistance of heat, by the same acid in a diluted state, and this process is attended with the copious production of hydrogen gas, which indicates the decomposition of the water. From this solution may be obtained white vitriol, which, as well as the flowers of zinc, is employed in medicine.

The diluted nitrous acid acts on zinc with singular violence, and nitrous gas is so copiously disengaged, that the mixture sometimes exhibits the appearance of boiling. The solution is very caustic, and affords crystals by evaporation and cooling, which slightly detonate on hot coals, and leave a calx behind. This salt is deliquescent. The diluted muriatic acid acts on zinc with the same production of hydrogen gas as the vitriolic; but this solution does not afford crystals.

The vegetable acids acquire from zinc a sweetish taste and stipticity. The action of the fluoric and boracic acids on zinc are not known. Water impregnated with carbonic acid, dissolves a considerable proportion of zinc.

All the solutions of zinc in acids are precipitated by lime, magnesia, the fixed and volatile alkalis; the

latter re-dissolves the precipitate if it is added in excess.

Zinc has the property of decomposing several neutral salts. If it is considerably heated with vitriolated tartar in a crucible, it decomposes the salt, and forms a liver of sulphur, in the same manner as the regulus of antimony does. In this experiment the metal seizes the oxygen of the vitriolic acid, and the acid passes into the state of sulphur, which the alkali dissolves. The hepar formed by this combination dissolves a portion of the calx of zinc. All the vitriols are likewise decomposed by zinc.

When pulverized zinc is added to fused nitre, or projected together with that salt into a heated crucible, a very violent detonation takes place. The activity of the inflammation is such, that portions of burning matter are thrown to a distance out of the crucible, in such a manner as to require precaution on the part of the operator. Only small quantities of the mixture should be cast into the crucible at once. The zinc burns by the assistance of the oxygenous gas afforded by the nitre, and is afterwards found in a calciform state, more or less perfect, according to the proportion of nitre used. Part of the calx combines with the alkali, and forms a compound soluble in water.

Zinc decomposes common salt, and also sal ammoniac, by seizing the marine acid. The filings of zinc also decompose alum when boiled in a solution of that salt.

The relation of zinc to sulphur is remarkable, as it is the only metal which does not unite with it in a reguline state. M. Morveau, however, has discovered, that the calx of zinc unites easily with sulphur by fusion.

The regulus of zinc is capable of being united with
that

that of arsenic, but it more readily unites with arsenic in its calciform state. Zinc distilled with white arsenic deprived it of part of its oxygen, and was converted into a calx, while a corresponding quantity of arsenic was reduced to a regulus.

Zinc does not combine with bismuth, and when these two metals are fused together, the bismuth takes the lower place on account of its greater gravity, and may be separated by a stroke of the hammer. It will not unite with nickel. Its volatility renders it extremely difficult to combine it with metals which are of difficult fusion, as iron and copper. It is, however, united to several metals for particular purposes in the arts. It is added in small quantities to tin, or to a mixture of tin and lead, in the composition of pewter, which it improves both in adding to the whiteness and brilliancy, and increasing the hardness. It is employed in many alloys, particularly in tombac, prince's metal, and the various kinds of brass. Fine filings of zinc are used to produce brilliant sparks in fire-works. Some persons have proposed to substitute zinc for tin in lining copper vessels; the latter metal, in conjunction with lead, having been supposed insufficient to prevent the dangerous effects of the lead. Macquer allows that this metal spreads more evenly on the copper, is much harder, and less fusible, than the lining of tin, but objects to it, because it is soluble in vegetable acids, and has a considerable emetic power. Mr. De la Plance, however, has taken the salts of zinc, formed by the vegetable acids, in greater quantities than they can be contained in aliments which have been dressed in vessels lined with zinc, without experiencing any dangerous effect. Experiments are yet wanting to prove the superiority of zinc lining over that of tin,

Zinc is found in the following states: It is sometimes, though rarely, discovered native in flexible, greyish, and inflammable fibres. Zinc in its ore is generally in the form of a calx; when the ore contains no other metal but zinc it is never in any other form, but it is often mixed with other ores, which contain sulphur and arsenic, and these must be evaporated by roasting. The richest ores are compact and ponderous, and are called lapis calaminaris, or calamine; they are found in the parish of Holywell, in Flintshire.

Margraff has ascertained the quantity of zinc contained in different sorts of calamine:

	Parts.		Parts.	
Calamine, from near Cracow	} 16	gave	2½	zinc.
— from England				
— from Breslaw	16	—	4½	—
— from Hungary	16	—	2½	—
— from Holywell	16	—	7	—

In one hundred parts of lapis calaminaris were found eighty-four of calcined zinc, three of calcined iron, about one of pure clay, and twelve of siliceous earth, according to Bergman.

There is another species of mineral used in making brass called blende, mock lead, or black jack, which consists of zinc mineralized by sulphur, and sometimes by iron.

The method of making ordinary brass is as follows:—Copper in thin plates, or, which is better, copper reduced (by being poured when melted into water) into grains of the size of large shot is mixed with calamine and charcoal, both in powder, and exposed in a melting pot for several hours to a fire not quite strong enough

enough to melt the copper, but sufficient to reduce the zinc, and convert it into vapours. These vapours penetrate the copper in proportion to the surface exposed to their action, changing its colour from red to yellow, and augmenting its weight in a great proportion. When they make brass, which is to be cast into plates, from which pans and kettles are to be formed, and wire is to be drawn, they use calamine of the finest sort, and in greater proportion than in the composition of common brass.

Tutty is the flowers of zinc taken from the furnaces in which the ores containing this metal are wrought. It varies in colour and consistence according as the calx is more or less perfect, and is mixed with more or less of an argillaceous substance. Newman says, that the lapis tutiæ is composed of clay beaten up with a small quantity of lapis calaminaris.

Zinc and copper, when melted together in different proportions, constitute what are called pinchbeck, &c. of different shades of yellow. Margraff melted pure zinc and pure copper together in a great variety of proportions, and he found that eleven, or even twelve parts of copper, being melted with one of zinc, gave a most beautiful and very malleable tombac or pinchbeck,

C H A P. XXVIII.

OF THE NEWLY DISCOVERED SEMI-METALS.

Sylvanite.—Menachinite.—Uranite.—and Titanite.

BEFORE the account of semi-metals is concluded, it is proper briefly to notice four semi-metallic substances which have lately fallen under the observation of mineralogists, but which have not yet undergone a complete examination.

A new semi-metal has been discovered by Facebay, to which Mr. Kirwan gives the name of SYLVANITE, from its being found in Transilvania. Its colour is grey inclining to red, its fracture broad or granularly foliated, with a slight degree of malleability. Its weight is about six times that of water. When heated it melts as easily as lead, gives a thick white smoke, and at last a brownish flame. In cooling it shews some disposition to crystallize. By continued heat it entirely evaporates. It easily amalgamates with mercury by simple trituration. It combines with sulphur, and forms with it a striated mass like crude antimony.

Sylvanite is soluble in concentrated vitriolic acid, and the solution in a moderate degree of heat is crimson red, but by the addition of water or heat it is precipitated. It may also be dissolved in a small proportion in nitrous acid, and the solution until it heats is greenish. The best solvent is aqua regia, with which a yellow solution is produced. Its calx is of an acid nature and unites with alkalis; it is also soluble in acids. This singular substance was at first taken for regulus of antimony, and afterwards for sulphurated bismuth.

A substance

A substance of a peculiar nature was discovered by Mr. M'Gregor in the valley of Menachan in Cornwall, which has been therefore called **MENACHANITE**, and is considered as a semi-metal. It is found in the form of small black grains resembling gunpowder, of no determinate shape, and often mixed with a grey sand of great subtilty. Its specific gravity when in grains is 4,427; in a high heat it slightly agglutinates and acquires a small increase of weight. When in grains it is easily pulverized, and is possessed of some magnetic power. It is insoluble in acids except by particular management; but is then found to consist of about equal proportions of iron, and a peculiar white calx with a little filix. The solution of menachanitic calx in vitriolic acid, is precipitated deep green by Prussian alkali, white by common alkali, and becomes orange coloured with tincture of galls. With several other solvents it exhibits properties so peculiar, as to entitle it to be considered as a new substance.

URANITE was first discovered by Klaproth, who found it to possess the following properties. Its colour is dark steel or iron grey, internally somewhat browner. Its specific gravity 6,440. It is rather more difficultly fusible than manganese, and has as yet only been produced in small globules imperfectly agglutinated. It is soluble in nitrous acid; but it does not appear that other acids have been tried. Its calx is yellow and manifests the following properties. It is easily soluble in acids; with the dilute vitriolic acid it affords yellow crystals. With the concentrated acetous acid it affords yellow quadrangular crystals. It is also soluble in many other acids, the products of which solutions vary considerably both in colour and form. Uranitic calx is insoluble in alkalis, either in the moist or dry way, which fully distinguishes

distinguishes it from tungstenic calx, which it resembles in colour.

TITANITE, which many mineralogists have considered as a red shirl, has been lately transferred to the class of metallic substances by the labours of Klaproth. Its colour is brownish red. It occurs crystallized in right angled quadrangular prisms, longitudinally streaked or furrowed. None of the acids have been found to have any action on this substance, even when heated. The calx of titanite is white, and is soluble in the mineral acids. Fifty grains of the calx were by ignition reduced to twenty-eight. Mr. Kirwan is of opinion that titanite is red when in its metallic state; that is, as it is found in nature. Heated on charcoal it becomes rosy red, and afterwards slate blue, and finally melts into an imperfect bead with a fine striated surface. The different productions of nature seem universally to pass into each other; and titanite, as far as we can judge, from what is as yet known concerning it, forms a link between earthy and metallic substances.

C H A P. XXIX.

I R O N.

Extensive Utility of this Metal.—Its Properties.—Natural History of Iron.—Eagle-Stones.—Blood-Stones.—The Loadstone.—Emery.—Ochres.—Smelting of Iron.—Forging of Iron.—Making of Steel.—Tempering of Steel.—Cast Steel.—Great Disposition in Iron to unite with other Bodies.—Green Vitriol, how procured.—Prussian Blue.—Ink.—Inflammation of Sulphur and Iron.—Tinning of Iron.—Preparations of Iron used in Medicine.

OF all metals, and I might perhaps be justified in adding, of all mineral substances, the most generally useful is iron. To specify its uses would be to produce a catalogue of every thing that contributes to the sustenance and the convenience of life. By the assistance of this metal we till the land, and obtain the fruits of the earth in greater abundance and perfection than we could by any other means; by its agency we are enabled to penetrate the earth itself, and procure whatever it contains that may be useful or ornamental to man; there is scarcely a mechanical trade, which could be conducted on the present principles without its aid, and many of them could not even exist were we deprived of it: even in domestic life our safety, our comfort, and our pleasure, all seem in some measure to depend on this most valuable production of the earth. As the quantity of this, as well as of some other minerals, which appear almost necessary to social existence, must be limited, I have often thought that the want of a sufficient supply, which, on the supposition of the present system of things being continued for ever, must at some time necessarily take place, forms a forcible argument

argument against the absurd and ignorant hypothesis of the eternity of the world.

The external appearance of this metal is well known, and its hardness and elasticity are seen in the various instruments and utensils which are formed of it.

It is the most sonorous of all the metals, except copper; but in specific gravity it is inferior to most of them, being only about seven times and a half the weight of water. Iron has a considerable smell, especially when rubbed or heated. It likewise has a very perceptible styptic taste.

Iron is very ductile, and may be drawn into wire as fine as a human hair; and it is so tenacious, that an iron wire of one tenth of an inch diameter will support a weight of fifteen hundred pounds. Iron may be ignited, or at least made sufficiently hot to set fire to brimstone, by a quick succession of blows with a hammer; but it requires a most intense heat to fuse it, on which account it is brought into shape by hammering while it is in a heated state. Iron is also possessed of another property, which supplies in a great measure the purposes of fusion. When pieces of common soft iron are heated to a certain degree, and are suddenly taken out of the furnace and exposed to the air, we observe their surface covered over with an appearance of varnish, which proceeds from the surface of the metal being partly fused. If two pieces of iron in this state are struck together, they unite very firmly, and this process is called welding. It is distinguished from all other metals by being attracted by the loadstone. Another property, which distinguishes iron from all other metals, is that of striking fire with flint. This phenomenon depends on the actual inflammation of small particles of the metal, which present a large surface to the action of the air, and which are heated by
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the friction which separates them from the mass, so as to dispose them to inflammation. These particles are seldom larger than the two hundredth part of an inch in diameter, and when examined by a magnifier, are found to be brittle, of a greyish colour, resembling the scales of burnt iron. Another proof of the inflammability of iron is, that iron wire, heated at one end, and plunged in a jar of oxygen gas, burns with considerable rapidity, and with a very brilliant flame.

Iron is by far the most abundant in nature of all the metals. It is not only contained in almost every fossil, particularly in those which are coloured, but makes a part of vegetable and animal matter. With respect to the ores of iron, however, as they are very numerous, it will be necessary only to notice those from which the metal may be extracted with advantage. In these ores iron exists either in the metallic or calciform state, or mineralized by different substances.

Native Iron is known by its colour and malleability. It is very rare, and is only found occasionally in iron mines. Some naturalists think that these apparently native specimens of iron have been produced by art, and have been buried in the earth by accident.

In the Philosophical Transactions for the year 1788, vol. lxxviii. is an account of a mass of native iron, weighing by admeasurement about three hundred quintals, which lies in the midst of a wide extended plain, in the middle of South America, in latitude $27^{\circ} 28'$ south, and at the distance of seventy leagues east, one quarter south, from the hamlet of Rio Salado. It has the appearance of having been liquid, and bears the impression of human feet and hands of a large size, as well as of the feet of large birds common in that country. The extraordinary fact of such a mass of

iron being found in the center of a vast tract of level land, where there are no mountains, nor even the smallest stone, within a considerable distance, projecting above the surface of the earth, is referred by the writer of the article in question to an ancient volcanic explosion, of which there are some vestiges near it. The same supposition is urged with equal probability to account for the production of another mass of native iron, in the shape of a tree with its branches, which the same author asserts, on indubitable authority, is known to exist in these immense forests. Some specimens of the iron were presented to the Royal Society, who afterwards deposited them in the British Museum. That large masses of iron were really observed in these situations there is no reason to doubt, but I should rather attribute the supposed impressions to accidental resemblances.

The largest quantities of iron ores are in a calciform state, as in ochres, bog ores, &c. which are disposed in strata, in the manner of stones. The *ætit*es, or eagle stones, are a variety of the bog ores; they are in different forms, commonly oval or polygonous, composed of concentric layers disposed round a nucleus, which is frequently moveable in the center of the stone. The *hæmatites*, or blood stones, are named from their colour, which is commonly red. The loadstone is a dull iron ore, the varieties of which are distinguished by their colour.

Emery is a grey or reddish iron ore; it is very hard and refractory, and is found in abundance in the islands of Guernsey and Jersey. It is reduced into powder in mills, and in this state is used to polish glass and metals. Spathose iron ore is a calx of iron combined with carbonic acid; it is usually of a white colour,

Nature likewise presents iron in a saline state, united to the vitriolic acid, and forming green vitriol. This salt is particularly found in mines which contain pyrites. Iron is often found united to sulphur, and then forms what are called martial pyrites. This metal is also found combined with arsenic, both being in the metallic state. There is also a black iron ore, which is in some measure attracted by the magnet. Iron is sometimes found in the form of a blue powder. In this state it is called native Prussian blue. It is mixed with vegetable earths, and especially with turf. It was discovered some years ago, that iron is often united with the phosphoric acid. The muddy or bog ores are sometimes of this nature.

The ores of iron do not afford the metal unless urged by a great heat. Some ores are melted without addition; but it is necessary to assist the fusion of others by calcareous matters. The limestones, the iron ore, and charcoal, are alternately thrown into the furnace, and the whole is covered with a layer of charcoal. The melted ore is reduced by the contact of the coaly matter, and is then suffered to run into a cavity usually formed in sand. The metal in this state is called crude or cast iron. A vitreous matter, called slag, passes after the iron, and consists of the stones which were added to facilitate the fusion. The metal thus obtained has not the least ductility; but it is deemed better in proportion as its colour is darker.

The cast iron is carried to be refined in a forge furnace, with a hollow hearth, in which it is surrounded with charcoal, where the fire is urged by bellows till the metal begins to soften. When it is in this state, it is repeatedly stirred, in order that it may present a larger surface to the air. By the action of the heat and air it emits sparks, which proceed from the consumption of a quantity of plumbago, or black lead

which is contained in the crude iron, and which it is commonly supposed to acquire from the fuel during the process of smelting *

The iron, by this mode of refining, loses, besides the plumbago, a quantity of siderite, which Bergman supposed to be a peculiar metal, but which is now found to be a combination of iron and phosphoric acid.

After the iron has been kept in this situation a certain time, it is carried to a large hammer, generally moved by water, where it is formed into bars. The hammering, by bringing the particles of the iron nearer together, presses out the impurities, and thus completes what was left deficient by the fusion. This heating and hammering are repeated a number of times, till the iron has acquired the desired degree of perfection. Crude iron loses from a quarter to a third of its weight by the process of refining, and is then called forged iron.

Steel is made by surrounding the bars of iron with a composition of which charcoal is the chief and only essential ingredient, and by keeping them in an intense heat a longer or shorter time, according to their thickness. They are then taken from the furnace, and plunged in cold water. The metal is now found to be more fusible than it was before, but to have less ductility and softness. Its texture is finer; it breaks short, its fracture is always grey, and it has gained a small increase of weight.

With respect to the chemical states of the metal, in the three forms of cast iron, forged iron, and steel, it appears that they chiefly depend on the quantities

* Plumbago consists of carbon, with about one tenth of its weight of iron.

of plumbago. By solution in acids, it is found that cast iron contains a large quantity of plumbago, that steel contains some of it, but that the most malleable forged iron contains scarcely any; it therefore appears, that steel is in an intermediate condition between cast iron and forged iron, and that, in making the former into the latter, the metal must pass through the state of steel. In some foreign works they actually manufacture steel by only stopping the process of refining at a certain point. In these manufactories, however, they make use of an ore of uncommon purity; and the same process does not succeed with ordinary ores, because the metal obtained from these contains other impurities besides plumbago, which cannot be separated without reducing the iron to its malleable state.

There are differences in the working of iron, according to the ores from which it is obtained, the causes of all of which have not been discovered. The presence of phosphoric acid, however, is known to produce a brittleness in iron when cold, which occasions that sort of iron to be called *cold short* iron by the workmen. Phosphoric acid is chiefly found in iron obtained from bog ores.

The workmen employed in tempering steel judge, by the different colours it assumes during the operation, of the degree of hardness it has acquired. That these colours may be properly observed, some part of the metal to be tempered should be smooth.

The changes of colour depend on the calcination of the iron; for if the contact of air is prevented by the thinnest covering of any oily matter, the effect is entirely prevented. The colour is first a pale yellow; if a piece of steel is then struck off, it will be very hard. If the steel is left in the fire for a longer time,

it acquires a deeper yellow and more toughness, with scarcely any diminution in the degree of hardness; when brought down to the colour of watch springs, it is of the fittest temper for cutting wood. Steel, by being heated in this manner, becomes successively white, yellow, orange, red, violet, and lastly blue; which colour remains a considerable time; but if the heat is raised it becomes whitish.

Steel strongly heated while in the fire, assumes a red and sparkling appearance, it next becomes very white and dazzling, and then burns with a sensible flame.

Cast steel is nothing more than steel refined by fusion. During this process it throws up scoria, whilst the metallic matter which remains is much harder than before, and its texture more uniform.

Iron is one of the metals which is acted on most powerfully by acids. But not only acids, but all saline substances seem to affect it, and even water is capable of acting on it so as to acquire from it a peculiar taste. The tendency, indeed, which this metal has to combination with other bodies, particularly with oxygen, which occasions rust, renders it incapable of permanency, and for this defect no sufficient preventative has yet been discovered.

M. Lavoisier, having exposed iron with water in a glass vessel over mercury, observed that the iron became rusty, and that the water was diminished in quantity. The iron was increased in weight, and there was a production of inflammable gas, so that in this experiment the water was decomposed by the iron, even without the presence of air.

Iron is acted on by the vitriolic, muriatic, and nitrous acids, with nearly the same phenomena as zinc. The products, however, are very different. The solution

lution of iron in the vitriolic acid is of a green colour, and by evaporation produces the green crystals, well known under the names of sal martis, green vitriol, and copperas. The green vitriol used in commerce is obtained in the following manner: Pyrites, which are natural combinations of iron and sulphur, are exposed to the action of the air and rain in shallow pits lined with clay. After having been in this situation a week or a fortnight they grow hot and crumble down, and when carefully examined are found to contain small crystals. These are dissolved by the rain, and conveyed by pipes into a reservoir in a house, whence the liquor is pumped into a boiler made of lead. This liquor is found to have an excess of acid, which is remedied by casting pieces of iron into it when heated so as to simmer. By the addition of the iron a quantity of the earth of alum is also deposited. As the liquor cools, the greater part of the sal martis is deposited. By the exposure of the pyrites to the action of air and water, the sulphur attracts the oxygenous principle, and is thus converted into vitriolic acid. Sal martis is liable to the watery fusion; when exposed to a strong heat the acid begins to exhale, and as it exhales, the natural colours of the calx of iron appear. It is first yellow, then orange, then red; if it is calcined to a greater degree, scarcely any of the acid is left, and the calx remains of a deep purple colour, and is known under the name of colcothar of vitriol. The nitrous acid acts with so much violence on iron as to convert it into a brown calx. With the muriatic acid iron affords crystals of a livelier green colour than copperas, which will not, like copperas, part with the acid by the application of heat.

All solutions of iron, if exposed to the air, deposit part of the metal in the form of a calx. Alkaline salts

precipitate the metal of a blueish grey colour, if the solution is fresh, but if long kept, in the form of a yellow powder. Mild vegetable alkali separates a yellow calx from the solution of iron in the nitrous acid, which soon becomes of a beautiful red orange colour. If the mixture is agitated during the effervescence, the precipitate is re-dissolved in much greater quantity than by the pure vegetable alkali. This solution is known by the name of Stahl's martial alkaline tincture.

But the most remarkable precipitation is that produced by a fixed alkali prepared with animal inflammable matter. The alkali is treated by mixing it, when dry, with twice its weight of blood, which has been indurated and reduced to powder; the mixture is put into a crucible, and a gentle heat applied; particular care must be taken to use the due degree of heat, which is known by the disappearance of a blue flame and smoke, which is at first observable on the surface. The matter thus prepared, being infused in water, affords an alkaline solution, which precipitates iron of a deep blue colour, especially if a little muriatic acid is added. The essential ingredients of the matter obtained by the above process seem to be a peculiar matter called prussic acid, and an alkali. The basis of the prussic acid, according to M. Berthollet, consists of carbon, hydrogen, and azote. When the alkali, combined with this peculiar acid, is added to a solution of iron, the alkali takes the acid from the iron, while the prussic acid unites with the metal and falls to the bottom in the form of a blue powder. This effect of the alkali, thus prepared, is the foundation of the process for obtaining that valuable pigment, known by the name of Prussian blue.

Another singular, and not less useful circumstance,
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in the history of iron, is the effect produced on it by astringent vegetable substances. The principle of astringency, which is now found to be a peculiar acid, called, in the new nomenclature, gallic acid, resides in a great number of vegetable matters, particularly oak galls, tea, &c. According to M. de la Metherie, however, the acid of galls is only a variety of the colouring principle. Galls are protuberances on the leaves of the oak, occasioned by the puncture of a particular insect. Any of these substances, added to a solution of green vitriol, precipitates a fine black fecula, which may be suspended a considerable time in the fluid by the addition of gum arabic. Oak galls are commonly made use of in this process, which is that of making ink. The following proportions of these ingredients for making ink answer very well. One ounce of martial vitriol to three of powdered galls; to which one ounce of powdered logwood may be added, to render the ink more permanent, and one ounce of gum arabic to suspend the colouring matter. Let these be infused in a quart of water or vinegar for ten days, and shaken occasionally, when the ink will be fit for use.

The colouring matter of ink seems to be produced from an union of the acid of the galls with some part of the iron in a calciform state. A small quantity of any of the mineral acids destroys the colour of the ink, by dissolving the iron, which was imperfectly precipitated; and this colour is again restored by the addition of an alkali, which takes away the acid. The black fecula of ink is not magnetical; but it may be converted into a brown magnetic calx by heat. Ink becomes blacker by exposure to the air, which acidifies more completely the principle combined with the iron; but ancient writings become more and more yellow

yellow in consequence of the decay of the vegetable matter. Their legibility may be restored by the use of infusion of galls, or gallic acid. The best method, however, of restoring the legibility of ancient writings, consists in spreading a solution of the Prussian alkali thinly with a feather over the traces of the letters, and then to touch it gently, and as nearly upon or over the letters as can be done, with a diluted acid, by means of a pointed stick.

The only essential ingredients of ink are green vitriol, galls, and water. Dr. Lewis has made many useful experiments on the proportions of these ingredients which produce the best ink. He found that equal quantities of galls and green vitriol produced the deepest colour, but not the most durable; he found, that by increasing the quantity of the galls the colour was rendered more durable; that with three times the weight of the galls to one of the vitriol, the colour was very permanent; but that if the proportion of galls was increased beyond this, the colour was too weak; in this case the writing was much refreshed by washing it with a solution of vitriol. He also endeavoured to ascertain the best proportion of the fluids to the vitriol and the galls. He first tried water, and found that by considerably diminishing the quantity of it the ink was more durable, but too thick for use. He found that all waters were much the same; that white wine and vinegar made a more durable ink; but that both these were exceeded by a decoction of forty ounces of water to one of logwood, which of itself gives a permanent red stain. If the colour of the ink should fail, that of the logwood will remain, and it produces, with ink, a much stronger and blacker colour than usual; for the common colour of ink is a purplish blue, which, mixed with red,
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makes a deep black. He did not find any vegetable astringent equal in all respects to galls.

Mr. Nicholson states an objection to the use of vinegar in the making of ink, which is, that it acts so strongly on the pens that they continually require mending. Ink is very apt to become mouldy, which is best remedied by the addition of a few cloves reduced to powder; for hot aromatics are excellent preservers of animal and vegetable matters.

Iron detonates strongly with nitre. It appears to combine with alkalis by fusion. The calx of iron combines with earths, assists their fusion, and imparts a green colour to the glass. Iron has a remarkable attraction for sulphur, and combines with it either by the action of heat or moisture. A mixture of equal parts of iron filings and sulphur, made into a paste with water, becomes hot, emits watry vapours and inflammable air, in a little time the mass takes fire, and, by attracting the oxygen of the water, becomes converted into green vitriol, in the same manner as pyrites. This is the mixture used in the production of an artificial earthquake, which will be spoken of more fully under the head of earthquakes.

With respect to the relations of iron to the other metals, there is little worthy of note, except its attraction for tin, on which is founded the process of tinning iron. In some countries iron is made into plates, by being repeatedly heated and submitted to the action of a heavy hammer. In England, however, the plates are not hammered, but rolled out to the proper dimensions, by being put between two cylinders of cast iron, cased with steel. When the iron plates have been either hammered or rolled to a proper thickness, they are scoured with a weak acid, which renders their surface perfectly clean and bright, and takes off all
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the rust, which would prevent the adhesion of the tin to their surface; they are then wetted with a solution of sal ammoniac, and plunged into a vessel containing melted tin, the surface of which is kept covered with pitch or tallow to prevent its calcination. The tin adheres to each side of the plate, and intimately combines with the iron to a certain depth, which renders the tinned plates less disposed to harden by being hammered, and forms an excellent defence for the iron against the action of air and moisture.

Bishop Watson proposes it as a question of some importance, whether iron of a greater thickness might not be advantageously tinned? He desired a workman to break off the end of a large pair of pincers, which had been long used in taking the plates out of the melted tin; the iron of the pincers seemed to have been penetrated through its whole substance by the tin; it was of a white colour, and had preserved its malleability. It is usual to cover iron stirrups, buckles, and bridle bits, with a coat of tin; by dipping them, after they are made, into melted tin; and pins, which are made of copper-wire, are whitened, by being boiled for a long time with granulated tin in a ley made with alum and tartar. On these circumstances he founds two queries; 1. Whether the iron bolts, used in ship building, would be preserved from rusting by being long boiled in melting tin? 2. Whether it would be possible to silver iron-plates, by substituting melted silver for melted tin?

It is customary, in some places, to alloy the tin used for tinning iron plates with about one-seventieth part of its weight of copper. Too much copper renders the plates of a blackish hue, but when added to

tin in a proper proportion, it enables the manufacturers to lay on a thinner coat of tin without injury to the colour. This practice, however, is rather of prejudice to the duration of the plates. When the tin is heated to a great degree, the covering which it imparts to the iron is thinner but more even. The plates are apt, from this cause, to have yellow spots on them; but this inconvenience may be removed by boiling the plates for two or three minutes in lees of wine, or, where they cannot be had, four small beer, or other similar fluids, may probably be used with the same success.

Iron is justly considered as a valuable article of the *materia medica*, and while its utility is considerable, it is entirely free from those deleterious and debilitating effects which proceed from most of the other metals that are used as medicines. The *ferrum vitriolatum*, or green vitriol, has been already mentioned. The *ferrum subigo* is made by merely exposing iron filings to the air, and moistening them with water till they are converted into rust. The *ferrum tartarifatum* is prepared by mixing one part of iron-filings with two of crystals of tartar moistened with water, and exposing them to the air for eight days. In this preparation the iron is chiefly brought to the saline state by means of the acid of tartar. The *ferrum ammoniacale*, or *flores martiales*, is made by mixing one pound of iron filings with two of sal ammoniac, and applying a brisk heat. The sal ammoniac sublimed and carries up so much of the iron as to be changed to a deep orange colour. The *flores martiales* may be made equally well with the colcothar of martial vitriol as with the iron-filings. The *tinctura ferri ammoniacalis*, or ammoniacal tincture of iron, is made by digesting one pint of proof spirit

spirit of wine with four ounces of ferrum ammoniacale. The tinctura ferri muriati is prepared by dissolving the rust of iron in the muriatic acid, and adding a quantity of rectified spirit of wine. Wine of iron is obtained by digesting rust of iron with Spanish white wine, in the proportion of an ounce to a pint, for a month.

[The following text is extremely faint and largely illegible, appearing to be bleed-through from the reverse side of the page. It contains several lines of text, possibly including a recipe or a list of ingredients, but the characters are too light to transcribe accurately.]

C H A P. XXX.

T I N.

General Properties of Tin.—Granulated Tin.—Natural History of Tin.—Its Union with the Acids.—Use of Tin in improving the red Dyes.—Smoking Liquor of Libavius.—Aurum Musivum.—Combinations of Tin with other Metals.—Different Species of Pewter.—Putty.—Application of Tin in dying.—Use in Medicine.

TIN, when its surface is fresh, is bright, and with respect to whiteness holds a middle place between lead and silver. Tin is the lightest of all metals, being only about seven times heavier than water. It produces a cracking noise when it is bent, though it yields easily. It is very soft, and, probably from this cause, it is scarcely at all sonorous. It is considerably malleable, and may be reduced beneath the hammer into laminæ thinner than the leaves of paper (commonly known by the name of *tin foil*) which are of great use in several arts, particularly the foiling of looking glasses. Its degree of toughness is such, that a wire of tin of the tenth of an inch in diameter supports a weight of forty-nine pounds and an half without breaking.

Tin is the most fusible of metals, and melts at a little above the heat of 400° , which is long before it becomes red hot. In passing from the fluid to the solid state it remains a short time in an intermediate condition, in which it has little more cohesion than wet sand, and may be broken by a blow of a hammer, or by agitation, into grains. Tin is easily calcinable in an obscure red heat; it at first forms a grey pellicle; and in a strong heat it calcines with inflammation into
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a white powder. The calx of tin resists fusion more than that of any other metal; from which property it is useful to form an opaque white enamel, when mixed with pure glass in fusion.

It is observed by miners, that though tin is the lightest of the metals, its ores are some of the heaviest. Tin is seldom or never found in the metallic or reguline state. The ores are often crystallized, and of different colours. Those which are of a reddish colour generally contain a large proportion of iron. There also is a sulphureous tin ore of a brilliant colour, similar to that of zinc, or golden, like *aurum musivum*. The more transparent ores of tin often contain arsenic, and this is separated, almost entirely, by repeated roastings.

In order to reduce the ores of tin, they are first cleansed from foreign admixtures by sorting, pounding, and washing. In the smelting of the ore, care is taken to add a larger quantity of fuel than is usual in the revival of other metals, and to avoid a greater heat than is necessary to reduce the ore, in order that the loss by calcination may be as little as possible. Almost all the tin used in Europe comes from Cornwall, which has been famous for its tin mines from the remotest periods of history.

Tin is five times as dear as lead, and as a small quantity of the latter mixed with a large quantity of the former is with difficulty discovered, the temptation to adulterate tin is great, and the fear of detection small. Bishop Watson states, in his *Chemical Essays*, that in Cornwall the purity of tin is ascertained, before it is exposed to sale, by what is called its *coinage*. The tin, when smelted from the ore, is poured into quadrangular moulds of stone, containing about three hundred and twenty pounds of metal, which when hardened

hardened, is called a *block* of tin; each block of tin is coined in the following manner: the officers appointed by the duke of Cornwall assay it, by taking off a piece of one of the under corners of the block, partly by cutting and partly by breaking, and if well purified, they stamp the face of the block with the impression of the seal of the duchy, which stamp is a permission for the owner to sell, and at the same time an assurance that the tin so marked has been purposely examined, and found merchantable*.

The concentrated vitriolic acid acts on tin with the production of sulphureous vapours, part of the oxygen of the acid, as is usual in the solutions of metals in their reguline state, being abstracted: The acid dissolves about half its weight of tin, but not without the assistance of heat. The solution is very caustic. The nitrous acid is decomposed by tin, as it is by most of the metals, with great rapidity. The tin is converted into a white calx, which it is very difficult to reduce. M. de Morveau has remarked the formation of a quantity of volatile alkali during the solution of tin in the nitrous acid. This is probably owing to a combination of the azote, produced by the acid, with the hydrogen, derived from the decomposition of the water contained in the menstruum. The advocates for the phlogistic hypothesis, however, say, that the hydrogen is the phlogiston of the tin set at liberty during the solution.

The fuming muriatic acid acts strongly on tin, instantly losing its colour and its property of emitting fumes. The muriatic acid dissolves more than half its weight of tin, and does not let it fall by repose. By evaporation it produces brilliant and very regularly

* Borlase's History of Cornwall, p. 183.

formed needles, which slightly attract the humidity of the air. The oxygenated muriatic acid dissolves tin very readily, and without the least sensible effervescence. Aqua regia, consisting of two parts nitrous and one muriatic acid, combines with tin with effervescence and the developement of much heat. The solution of tin in aqua regia is used by dyers to heighten the colours of cochineal, gum lac, and some other red tinctures, from crimson to a bright scarlet, in the dying of woollens. By first dissolving tin in the marine acid, and then boiling the solution with nitrous acid distilled from manganese, M. Hermstædt has succeeded in acidifying tin to such a degree as to convert it into an acid; it had then the form of a white powder, soluble in three times its weight of water.

Tin has a stronger affinity with the muriatic acid than mercury has, and decomposes the corrosive mercurial sublimate. To effect this, the tin is first divided by the addition of a small portion of mercury; equal parts of this amalgam and the corrosive sublimate are triturated together, and the mixture exposed to distillation in a glass retort with a very gentle heat. A colourless liquor first passes over, and is followed by a thick white vapour. The vapour becomes condensed into a transparent fluid, which continually emits a thick, white, and very abundant fume. It is called the fuming liquor of Libavius, and is a combination of the muriatic acid and tin. The smell of this fluid is very penetrating, and excites coughing. The vapours are not visible without contact of air, and seem to consist of a peculiar gas, which is decomposable by air, and which then deposits the calx of tin in the same manner as the hepatic gas of Bergman deposits sulphur by the contact of air. M. Fourcroy proposes it as a query, whether this elastic fluid is a
composition

composition of the oxygenated muriatic acid and tin? When water is added to this fuming liquor in a certain quantity, it becomes solid, and ceases to emit fumes. It is found that this concreté substance, when rendered fluid by an increase of temperature, is capable of dissolving more tin without the escape of hydrogen gas. Hence it appears that the oxygen necessary for the solution of this additional quantity of metal is not derived from the water but the acid, and that the acid to impart it must be in an oxygenated state. The experiments of M. Adet have thrown much light on the nature of the fuming liquor of Libavius, and are published in the *Annales de Chemie*.

Tin is capable of decomposing all the vitriolic neutral salts. Tin has a considerable attraction for sulphur, and easily unites with it, when in a state of fusion, into a black mass. *Aurum musivum* is a combination of tin and sulphur, obtained by a particular process. Arsenic cannot easily be united to tin, on account of the volatility of the former metal. Cobalt unites by fusion with tin, and forms an alloy in small close grains of a light violet colour. Bismuth in small quantities as well as zinc, impart a firmness and whiteness to tin. Mercury dissolves tin with great facility, and in all proportions.

The uses of tin are very numerous. It is applied to many purposes in the arts. Its amalgam with quicksilver or mercury is applied to silver looking-glasses. The use of tin in covering plates of iron has been already specified; and it is also employed in lining the inside of copper vessels. It enters into the composition of bronze and bell metal. It is the chief ingredient in the composition of pewter. Pewter consists of tin united to small portions of other metallic substances, such as lead, zinc, bismuth, and antimony.

We have three sorts of pewter in common use; they are distinguished by the names of *plate*; *trifle*; *ley*. The plate pewter is used for plates and dishes; the trifle chiefly for ale pints, quarts, &c. and the ley-metal for wine measures and other coarser uses. Our very best pewter is said to consist of one hundred parts of tin to from ten to seventeen of antimony. To this composition the French add a little copper. In general the lightest pewter is the best. The inferior kinds are heavier and softer, from a quantity of lead with which they are adulterated. Putty is prepared from the white calx of tin. The solution of tin in aqua regia has been already mentioned as useful in dying. When it is mixed in the dyer's bath it forms a precipitate, which carries down the colouring matter, and deposits it on the stuff which is to be dyed scarlet. The operation of tinning copper will be afterwards described. The powder of tin has been used as a remedy against worms in large doses, and therefore the scruples which have been entertained against the use of vessels lined with tin must be wholly without foundation. Tin has been analyzed by many chemists, with a view to discover the quantity of arsenic contained in it. The results of these experiments have been by no means uniform. The largest proportion, however, which has been detected in any tin used in commerce, is a grain in an ounce, or one five hundred and seventy-sixth part of the compound; but more frequently no arsenic whatever has been discovered.

C H A P. XXXI.

L E A D.

General Properties of Lead.—Red Lead.—Litharge.—Natural History of Lead.—Slickensides.—Curious Phenomenon.—Smelting Lead Ores.—Union with Acids.—Plumbum Corneum.—White Lead; how made.—Sugar of Lead.—Union with other Metals.—Common Solder.—Uses of Lead.—Great Danger from leaden Vessels.—Devonshire Colic.—Means of detecting Lead in Liquors.—Medical Uses of Lead.—Uses of its Calces in the Arts.

THE appearance of this metal is well known. It is so soft as to be cut with a knife without much difficulty. It is neither sonorous nor elastic. It has very little tenacity, and therefore cannot be drawn into fine wire. It spreads easily under the hammer, but cannot be extended into very thin leaves like gold, silver; and tin. Its specific gravity is rather greater than that of silver, being eleven times heavier than water, and it is exceeded in this respect by only three metals, gold, platina, and mercury. Lead melts at the five hundred and fortieth degree of Fahrenheit's thermometer, before it becomes red hot.

Lead, like tin, at a certain point between its fluid and solid states, possesses very little cohesion, and may be separated by a smart blow with a hammer into grains, which are used in assaying the ores of gold and silver.

Lead, soon after it is melted, acquires a film on its surface, which presents in succession a variety of colours. This film becomes thicker, and of a grey colour, by the continuance of the calcination, and is then called *plumbum ustum*. If the first pellicle is removed, another is quickly formed, and in this way

almost the whole of the lead may be converted into a greyish powder tinged with green and yellow. This powder, being ground in a mill and washed, becomes of a more yellow colour. By further exposure to a moderate heat, assisted by the reverberation of the flame of the fuel on the surface of this calx, it gradually assumes an orange, and then a bright red colour, and is thus, in about forty-eight hours, converted into the substance called minium, or *red lead*. If lead is, in the phrase of the chemists, *urged* with a more violent and sudden heat, the appearances which it exhibits are different. It is first converted into a flaky substance, called litharge, which by the process just described, may be converted into minium, but which, by an increase of heat, becomes fluid, and acts so powerfully as a solvent on earthy substances as quickly to make its way through ordinary crucibles.

All these calces of lead may be easily reduced to the metallic state, by melting them in contact with inflammable substances. In calcining and reducing sixty hundred weight of lead, there is found to be a loss of eight hundred. This loss was explained by the old chemists on the supposition of the escape of a volatile substance called by them mercurial earth, but which was never proved to have any existence. The loss, however, ought to be attributed in some measure to the evaporation of part of the lead itself, and partly to the imperfection of the process, as it is seldom performed so accurately as to reduce the whole of the calx.

Lead is very rarely found native. It is sometimes found in the form of a calx, called native ceruse, or lead ochre, or in that of lead spar of various colours, and which are in general either rhomboidal or cubical. Lead combined with sulphur is called galena, which

is composed in general of laminæ which have nearly the colour and aspect of lead, but are more brilliant, and very brittle. A great variety of these ores have been discovered, which it will not be necessary to enumerate. One species however is too curious in its nature and effects to be omitted. It is called by the miners *slickensides*, and consists of galena united with phosphorated hydrogen. The mineral has the appearance of black marble, and breaks with a polished surface, not truly plane, but lying in waves. It is found in fissures of lime-stone in Haycliff and Lady-wash mines at Eyam, and in Oden at Castleton, in Derbyshire. It is divided into two equal parts or slabs, by a line parallel to the sides of the fissure, and these slabs are joined by two polished faces, which seem to be in perfect contact without any cohesion. The surfaces are of the colour of lead, but the covering is as thin as that from a black lead pencil. If a sharp-pointed tool, which the workmen call a pick, is drawn over the vein with some force, the mineral begins to crackle like sulphur excited by electricity; in a few minutes after which the laminæ explode with violence, and fly out as if they had been blasted with gun-powder, insomuch that the weight of forty tons has been blown out together. These dangerous effects deterred the workmen from proceeding for several years; but at length it occurred to them that this power might be used for the carrying on of their works with better advantage than by the common method of blasting with gun-powder. Accordingly a workman makes a scratch with his tool upon the joint of the slickensides, and runs away as fast as he can, to escape the explosion, which, it is said, loosens as much of the rock as ten men would have brought away in three months, by the ordinary methods.

From the component parts of this mineral, the reason of the explosion will easily be understood.—By the friction, the phosphorated hydrogen gas, which it contains, is inflamed, but being encumbered with the mass of galena with which it is united, the inflammation is rather gradual than instantaneous.

Lead, in some instances, has been found combined with various acids; the vitriolic, the phosphoric, the carbonic, and the arsenical. The ores of lead very commonly contain silver, and sometimes antimony.

In smelting lead ores the sulphur is dissipated for want of a proper apparatus for collecting it. According to bishop Watson's experiments, the Derbyshire lead ores contain in general from one-seventh to one-eighth part of their weight of sulphur. One of the chief circumstances to be attended to in the smelting of lead ores, particularly such as contain much sulphur, is to keep them for some hours in a moderate heat, by which that substance may be gradually dissipated. After this the fire must be raised to fuse the mass completely, by which the metal flows through the scoriæ, and is collected in the cavity at the bottom of the furnace. The scoriæ being then thickened by the addition of lime, so that they may be raked aside, a stopper is drawn out, and the lead suffered to flow into an iron pot, whence it is laded into moulds, which form it into the masses called pigs of lead.

Lead is soluble in the concentrated vitriolic acid, by the assistance of heat only. The lead then forms, with the vitriolic acid, a substance scarcely soluble in water. It seems to have a peculiar affinity with this acid, and leaves all others to combine with it, which is not the case with the other metals.

The nitrous acid acts strongly on lead. When the acid is concentrated, it corrodes the lead into a white calx;

calx; but if it is considerably diluted, it dissolves the lead. This solution does not afford a precipitate on the addition of water. Its crystals, obtained by cooling, are of an opaque white. This salt decrepitates in the fire, and melts with a yellowish flame when laid on ignited charcoal. The calx, which is at first yellow, is quickly reduced into globules of lead. The vitriolic acid added to this solution combines with the metal, and forms a precipitation. The marine acid, in the same manner, seizes the lead, and forms a combination, which, if exposed to heat, melts into a mass of a brown colour, called *plumbum corneum*, from some resemblance to the combination of the same acid with silver, called *argentum corneum*.

The acetous acid, or vinegar, acts on lead, particularly when applied to it in steam, in which process the action of the air probably assists that of the acid. To procure white lead, sheets of lead are rolled up spirally, so as to leave the space of about an inch between each coil, and placed vertically in earthen pots, which have some good vinegar at the bottom. The pots are covered, and exposed to a gentle heat for a considerable time by surrounding them with horse dung. The steams of the vinegar circulate in the vessel, and attach themselves to the surface of the lead, converting it into white flakes, which come off when the lead is uncoiled. The remaining lead is again exposed to the steams of the vinegar, till another crust is formed, and the process is repeated till its whole substance is converted into the white flaky matter called *ceruse*, or white lead.

Such are the deleterious effects of lead, when taken into the human body, that the wretched labourers in white lead works are seldom known to survive more than three years, when they expire in excruciating
pain

pain from the Devonshire colic, lose the entire use of their limbs, or gradually pine away by a wasting, marasmus. In a well regulated community such works ought to be entirely prohibited, or at least only carried on by the worst of felons, whose lives would be otherwise forfeited.

Lead, after being thus reduced to the state of ceruse by the fumes of the acetous acid, may be easily dissolved in the same acid in a fluid state, and the saline matter thus formed, is then called, from its sweet but astringent taste, sugar of lead.

To have this salt of lead in the form of transparent crystals, it is necessary to use much acid; if there is not a redundancy of acid, most of the crystals are small and mealy. This may be remedied by dissolving them again in distilled vinegar, and repeating the crystallization. In this manner so much of the acid may be united to the metal as to change the appearance of the salt to that of an oily fluid. This metallic salt, like others, may be decomposed by an alkali. In all these cases the precipitates of lead are white, but the calces are coloured.

The *saccharum saturni*, or sugar of lead, may be decomposed by heat alone, for, when exposed to a gradual heat, the acid rises in a very concentrated state. This process is attended with the remarkable phenomenon of the production of a quantity of ardent spirit*. To understand the causes of this phenomenon, it is only necessary to be informed that alcohol, or ardent spirit, is a combination of hydrogen, charcoal, and a small quantity of oxygen. Now all these principles

* By the phlogistic hypothesis this fact admitted of explanation, by supposing that the principle of inflammability of the metal combined itself with a portion of water, contained in the acetous acid, and thus formed alcohol, or spirit.

exist in vinegar, the basis of which is hydrogen and charcoal, brought to the state of an acid by their union with a large proportion of oxygen. The chief difference, therefore, between vinegar and alcohol is, that the former contains much more oxygen. As part of the oxygen, however, after this operation, is still retained by the lead, which is not reduced to its metallic form, it is very natural to suppose that part of the fluid which passes over should be reduced to the state of alcohol.

Nitre, heated with lead, calcines it into a yellow substance, but without producing deflagration. Sal ammoniac and common salt are decomposed by being heated with the calces of this metal, but the neutral salts, in general, are not acted on by it. Sulphur readily dissolves it by the assistance of heat, and produces a brittle compound of a deep grey colour and brilliant appearance. Phosphorus may be united with lead, and forms with it a malleable and soft compound, not very different in appearance from lead itself.

Lead combines with bismuth, and affords a metal of a fine close grain, which is very brittle. The alloy of lead with arsenic has not been examined. Nickel, manganese, cobalt, and zinc, do not unite with lead by fusion. With antimony it forms a brittle alloy, with some brilliant facets. Mercury dissolves lead with the greatest facility. Lead unites very easily with tin. Two parts of lead with one of tin form an alloy more fusible than either of the metals taken separately, and which is, therefore, used by plumbers as a solder.

Lead is used for a great number of economical purposes. Leaden vessels, however, are very apt to communicate injurious properties to all fluids which are kept in them for any length of time, and should wholly

wholly be rejected in the management of such fluids as contain an acid capable of acting immediately on the metal; as such fluids, if impregnated with even a small portion of lead, will be found, when taken into the body, irreparably to injure the constitution of persons who are in the habit of using them. Instances in which lead received into the body has produced the lingering and painful disorder called the painter's colic, or the colic of Poitou, are too numerous to leave any question as to the pernicious effects of this metal. The liquors in which an admixture of lead is most to be apprehended are, cyder, wines, and rum. In Devonshire, from the great use of cyder, and the improper methods of making it, by which, either through carelessness or design, lead becomes dissolved in it, the disorder above mentioned prevails so much, as to have obtained the name of the Devonshire colic.

It is unfortunately the case, that lead dissolved in vinous liquors is capable of imparting a rich and agreeable flavour to them, and even of restoring them after they have become considerably acidulated. The temptation to use lead, therefore, in this way, is great; and so long as dealers are ignorant of the pernicious effects of this metal, or want honesty to prefer the safety of their customers to their own profit, there is no reason to hope that the habit of occasionally using it will be abolished. The adulterating of wines in this manner was so common a few years ago in France, that it was unsafe for strangers to use the wines which were sold at their inns. It is very desirable to be furnished with the means of detecting this pernicious ingredient, and the following are recommended by an author, whose speculations even on the most common subjects have ever been directed to the public good, and are always productive of public advantage;

tage*: Boil together, in a pint of water, an ounce of quick lime and half an ounce of flowers of brimstone, and when the liquor, which will be of a yellow colour, is cold, pour it into a bottle, cork it up, and reserve it for use. A few drops of this liquor, being let fall into a glass of wine or cyder containing lead, will change the whole into a colour more or less brown, according to the quantity of lead which it contains; if the wine is wholly free from lead, it will be rendered in some measure turbid by the liquor, but the colour will be rather a dirty white than a blackish brown.

In general, a solution of common liver of sulphur will precipitate the lead, but unfortunately iron as well as lead is precipitated by both these tests, and it is said that many honest wine merchants have been ruined by this means, by having unjustly fallen under the suspicion of adulterating their wines with lead. M. Hannemann has published a paper in the *Journal de Physique*, in which he assures us, that the following liquor, whilst it does not precipitate iron, will precipitate lead and copper of a black colour, and arsenic of an orange. Mix equal parts of oyster shells and crude sulphur in fine powder, and put them into a crucible; apply a brisk fire in an air furnace, so as to make the crucible of a white heat for about fifteen minutes. The mass, when cold and powdered, should be kept in a bottle well corked. To prepare the

* Bishop Watson. This excellent and truly respectable author, this great ornament of the English church, will, I flatter myself, forgive the very free and frequent use I have made of his incomparable *Essays*. He has ever been

“Mihi magnus Apollo.”

“My guide, philosopher——”

and, if I was not afraid of presuming too far, I would add the conclusion of that well known line,

Liquor,

liquor, put one hundred and twenty grains of this powder, and one hundred and eighty grains of cream of tartar, into a very strong bottle, fill it with water, let it boil for an hour, and then cool. Cork the bottle, and frequently shake up the ingredients. After it has stood for some hours to settle, pour off the clear liquor, and put it into little bottles, which contain about an ounce; having previously dropped into each twenty drops of marine acid. Cork them close by means of wax mixed with a little turpentine. One part of this liquor, mixed with three parts of the wine supposed to contain noxious metallic particles, will discover, by a black precipitate, the smallest particle of lead or copper, but will not affect the iron contained in it. Pure wines are not discoloured by the addition of this liquor.

The deleterious effects of lead are not confined to its action on the stomach. Men who work in the manufactories for the different preparations of lead are liable to complaints very similar to those who drink liquors containing lead. Painters are so liable to this complaint, from the lead contained in paint, that it has obtained, on this account, the name of the painter's colic.

Lead is the most powerful article in the materia medica in restraining hemorrhages and excessive discharges, but its use is so dangerous that it is not very often employed internally by physicians. The preparations of lead are, however, highly beneficial, without being generally dangerous, as ingredients in plasters and other external applications, particularly in the well known Goulard's extract.

The calces of lead are used in making some kinds of glass, of which they increase the solidity, and to which they impart a kind of unctuousity which fits them for
being

being cut and polished with less danger of breaking. Lead enters particularly into the composition of flint glass, and the compositions called pastes, or artificial gems. The chief defect of flint glass is, that it is apt to be of unequal density, which renders it difficult to find pieces of any considerable dimensions free from striæ. Litharge is also employed by potters for glazing their ware.

The uses of red and white lead, as pigments, are well known. The common red wafers are coloured with red lead, as may be easily seen by holding one of them in the flame of a candle, when the lead will be reduced, and appear in little globules; these wafers should, therefore, never be left in the way of children, as they may be induced to swallow them, and may consequently subject themselves to all the ill effects arising from this fatal poison. The best red wafers are coloured with vermilion.

C H A P. XXXII.

C O P P E R.

General Properties of Copper.—Its Natural History.—Turquoise Gem.—Smelting and refining of Copper.—Antique Statues preserved by the Green Rust.—Union with Acids.—Blue Vitriol.—Colouring of Guns.—Cuprum Ammoniacum.—Verdigris.—Union with Metals.—White Copper.—Pinchbeck.—Gun Metal.—Bell Metal.—Metal of ancient Statues.—Bronze.—Speculums of Reflecting Telescopes.—Pot Metal.—Tinning of Copper.

COPPER is a metal of a peculiar red colour, and when its surface is fresh and clean it has a considerable degree of splendor. It is hard, ductile, and malleable to a considerable degree, and remarkably sonorous. It has a peculiar and unpleasant smell, particularly when rubbed. Its taste is styptic and nauseous. Its tenacity is such, that a copper wire of one tenth of an inch in diameter is capable of supporting a weight of about three hundred pounds. Its fracture exhibits the appearance of small grains. Its gravity is about nine times that of water.

Copper has a great degree of strength and rigidity, approaching to that of iron. It is not inflammable like iron, and is therefore used in gun-powder works; instead of that metal. It does not admit, like iron, of being welded, but this defect is compensated by its greater fusibility, by which it may be always formed into the desired shape. It requires for its fusion about the same heat as gold and silver. When in fusion, for which it requires a strong white heat, it appears of a blueish green colour, which arises from a flame of that colour on its surface. By a very violent heat it boils; and

and is volatilized partly in the metallic state. Copper, in a heat far less than is sufficient to melt it, becomes calcined at its surface, and exhibits various colours. In a greater heat than is sufficient to produce this effect, its surface is converted into thin scales, which may be easily scraped off.

Copper is sometimes found native, having the metallic splendor, the malleability, and all the properties of ordinary copper. It has sometimes the form of plates, sometimes that of fibres or branches, and is sometimes crystallized. Copper, in its metallic state, is sometimes found deposited on ores of iron, in which case it must be considered as having been separated from native vitriol of copper by the superior attraction of iron for the vitriolic acid. The native solutions of copper often deposit that metal in a calcined state in beds of calcareous earth. The turquoise stone is the tooth of an animal, penetrated with the blue calx of copper. Copper is generally found, however, in ores. These are frequently mineralized by sulphur. What are improperly called the vitreous ores of copper are of this kind; they are brown, red, and grey, and these colours are frequently mixed with a greenish or violet tinge. These melt easily, are very ponderous, may be scratched or even cut with a knife, and are very rich in metal, as an hundred pounds of them usually yields from eighty to ninety of copper. The azure copper ore differs from the former chiefly in containing a considerable quantity of iron. The grey copper ores, which have not much splendor, consist of copper, sulphur, arsenic, and some iron. What are called copper pyrites contain in reality more iron than copper, but yield enough of the latter metal to answer the expence of working them;

they are generally of a yellow and brilliant aspect. Copper is also, in some specimens, found united with slate, pitcoal, zinc, and antimony.

Copper is separated from its ores by different processes, according to the nature of those ores. If they contain much sulphur, after being pounded and washed, they are roasted in the open air to dispel the sulphur, which in a great measure supplies the want of other fuel. The ore is afterwards roasted once or twice more with wood, and is melted in an open fire into a mass called a mat of copper. In this state it still contains a large quantity of sulphur, which the workmen continue to expel by repeated roastings and fusions, till the metal acquires a certain degree of purity, and is called black copper, which is somewhat malleable, but still contains sulphur, iron, and generally some other impurities. In order to clear it entirely of these, the copper is hastily fused with three times its weight of lead. The lead unites with the copper and expels the iron, and the imperfect metals, which happen to be mixed with the copper, are expelled by cupellation. The copper is afterwards refined, by keeping it heated in crucibles for a considerable time, so that it may throw up all the foreign substances it still contains in the form of scoriæ. It is examined, from time to time, by immersing iron rods in it, which become coloured with a small quantity of copper, and its purity is judged of by the brilliant redness of these specimens.

Copper is not so easily acted on by the air as iron. In situations, however, where it is exposed to the action of moist air, it becomes gradually covered with a green rust or calx, which is sapid and soluble in water. This rust never penetrates into the substance of copper, but
seems

seems rather to contribute to the preservation of its internal parts, as may be seen in antique medals and statues of this metal.

Copper does not unite with earthy matters; its calx, however, promotes their fusion, and forms with them glasses of a deep brown. Caustic fixed alkalies, digested in the cold with filings of copper, assume, after a time, a light blue colour, the copper becoming covered with a powder of the same colour. Copper, treated in the same manner with volatile alkali, produces, in a few hours, a deep and most beautiful blue, the quantity of copper taken up being very inconsiderable. From the strong blue colour produced by the action of copper and volatile alkali, they become excellent tests of the presence of each other in any body; fluid or solid.

Copper is in general easily acted on by acids. The vitriolic acid, however, does not act on it unless concentrated and assisted by heat; it then corrodes the copper into a brown matter of a thick consistence; which, by the addition of water, affords a solution of a deep blue colour. If this solution is evaporated to a certain point; and suffered to cool, long rhomboidal crystals are afforded of a deep blue colour, called vitriolated copper, or blue vitriol; it appears therefore that vitriolic acid forms, with iron, green crystals; with zinc, white crystals; and with copper, blue crystals.

Copper may be obtained from the solution of blue vitriol, by dipping into it pieces of iron. The vitriolic acid dissolves the iron in preference to the copper, and deposits the latter, in its metallic form, on the surface of the iron. Upon this circumstance is founded the process for browning fowling-pieces. The barrels

are moistened with a solution of blue vitriol, which dissolves the iron to a very inconsiderable depth, and deposits in its place a thin lamina of copper.

Blue vitriol has a strong styptic taste, and is in some degree caustic. Exposed to heat it parts with its water of crystallization, melts, and becomes of a pale blue colour. A strong heat is required to separate from it the vitriolic acid, which adheres more firmly to copper than iron. Blue vitriol is decomposed by magnesia and by lime. If the mild vegetable alkali is poured into a solution of blue vitriol, a precipitate is formed of a pale blue colour, which, however, becomes green by exposure to air: in this experiment no effervescence takes place, and we may therefore conclude that the carbonic acid of the mild alkali unites with the calx of copper. Volatile alkali precipitates the solution of blue vitriol, in the same manner, of a blueish white colour; but the mixture very soon becomes of a deep blue colour, which happens from the alkali re-dissolving the precipitate. In order to obtain the *cuprum ammoniacum*, which has been recommended as a remedy for epilepsy, add volatile alkali till the whole precipitate of copper is re-dissolved, then set the solution before a fire in a flat vessel, and let it gradually evaporate, which should be done with a heat not exceeding that of the human body; the matter which remains at the bottom, in the form of a crust, must be rubbed in a mortar, that it may be intimately mixed.

The blue vitriol of the shops is made by means of the action of sulphur upon copper; these are gently calcined together: the sulphur attracts the oxygen of the atmosphere, and unites with the copper into a soluble powder, which is afterwards crystallized into blue vitriol.

A beautiful

A beautiful green paint may be precipitated from blue vitriol, by means of white arsenic dissolved in water together with vegetable alkali.

The nitrous acid dissolves copper with great rapidity, without the assistance of heat, with the production of a large quantity of nitrous gas. Part of the metal falls down in the form of a calx, and the filtrated solution, which is of a much deeper blue colour than the vitriolic solution, affords crystals by slow evaporation. This salt is more corrosive than vitriolated copper; it so powerfully attracts the humidity of the atmosphere that it deliquesces, unless kept in close vessels or in a very dry place. When melted in a crucible it emits large quantities of nitrous vapour and becomes brown, in which state it is merely a calx of copper. In a dry and hot air this salt becomes covered with a green efflorescence. It detonates lightly on burning coals.

The muriatic acid acts with great difficulty on copper in its metallic state, but dissolves its calces with considerable rapidity. This may be easily accounted for from the strong attraction which the basis of the muriatic acid has for oxygen, so that it will not part with any of it to oxygenate the metal, and no metal is soluble in acids without being oxygenated. When, however, the metal has been prepared for solution by an union with oxygen, that is by being calcined, the acid then dissolves it, and adheres very closely, so that it is with great difficulty separated by heat. The muriatic solution of copper is of an agreeable green colour, and affords crystals of the same, and in this particular differs remarkably from the vitriolic and nitrous combinations of copper, which are of a deep blue.

The vegetable acids dissolve copper when calcined,

but scarcely act on it in its metallic state. It is a curious circumstance, which has never been sufficiently explained, that vegetable acids act more powerfully on copper when cold than when they are heated. Thus pickles, or even lemon juice, may be boiled in clean copper vessels without danger; and yet, if left for a few hours, when cold, in copper vessels, they are apt to contract a metallic impregnation sufficient to produce dangerous effects. This fact has by some chemists been attributed to the steams of the boiling fluid keeping off the air, which is thought to assist the action of the acids.

Verdigris is a very beautiful green rust or calx of copper, much used by painters, and prepared in large quantities near Montpellier in France. The process for making verdigris was thus described by M. Monnet, of the Royal Society of Montpellier, about the year 1750. Vine stalks, well dried in the sun, are steeped, during eight days, in strong wine, and afterwards drained; they are then put into earthen pots, and wine is poured upon them; the pots are kept carefully covered. The wine undergoes the acetous fermentation, which in summer is finished in seven or eight days, but requires a longer time in winter, though this operation is always performed in cellars. When the fermentation is sufficiently advanced, which may be known by observing the inner surface of the lids of the pots, which, during the progress of the fermentation, are continually wet by the moisture of the rising vapours, the stalks are to be taken out of the pots. The stalks are by this method impregnated with all the acid of the wine, and the remaining liquor is only a very weak vinegar. The stalks are now drained some time in baskets, and layers of them are put into earthen pots with plates of Swedish copper, so disposed that

that each plate may rest on and be covered with layers of stalks. The pots are covered with lids, and the copper is thus left exposed to the action of the vinegar for three or four days or more, in which time the plates become covered with verdigris. The plates are then taken out of the pots, and left in the cellar three or four days, at the end of which time they are to be moistened with water, or some of the weak vinegar above mentioned, and left to dry. When this moistening and drying of the plates has been repeated three times, the verdigris will be found to have increased considerably in quantity. and it may then be scraped off for sale.

A solution or erosion of copper may be obtained by employing ordinary vinegar instead of wine, as is directed in the above process. It would not, however, have the unctuousity of the best verdigris, which quality is necessary for painting. Good verdigris cannot be prepared, except with a vinous acid, or a solvent partly acid and partly spirituous. Accordingly the success of the operation depends chiefly on the degree of acetous fermentation to which the wine has been carried.

By distilling verdigris, the acetous acid may be separated in a concentrated state, and of a strength equal, or perhaps superior, to the muriatic acid.

Copper is capable of a very slight detonation with nitre. It decomposes sal ammoniac, and at the same time the volatile alkali is in some measure resolved into its constituent parts, azote and hydrogen.

Sulphur and phosphorus may be united to copper; they deprive it of its metallic splendor, and change it to a black colour. If plates of copper are stratified in a crucible with sulphur, they unite, and form a compound which is used in the dying and painting of

calicoes. Liver of sulphur and hepatic gas have a strong action on copper; the former dissolves the metal by the dry, as well as by the humid way; the latter strongly colours the surface, but its effect has not yet been well examined into. Oils also dissolve copper, particularly those of an aromatic kind.

There are few metals which will not form alloys with copper. A metallic compound is made with copper and arsenic in imitation of silver, but it soon tarnishes. In treating of zinc, the process for making brass has been described. Pinchbeck is a kind of brass made in imitation of gold. Copper is the basis of gun metal and bell metal. Gun metal is said to consist of copper, with about one-tenth part of tin; bell metal, of copper with about one-fifth of tin. It may in general be observed, that a less proportion of tin is used for making church bells than clock bells, and that a little zinc is added for the bells of repeating watches, and other small bells.

Copper, in a state of fusion, is liable to a violent explosion if touched with any humidity. In the casting of bells and cannon they are particularly careful to have the moulds dry; for if the least moisture finds access, it is suddenly converted into vapour, and by its expansion throws the metal to a considerable distance, to the great danger of the persons present.

The best possible proportions of copper and tin, for the above purposes, have never, I believe, been accurately ascertained. The metallic compound used by the Romans for their statues and plates for inscriptions, is described by Pliny the naturalist. They first melted a quantity of copper; into the melted copper they put a third of its weight of old copper, which had been long in use; to every hundred pounds weight of this mixture they added twelve pounds and

an half of a mixture composed of equal parts of lead and tin. Tin melted with copper forms the compound called bronze. Of this compound the specific gravity is always greater than would be deduced by computation from the quantities and specific gravities of its component parts. There seems to be a happy relation^l between these metals, which fits them for forming, in conjunction, compounds of great firmness, density, and closeness. From these properties they admit of an excellent polish, and Pliny accordingly informs us, that the best looking-glasses of his time were made of a composition of copper and tin. But the attention of philosophers is more particularly directed to the mixture of copper and tin, on account of its being the substance of which the speculums of reflecting telescopes are made. Mr. Mudge found, after a number of trials, that fourteen ounces and an half of grain tin, with two pounds of copper, made the best composition for this purpose; an addition of half an ounce more of the tin rendered the composition too hard to be properly polished.

Pot metal is made of copper and lead, the latter being one-fourth or one-fifth of the weight of the former. Lead, however, does not seem to have any remarkable attraction for copper, and does not promote its fusion, unless the lead is heated to a high degree; the copper then dissolves with some degree of effervescence. On allowing the compound to cool, the copper separates again, and forms little grains in the mass, through which the lead remains dispersed. It is easy to separate the lead again from the copper, if the mass is exposed in a furnace; for the lead melts first and leaves the copper; the lead, however, which runs off at first, contains some of the copper, which may be easily separated by melting the lead and taking off the
scum,

scum, which contains the copper. Silver is separated from copper by melting the latter with three times its weight of lead; the lead is then melted out, and carries with it the silver. The silver is afterwards separated from the lead by the calcination of the latter metal.

From the pernicious effects which have been experienced from impregnations of copper in aliments dressed in copper vessels, it has become a very general custom to cover these vessels with an internal coat of some other metal. The method of tinning iron has been described, and that of tinning copper is very similar, except that the composition for covering the surface of copper consists of about one part of lead to two of tin, whereas iron is covered with tin alone. Zinc has been recommended as a substitute for tin in these operations, and has the advantage of superior hardness. The method of tinning copper vessels is by making their internal surface perfectly bright, and then washing them with a solution of sal ammoniac. The vessel is next heated, and the tin or metallic mixture is melted and poured into it, and being made to flow over every part of the surface of the vessel, it incorporates with the copper, and when cold remains united with it. Rosin, or pitch, are sometimes used to prevent the tin from being calcined, and the copper from being scaled, either of which circumstances would prevent the adhesion of the tin. Bishop Watson estimated the quantity of pure tin which is used in tinning a definite surface of copper, and found that half an ounce of tin was spread over two hundred and fifty-four square inches, or somewhat less than a grain of tin on each square inch; but the same author suspects, that not a quarter of a grain of tin is spread over a square inch in the ordinary mode of tinning, and therefore recommends it as a necessary caution against the coat being rubbed off,

off, and the copper becoming exposed, to make it as thick as possible, and to use tin nearly pure.

A very excellent method of tinning, and one much practised in England, is, to make use of pure tin, and hammer it on the copper. It seems probable, however, that when copper vessels are kept well scoured, that no danger will arise from them in the dressing of animal food, or even of vegetable aliments, unless suffered to remain in the vessels when cold.

C H A P. XXXIII.

M E R C U R Y.

Great Attraction of this Metal for the Matter of Heat.—Quicksilver; rendered solid; malleable.—General Properties of Quicksilver.—Hydrargyrus calcinatus.—Natural History of Mercury.—Cinnabar.—Native Vermilion.—Action of Acids on this Metal.—Turbit Mine-ral.—Red Precipitate.—White Precipitate.—Corrosive Sublimate.—Calomel.—Keyser's Pills.—Ethiop's Mineral.—Vermilion.—Amalgams.—Gold made brittle by Mercury.—Mode of gilding Metals.—Use of Quicksilver in extracting the precious Metals from the Earth.—Making of Looking Glasses.—Conditions necessary for the Operation of Mercury on the human Body.

THE circumstance which most remarkably distinguishes mercury, or quicksilver, from the other metals, is its strong attraction for caloric, so that it retains the state of fluidity at the ordinary temperature of the atmosphere, and at the temperature of 600 degrees of Fahrenheit is converted into vapour; few of the other metals, therefore, melt at so low a point as that at which mercury boils and is volatilized. It was long taken for granted that there was something peculiar in mercury, which rendered it necessarily fluid; but the academicians of Petersburg have proved that this is an erroneous idea, and have shewn that mercury differs from other metals merely in the degree of heat at which it passes from its solid to its fluid state. The congelation of mercury has been effected in a variety of instances by the help of the nitrous acid and snow, or pounded ice, commonly called the freezing mixture, and the congelation is found to take place at the thirty-ninth degree below 0 of Fahrenheit's thermometer. Mercury, in its solid form, is found to have considerable

considerable malleability, but this cannot be proved to its fullest extent, because the hammering of it produces very soon a degree of heat sufficient to melt it.

Mercury being a metal in a state of fusion, always affects the form of globules when it is divided; and when it is confined in a bottle, its surface is convex, from the strong attraction of its particles for each other. If the vessel, however, in which mercury is confined, is metallic, its surface appears concave, from the tendency which it has to unite itself to the sides of the vessel, which attraction overcomes that between its own particles.

When mercury is submitted to that degree of heat at which it is volatilized, and is at the same time exposed to the action of atmospherical air, it is gradually converted into a calx of a red colour, the hydrargyrus calcinatus of the London Pharmacopeia. A greater heat, however, revives this metallic calx, and at the same time the vital air is again extricated.

Mercury is not sensibly acted on by exposure to air, but by long continued agitation it becomes partly converted into a very fine black powder. The mercury is not changed in this experiment, unless, perhaps, it should be found that it absorbs some part of the vital air contained in the vessel in which it is confined. By a slight heat, or by trituration in a warm mortar, it may be made to resume its usual fluidity and brilliancy.

Mercury is found in the earth, either in its native metallic state, or combined with sulphur, when it is called cinnabar. Running mercury is found in globules, or larger masses, in friable earths or stones, and most commonly in the clefts or cavities of its ores. It is more frequently, however, imbedded in calcareous earths

earths or clays of different colours, from which it may be separated either by trituration or lotion, the smaller globules coalescing by mutual contact into larger; or by distillation.

More mercury is found in the state of cinnabar than in its metallic form. This ore consists of mercury and sulphur combined together in different proportions. Cinnabar is sometimes found in the form of a brilliant red powder, and is then called native vermilion, sometimes in an indurated state, and though generally red, has been sometimes observed of a yellowish or blackish cast. It is mostly opaque, but some specimens are as transparent as a ruby.

Mercury is too volatile to admit of the sulphur being separated from it by roasting; these substances are both so volatile that they would rise together. In order to separate mercury from its ore it is necessary to add quick lime, or iron filings, unless some substances of a similar nature happen to be naturally mixed with it; the mass is then submitted to distillation, and the calcareous earth, or iron filings, by superior attraction, detain the sulphur, while the mercury comes over in the state of vapour, and is condensed in the receiver. Different cinnabars yield from three parts to seven parts in eight of their weight of mercury. Mercury has sometimes been found united with the muriatic and vitriolic acids, and with the ores of some other metals. It is thought to be not abundant in nature; but this opinion may be partly owing to its volatility, which may prevent it from being discovered in many minerals that may contain it. Most of the mercury in commerce is afforded by the mines of Idria in the Austrian dominions, Almaden in Spain, and Guanacavelica in Peru.

The vitriolic acid does not act on mercury unless concentrated

concentrated and considerably heated; it then corrodes it into a white mass, and the vitriolic acid is rendered partly volatile by the abstraction of oxygen. The greatest part of this mass, which weighs considerably more than the mercury made use of, is a calx of mercury united to a small portion of vitriolic acid, but part of it is a perfect salt, formed by the union of the vitriolic acid and mercury. If boiling water is added to it, it assumes a bright lemon colour, which is owing to the abstraction of the vitriolic acid, the presence of which rendered the mass white. The more boiling water is used the yellower is the remaining powder, which, after repeated effusions of water, is found to have no causticity, and to be nearly a pure calx of mercury. This is the substance known under the name of turbith mineral. The water, which has been poured on the vitriolic mercurial mass, is found to contain a considerable quantity of vitriolic acid united to the calx of mercury.

The nitrous acid is decomposed by mercury with the greatest rapidity. Strong nitrous acid will take up its own weight of mercury in the cold, and this solution will bear to be diluted with water. If the solution is made by the assistance of heat, a much larger quantity is dissolved; but a precipitate is produced by the addition of water. If cold water is employed, a white precipitate is afforded, but if hot water the precipitate is of a yellow colour, and greatly resembles the turbith mineral produced by the vitriolic acid. If acid is added to the solution produced by heat, it is not decomposed by water. This solution is very ponderous and acrid, and stains the skin of a deep purple, inclining in appearance to black, a portion of the mercury being precipitated by the animal matter, while the acid acts on it. Caustic alkali,
added

added to this solution, precipitates a pure calx; mild alkali, a calx combined with carbonic acid. The volatile alkali precipitates the mercury in the form of a dark grey powder. When this precipitate is examined, it is found to contain a quantity of uncalined mercury. For if this matter is dried and rubbed on pure gold, it turns white, by which we may discover small quantities of mercury in the metallic state. The near approach to the metallic state, observed in the precipitate afforded by the volatile alkali, seems to be owing to the presence of hydrogen, which is one of the constituent principles of volatile alkali, and which has a strong attraction for oxygen.

The precipitates of mercury, formed by alkaline intermediums, have a property discovered by M. Bayen, which must not be passed over in silence. They detonate like gun-powder, when exposed in an iron spoon to a gradual heat, after having been triturated in the quantity of half a drachm, with six grains of flowers of sulphur: after the detonation, a violet powder remains, which may be sublimed into cinnabar.

The nitrous acid may be separated from mercury by heat alone. Its first effect is to evaporate the watery parts; after this the acid flies off in deep coloured fumes; as the acid evaporates the calx becomes yellow, then of a deep red, but when removed some time, orange. This is the red precipitate of the shops. The nitrous acid, therefore, as in the case of other metals, though it acts with more rapidity, adheres with less force to the mercury than the vitriolic acid, which acts slowly and with difficulty. This proceeds, as was before mentioned, from the ease with which the nitrous acid is decomposed, so as to afford to metals the oxygen which is necessary to render them soluble.

The

The muriatic acid has no action on mercury in its metallic state, because that acid cannot part with the oxygen necessary to calcine the metal. It has, notwithstanding, a very strong attraction for mercury, and dissolves it with great readiness when the latter is previously reduced to the state of a calx. If a small quantity of muriatic acid is poured on a nitrous solution of mercury, it seizes the metal, and forms a salt, which is precipitated in the form of a whitish coagulum, which, when dried, is called white precipitate, and is a kind of corrosive sublimate. The marine salts, with a basis of alkali, or of any saline terrestrial substance, such as lime, magnesia, &c. produce the same effect, except that in this case, though the precipitate is the same, the nitrous acid, instead of being left uncombined, unites with the basis of the marine salt which was employed.

If mercury, corroded by the vitriolic or nitrous acids, and dried, is mixed with powdered sea salt, and exposed to heat, a double attraction takes place; the nitrous or vitriolic acid deserts the metal to unite with the fixed alkali of the common salt, while the muriatic acid seizes upon the mercury, and forms a metallic salt, which, in the degree of heat necessary for the operation, proves volatile, and, rising in vapour, is condensed in a solid form in the upper and cool part of the vessel employed. This is the hydrargyrus muriatus, or corrosive sublimate, which is a very acrid and powerful preparation of mercury.

The mild preparation, called calomel, is obtained by rubbing three parts of mercury, in its metallic state, with four of corrosive sublimate, till they form a greyish powder; the mass is then sublimed*, and forms a substance like corrosive sublimate, but more ponderous,

* Made volatile, or raised in vapour, by the application of heat.

and of a more silvery appearance. The ingredients, however, are not sufficiently mixed by the first sublimation; they must be rubbed together again and sublimed; and these processes must be repeated at least three times.

The conversion of the corrosive sublimate into the milder substance, calomel, may be explained on the following principles:—In the corrosive sublimate, the muriatic acid is found to be combined with a very large quantity of oxygen, which renders it extremely active. By the addition of mercury, a quantity of this superfluous oxygen is abstracted, for the calcination of the additional metal; and the whole mass, therefore, contains the acid not only in a milder state, but the same quantity of acid is diffused through a larger mass of the metal.

Ponderous earth, magnesia, and lime, decompose the corrosive sublimate, and precipitate a mercurial calx. The phagedenic water, made use of as a corrosive by surgeons, is made by throwing half a drachm of corrosive sublimate, in powder, into a pound of lime water; a yellow precipitate is then formed, which renders the liquor turbid.

Acids and neutral alkaline salts produce no change on corrosive sublimate, but it contracts an intimate union with sal ammoniac without decomposition. The sal ammoniac renders corrosive sublimate very soluble. The calx hydrargyri alba of the London Pharmacopeia is obtained from this combination. A quantity of sal ammoniac is dissolved in distilled water; an equal weight of corrosive sublimate is then added; when this is dissolved, fixed vegetable alkali is added, which produces a white precipitate. In this operation the fixed alkali disengages the volatile alkali of the sal ammoniac, which precipitates the mercury in the form

of a white calx. This preparation is chiefly used in liniments externally. It is sometimes adulterated with ceruse, as the red precipitate is with minium. The fraud may be discovered by exposing a small quantity to heat in a spoon; if pure they will be entirely dissipated, but if they contain lead, or other impurities, these matters will remain behind.

If the salt formed by the combination of acetous acid with the fixed vegetable alkali, commonly called regenerated tartar, or kali acetatum, is added to the solution of quicksilver in the nitrous acid, a double exchange takes place; the alkali unites with the nitrous acid, while the acetous acid enters into combination with the mercury, and is precipitated. This precipitate (being purified by solution in hot distilled water and filtration) has nearly the same medical properties as calomel, and is said to form the basis of Keyser's pills. The acetous acid does not act on mercury unless the latter is reduced to the state of a calx.

As mercury is commonly, in a state of nature, combined with sulphur, so it may be artificially united to it with great ease. When one part of this metallic fluid is triturated with three parts of flowers of sulphur, the mercury gradually loses its metallic appearance, and is converted, by its union with the sulphur, into a black powder, called Ethiop's mineral. This combination is more quickly effected by mixing the mercury with melted sulphur. When this compound is exposed to a considerable degree of heat it takes fire, the greater part of the sulphur burns, and after the combustion a matter remains, which when pulverized, is of a violet colour. To convert this powder into cinnabar it is put into matrasses*, which are heated till

* Vessels used in chemical operations, of glass or earthenware, generally of the shape of an egg, and open at the top, the necks are long or short, as occasion may require.

their bottoms become red, and kept in this state for several hours, till it appears that the matter is entirely sublimed. The Dutch prepare, in the large way, the cinnabar employed in the arts. When much divided by levigation * it has a brilliant red colour, and is called vermilion.

Mercury has the property of uniting itself to many of the metals, by penetrating their substance, and rendering them more or less soft, according to the proportion of mercury employed. If the proportion of quicksilver is very great, the mixture is like quicksilver, and is only distinguished from it by an appearance of foulness. If a smaller quantity is used, the mass is soft like butter; if still less, it is solid but brittle. These mixtures are called amalgams. It readily combines in this way with gold, silver, lead, tin, bismuth, and zinc, but not easily with arsenic and copper, and scarcely at all with iron, platina, nickel, or cobalt. Its action on the other metallic bodies has not been ascertained.

A piece of gold, being rubbed with quicksilver, is soon penetrated by it, and is rendered so fragile that it may be easily broken. A gold ring, which has become so tight on the finger that it cannot be drawn off, may be easily removed in this manner. Gold, united with quicksilver in certain proportions, forms a kind of paste. On this property is founded the process of gilding in *or moulu*. A small quantity of this paste is spread upon the surface of the copper which is to be gilded in *or moulu*, and the metal is then exposed to heat. Quicksilver evaporates in a far less degree of heat than is sufficient to melt either gold or copper; when, therefore, the mixture of gold and quicksilver is exposed to heat, the quicksilver is driven off in vapour; but the gold not being susceptible

* Reduced to a fine powder.

of evaporation, remains attached to the surface of the copper, and undergoing the operations of burnishing, &c. the latter is gilded, or gilt. This method of gilding copper, by means of gold and quicksilver, was known to the Romans. The surface of iron cannot be covered in the same way with gold; but the iron, by being moistened with a solution of blue vitriol, as in the process for browning firelocks, and being thus covered with a lamina of copper, becomes as susceptible of being gilded as if its whole substance was copper.

It is this property which quicksilver has of uniting with the precious metals, and dissolving them, which has rendered it so serviceable in the extraction of them from the earth with which they are mixed. The earth or stones, in which gold and silver are contained, being reduced to powder, are mixed with quicksilver, which dissolves every particle of the precious metals without contracting the least union with the other matters; the quicksilver is then driven off by heat, and, being condensed in the receiver, is again employed in the same process. The gold and silver are separated from each other by processes, which will be described in treating of those metals. Since the discovery of the American gold mines, the consumption of quicksilver has been much increased. Hoffman concludes, from calculation, that fifty times as much gold as quicksilver is annually extracted from the bowels of the earth.

Looking glasses are covered on one side with an amalgam of tin and mercury. Tin, being beaten into thin leaves, is called tin foil; on tin foil, evenly disposed on a flat stone, quicksilver is poured, and spread with a feather until its union has brightened every part of it; a plate of glass is then cautiously slid upon the tin foil, in such a manner as to sweep off the redundant quicksilver which is not united to the tin; weights are

then placed on the glass so as to press out still more of the quicksilver, and in a little time the tin foil, thus united to the quicksilver, adheres so firmly to the glass that the weights may be removed without any danger of its falling off. About two ounces of quicksilver are used in covering three square feet of glass.

In order to make mercury capable of acting on the animal body, it is necessary that it should undergo some preparation; for its particles must be very minutely divided before they can enter the vessels. Thus, if we apply quicksilver to a capillary tube, the attraction of its particles for each other is so strong that they will not rise in it; but minute division is not the only circumstance necessary to its activity, for Ethiop's mineral and cinnabar taken into the body have very little if any effect. Oxygenation seems to be the most essential circumstance; for in whatever way this is effected the mercury becomes very active*.

Mercury, in passing through the body, is reduced to the metallic state, and, exuding through the pores, sometimes attaches itself to the gold of watches, rings, sleeve-buttons, or ear-rings, and renders them white.

* Does not the effect of sulphur, in diminishing the activity of mercurial preparations, depend on its superior attraction for oxygen, by which it has a tendency to reduce the mercury to the metallic state?

C H A P. XXXIV.

S I L V E R.

Character of the perfect Metals.—General Properties of Silver.—Vegetation of Silver.—Natural History of Silver.—Assaying of Silver.—Cupellation.—Lunar Caustic.—Fulminating Silver.—Luna Cornea.—Diana's Tree.—Green Gold.—Standard Silver Coin.—Plating with Silver; how performed.—French Plate.

OF the different metallic substances only three have been dignified by chemists and mineralogists with the appellation of perfect, viz. silver, gold, and platina. These are distinguished from the other metals by their weak attraction for oxygen, which enables them to retain their purity and metallic splendor in situations in which other metals become gradually covered with rust or calx. Silver is the whitest of all metals, and is possessed of great brilliancy; it is harder than gold; in weight it is exceeded by gold, platina, quicksilver, and lead; its gravity being only about ten times that of water. Its malleability is so great, that a grain of it reduced to ordinary silver leaf measures about fifty-one square inches, in which state it is not more than the hundred and sixty thousandth part of an inch thick, which, however, is considerably more than one third thicker than gold leaf. Its tenacity is so considerable, that it may be drawn into wire about half the thickness of a fine human hair, and a wire of one tenth of an inch in diameter will support the weight of two hundred and seventy pounds without breaking. It is very sonorous, but in hardness and elasticity it is not equal to copper. It

hardens under the hammer, but very readily loses that hardness by heating.

Silver, exposed to the heat of the most powerful burning lenses, is partly vitrified and partly volatilized in fumes, which are found, when received on a plate of gold, to be silver in the metallic state. It is likewise said to have been partly calcined by twenty successive exposures to the heat of the porcelain furnace at Sèvres. This, however, may be doubted, as silver does not undergo any degree of calcination by exposure to heat, even with the addition of nitre. Silver melts in the first degree of white heat, and appears in the fire like the finest quicksilver. When it is hastily cooled, it exhibits a curious phenomenon, called vegetation; for we discover from different parts of its surface ramifications and branches like those of trees which sprout out with a stem. The reason of this appearance seems to be the irregular contraction which the silver undergoes in passing from the fluid to the solid state. The melted silver suffers the first commencement of congelation at its surface; by these means a crust is formed, which by its sudden contraction compresses the fluid silver within; thus a protuberance is formed, which, congealing in its turn, contracts and presses the intermediate fluid through its crust into branches.

The air alters silver very little, unless it contains sulphureous vapours, which it often does, from the putrefaction of animal substances or the exhalations of drains, or of sulphureous mineral waters. This metal, therefore, becomes somewhat tarnished by long continued exposure to the atmosphere, and in time becomes covered with a thin purple or black coating, which, after a long series of years, has been observed to scale off from images of silver exposed in churches,
and

and was found, on examination, to consist of silver united to sulphur.

Silver is often found in its native state, and may be known by its brilliancy and ductility. It is sometimes met with in irregular masses, sometimes in the form of capillary threads or fibres, and sometimes in that of branches, formed by octahedrons inserted one into the other. It is also often dispersed in a quartzose gangue*. Native silver is sometimes found alloyed with gold, copper, iron, or regulus of antimony; but native gold much oftener contains silver than native silver does gold. Silver is not naturally found in the state of calx.

The vitreous ore of silver is composed of that metal and sulphur. It is the richest of the silver ores, and yields from seventy to eighty pounds of the metal in the hundred weight. It is of a blackish grey colour, resembling lead; some specimens are brown, greenish, yellow, &c.; it may be cut with a knife, and is sometimes crystallized. If it is exposed to a heat not sufficient to melt it, the sulphur is dissipated, and the virgin silver is obtained in fibres.

The red silver ore contains arsenic as well as sulphur. It is a heavy shining substance, sometimes transparent, sometimes opaque, but commonly crystallized. It is often of a deep red colour on the outside, but appears paler within. It affords about half its weight of silver. If it is exposed to a fire carefully managed, and capable of igniting it, the silver is reduced, and forms capillary fibres, similar to native silver.

There is a silver ore containing arsenic, cobalt, and iron, mineralized by sulphur. This ore sometimes

* A quartzose or sparry crystallization, often found inclosing the ores of metals, and therefore called the matrix or rider.

yields half its weight of silver; it varies in its appearance, being sometimes of a grey and brilliant aspect, but often of a dull and tarnished colour, with efflorescences of cobalt. The goose dung ore belongs to this species. The grey ore of silver contains a large quantity of copper. The black silver ore, called *nigrillo* by the Spaniards, seems to be a middle state between native silver and some of its ores, or those ores in a state of imperfect decomposition. The corneous silver ore is a natural combination of silver and muriatic acid with a small quantity of vitriolic acid. Silver is also found in considerable quantity in the ores of other metals, particularly those of antimony, zinc, lead, and copper.

In the assaying of silver ores different processes are used, according to their nature. When found in its metallic state, nothing more is necessary than to separate it from the earthy or stony matter in which it is embedded. With this view it is first exposed to heat, to render the stony matter friable. The mass is then mixed and ground with quicksilver. Thus the silver is converted into an amalgam, which, from the intimate union of the particles of the metals, is specifically heavier than quicksilver itself. The stony matters are now easily washed off, without losing any of the metal. The quicksilver is afterwards partly separated by squeezing it through a piece of leather, and the remainder by distillation. Sulphureous silver ores require to be first roasted, and then mixed with a quantity of flux. In order to separate lead, copper, iron, &c. from silver, a particular process is employed, which is called *cupellation*, from the vessel in which it is performed, called a *cupel*, and which is chiefly formed of calcined bones, and is very porous. The metallic mass containing silver is mixed with a considerable

derable quantity of lead, and then exposed on the cupel in a state of fusion. The lead is vitrified and absorbed into the cupel, carrying with it the imperfect metals, and the silver remains behind on the cupel in a pure state.

The vitriolic acid acts on silver as on the other metals, with the assistance of heat; it then corrodes it into a white mass, which is soluble in water, and by evaporation affords small crystals.

The nitrous acid dissolves silver with great rapidity. When the strong nitrous acid is diluted with an equal weight of water, it is capable of dissolving about half its weight of silver. If the silver employed is quite pure, the solution is limpid like water; but as silver commonly contains a little copper, its solutions have usually a blueish tinge. If the silver employed contains gold, in this case, as the nitrous acid is not capable of dissolving the gold, it separates from the silver in the form of blackish flocks. From this difference in the action of nitrous acid on silver and gold, it is successfully used to separate these metals from each other.

The solution of silver in the nitrous acid is extremely bitter and caustic, and has the property of changing the skin or hair to a black colour, or, if very much diluted, to a brown, and formerly, when the caprice of fashion abhorred light hair as much as it at present admires it, was employed for that purpose. The colour is, however, very faint when the solution is first applied, and the production of colour seems in a great measure to depend on the action of light. Dr. Lewis mentions a remarkable phenomenon, which this solution presents when added to chalk or any pure absorbent earth. The chalk and solution are both at first quite white, and will continue so if kept in a dark place,

place, but if exposed to the light they soon become black; so that if a quantity of this mixture is put into a glass phial sealed up, any marks or letters may be made to appear on it as if by magic. To effect this, the phial is covered with thick paper, in which the marks or letters are nicely cut, and it is then exposed to the light, which, acting only through the apertures of the paper, produces the effect. When the stains are produced, aqua fortis, by re-dissolving the silver, will make them disappear again. It therefore seems, that the production of colour is owing to an imperfect reduction of the silver, and that the action of light disengages oxygen from this compound in the same manner as it does from the pale nitrous acid, and from vegetables.

When this solution of silver is evaporated with a gentle heat, it may be made to afford crystals nearly resembling those of nitre. These, being melted in a crucible, are freed from water, and being poured into moulds of a convenient form, become the silver or *lunar** caustic, or *argentum nitratum* of the pharmacopœia.

Silver is never given internally, and this is the only preparation of it made use of externally. The nitrous acid may be entirely separated from this compound by heat alone.

Silver, however, is most conveniently separated from its nitrous solution by immersing plates of copper in it. The copper is then dissolved, while the silver is deposited in its metallic state. This metal may be separated from gold by exposing the mixed metals to

* A name derived from the whim of the alchemists, who called the metals by the names of the heavenly bodies: gold, Sol; silver, Luna; copper, Venus; iron, Mars (whence martial vitriol, &c.); lead, Saturn; tin, Jupiter; quicksilver, Mercury, &c.

the action of nitrous acid, which dissolves the silver and leaves the gold, and the above method is used to obtain the silver from the acid.

To make the famous fulminating silver, which is so truly formidable in its effects, a small quantity of silver is dissolved in pale nitrous acid (or aqua fortis) from which it is precipitated by lime water. The calx or precipitate is to be dried by exposure to the air for three days. The inventor, M. Bertholet, supposes the action of light to have also some influence in the success of the experiment*. The dried calx is then agitated in a solution of the caustic volatile alkali, when it assumes the form of a black powder, which is left to dry in the open air. The fulminating silver then consists of an union of the calx of silver with volatile alkali.

The effects of this preparation are tremendous, and infinitely exceed those of gunpowder, fulminating powder, or fulminating gold. It explodes with the slightest agitation or friction. The falling of a few atoms of it from a moderate height produces a violent detonation, and a drop of water falling upon it has the same effect. When it is once fully prepared, it must not be touched or moved into any other vessel, but must remain in that in which it was dried; and to make the experiment with tolerable safety, not more than a grain of silver should be employed in the process. The cause of these explosions has been already intimated in the chapter on ignition, and will be further illustrated in treating of fulminating gold.

Though the nitrous acid dissolves silver with greater ease, it has not so strong an attraction for it as the muriatic or vitriolic acids. Either of these, dropped

* Journal de Physique for June 1788, p. 474.

into the nitrous solution, seize the silver, and forming a compound not equally soluble produce a precipitation. The neutral salts, containing vitriolic or muriatic acid, have the same effect. This difference of affinity between the acids and silver is the foundation of a process for obtaining the nitrous acid in a state of great purity. The solution of silver in nitrous acid is poured into the impure nitrous acid till no more precipitate is formed. The muriatic or vitriolic acids contained in the mixture are thus carried to the bottom by their union with the silver. The acid is then decanted and distilled to free it from the small quantity of salt of silver which it may still contain.

Notwithstanding the muriatic acid has the strongest affinity with silver of all the acids, it is nevertheless incapable of dissolving it unless the metal is in a calcined state, or itself superoxygenated. The common method of effecting this union is to add to the solution of silver, in the nitrous acid, any saline substance which contains the muriatic acid; it is no matter to what the acid is joined, whether alkali, earth, or metal; it immediately seizes the silver, and leaves the other matter to unite with the nitrous acid. Common salt is generally used, and the white precipitate, which is immediately formed, has the appearance of a coagulum. The compound thus made is so insoluble in water, that there cannot be a nicer test of the presence of the muriatic acid, or common salt, in waters, than the nitrous solution of silver; for if the most minute quantity of either are present a precipitation is produced.

This compound has many other qualities besides insolubility in water. If we collect it, and wash off the saline matter, it appears as a fine powder, and, when heated to a sufficient degree, melts into a substance of some transparency. From its transparency,
flexibility

flexibility, and softness, it is called *luna cornea*, or *argentum corneum*, and from this several other compounds of metals with the muriatic acid have been called *cornea*. It may be cut into transparent vessels resembling glafs.

Aqua regia, or the compound of nitrous and muriatic acids, acts strongly on silver, but forms a precipitation in proportion as it separates it from the mass. This effect may be readily understood from what has already been observed. The nitrous acid dissolves the silver, and the muriatic seizes it, and forms *luna cornea*, which is insoluble. This process may be used to separate gold from silver; the gold is held dissolved in the aqua regia, but the silver is precipitated.

After silver has been reduced to the calciform state by solution in nitrous acid, and precipitation by alkalis, it is capable of solution in vinegar, and even in lemon juice; but these compounds have not been applied to any use.

To have silver perfectly pure we must use quicksilver, which, if poured into a solution of silver, is attracted by the acid, and precipitates an amalgam with the silver at the bottom of the vessel. The quicksilver is easily separated from the silver by heat alone. A curious phenomenon arises from this amalgam; a kind of crystallization takes place, which is formed by the union of the silver with the running mercury. The amalgam puts forth shoots, which afterwards put forth others, like the branches of a tree. The crystallization varies according to the conduct of the process, and does not always answer, particularly if the mixture is shaken. It is called *arbor Dianæ*, or Diana's tree*. The method of making it most beautiful

* Diana's tree, from the whim of the alchemists already noticed, who appropriated silver to the Moon or Diana, as stated in a preceding note.

is very tedious, and would require the space of a month.

This phenomenon seems to admit of explanation precisely on the same principle as the branching of pure silver when passing from its fluid to its solid state. The amalgam of silver and mercury is specifically heavier than either of the metals in a separate state, and their union must consequently be attended with contraction. The silver, therefore, being precipitated on the surface of the mercury, in proportion as the latter metal is dissolved by its superior attraction for the acid, the mercury becomes surrounded with a crust, the contraction of which forces out its fluid contents; the excrescences thus produced being in their turn covered with a crust of amalgam, are again compressed, and produce smaller protuberances, and if the experiment is properly conducted, the brittle amalgam of the metals assumes a crystallized appearance, and the form of a thick bush. In this experiment it is necessary that there should be not only as much mercury as is sufficient to precipitate the silver, but besides this a quantity remaining in its fluid state, to unite with the precipitated silver into an amalgam.

Sulphur has a remarkably strong affinity with silver, and forms with it a compound which has the appearance and softness of lead. This metal seems also capable of attracting sulphur from antimony. But though silver has so strong an attraction for sulphur, gold has none, and this furnishes a method of separating these metals by fusion.

With gold, silver forms a pale alloy, the green gold of the jewellers and gold beaters. This mixture, however, is not made without some difficulty, on account of the different specific gravities of the two metals. It does not unite well with platina. It forms an alloy
with

with iron, but the properties of it have not been well examined into. With lead it forms an alloy, which is much more fusible than pure silver, and seems in all respects to be of an intermediate nature between these metals. Copper increases the hardness of silver, and renders it more sonorous, without impairing its ductility or colour, when the copper does not exceed the twelfth part of the weight of silver employed. The standard of silver coin is eleven ounces two pennyweights, troy, of silver, and eighteen pennyweights of copper.

The purity of silver cannot be accurately ascertained without submitting it to cupellation with lead, and its purity is calculated according to the weight it loses in that process. Silver is divided into twelve imaginary parts, called pennyweights. If it only loses one twelfth part of its weight by cupellation, it contains eleven twelfths of pure silver, and is said to be eleven pennyweights fine; if it loses two twelfths, it is ten pennyweights fine, and so of other proportions. For greater accuracy, each pennyweight is supposed to be divided into twenty-four grains.

The covering of the surface of copper with silver, or plating, is performed in the following manner: ' Upon small ingots of copper, plates of silver are bound with iron wire, generally allowing one ounce of silver to twelve ounces of copper. The surface of the plate of silver is not quite so large as that of the copper ingot. Upon the edges of the copper, which are not covered by the silver, a little borax is put, and by exposing the whole to a strong heat, the borax melts, and in melting contributes to melt that part of the silver to which it is contiguous, and to attach it in that melted state to the copper. The ingot, with its silver plate, is then rolled under steel rollers, moved

by a water wheel, till it is of a certain thickness; it is afterwards rolled by hand rollers to a greater or less extent, according to the use for which it is intended; the thinnest is applied to the lining of drinking horns. An ounce of silver is often rolled out into a surface of about three square feet, and its thickness is about the three thousandth part of an inch; and hence we need not wonder at the silver being soon worn off from the sharp angles of plated copper, when it is rolled to so great an extent.

What is commonly called French plate is not to be confounded with the plated copper. In making French plate, copper, or, more commonly, brass, is heated to a certain degree, and silver leaf is applied upon the heated metal, to which it adheres, by being rubbed with a proper burnisher*.

* Watson's Chemical Essays.

C H A P. XXXV.

G O L D.

General Properties of Gold.—Gold calcined by Electricity.—Extreme Ductility of this Metal.—Natural History of Gold.—Processes for separating Gold from other Substances.—Quartation.—The Touchstone.—Aqua Regia.—Reasons why the different Acids act on metallic Bodies.—Fulminating Gold.—Purple Powder of Cassius.—Golden Calf, how destroyed by Moses.—Union of Gold with other Metals.—Standard Gold Coin of different Countries.

G O L D is the heaviest of all the metals except platina, being between nineteen and twenty times the weight of water. When perfectly pure it is almost as soft as lead, and is neither elastic nor sonorous. For its fusion it requires rather more heat than silver, and when in fusion has a blueish green colour, and its surface is always perfectly bright. The most intense heat cannot calcine it, and only contributes to render it more pure if it had any foulness. The powerful burning mirrors are said to have volatilized it, and it has been driven up in fumes, in the metallic state, by flame urged upon it by a stream of vital air. The electric fluid, however, when made to pass in considerable quantities through gold leaf, inclosed between two plates of glass, converts it into a calx, which tinges the glass of a purple colour.

The tenacity of gold is so great, that a wire one-tenth of an inch in diameter is capable of supporting five hundred pounds. Its malleability and ductility exceed those of silver, and are so remarkable, that their limits could never be ascertained with any considerable exactness. On gold lace the thickness of the gold has

been computed to be less than the one hundred and thirty-four thousandth part of an inch, and the degree of extensibility has been carried still farther. In ordinary gold-leaf, which is made by hammering plates of gold between skins, or animal membranes, a grain is made to cover fifty-six square inches and a quarter. In this state its surface is so great that it may be made to float in the air with the slightest agitation, and its thickness is not more than the two hundred and eighty-two thousandth part of an inch.

Gold is produced by nature very plentifully. There is much of it in Brazil, in the Spanish East and West Indies, on the coast of Africa, and in Upper Hungary, where the mines have remained unexhausted for ten centuries. Peru and Mexico abound with gold in a variety of forms. It is met with in the sands of rivers and mountains. Some rivers in France, as well as in this country, contain gold in their sand. It is also found in the fissures of rocks, imbedded in hard stones. Pieces of gold of several ounces, and even pounds weight, are sometimes found, but in general it is diffused in so small portions, and through so large a quantity of sand, that the trouble of extracting it is scarcely repaid by the gains. In all parts of the world, particularly in Europe, gold is most frequently found in strata of sand, in which it seems to have been deposited by water. Gold mines were once wrought in Scotland, and it appears upon record that forty-eight thousand pounds sterling of this gold was coined in the Scotch mint. It is now a general opinion among mineralogists, that there are scarcely any sands entirely free from gold, and which, by accurate examination, cannot be made to afford more or less of that substance.

Considering that gold has no attraction for sulphur,
and

and very little for arsenic, which are the usual mineralizers of metallic bodies, it is not surprizing that it should be usually found in a separate and nearly pure state. The metallic bodies, with which it is alloyed in a state of nature, seldom constitute any considerable part of its weight; they are generally either silver, copper, or iron. Gold, however, is sometimes mixed with martial pyrites, and is sometimes contained in an ore, which is a mixture of lead, silver, and iron, mineralized by sulphur. In these cases the presence of gold is not known by the appearance of the mineral, and can only be discovered by roasting, and subsequent fusion with such matters as are capable of vitrifying the earthy and martial substances. The addition of lead is also useful, which unites with the gold, and carries it to the bottom of the mass. The gold is easily obtained free from the lead by the process of cupellation.

In order to separate gold, when in its native state, from the earthy and stony matters in which it is contained, the following process is employed: When it is contained in sand, the lighter particles of the latter are washed away by water, and the remaining matter, which may prove so heavy as not to be separated from the gold without danger of losing some of the precious metal, are amalgamized, by being ground with mercury, in the same manner as has been mentioned in the extraction of silver. If the gold is mixed with stones of considerable bulk, it is necessary that they should be reduced to powder in order to render them sufficiently light to be washed away. The mercury is also separated from gold in the same way as from silver; as much as possible is separated from it by pressure in bags of leather, and the remainder by heat.

All the imperfect metals may be abstracted from

gold by cupellation; but in order to separate silver from it, other processes must be employed. The best of these is called quartation, because the gold must not exceed the *fourth* part of the weight of the mass submitted to trial. The gold, therefore, must be first mixed with three times its weight of silver, the effect of which is, that the particles of gold are removed to such a distance that they cannot protect the silver from being acted on. The mass of gold and silver being then beaten out into thin plates to increase the surface, are exposed to the action of aqua fortis, which dissolves the silver, and leaves the gold in a spongy mass; this is washed two or three times with aqua fortis, and then exposed to heat in a muffle*, to recover its metallic brightness. When silver is thus separated by aqua fortis, a minute portion of the silver is apt to adhere to the gold, and, therefore, when it is an object to have the gold perfectly pure, it is proper to submit it to the action of aqua regia, which dissolves the gold, and converts the silver into luna cornea, which is precipitated to the bottom of the vessel. When it is intended to separate silver by aqua regia, the proportions of the metals must be reversed, and as the gold is to be dissolved, it must be three times the weight of the silver.

In this way gold may be obtained quite pure; but the goldsmiths find a difficulty in obtaining it perfectly ductile. To have it soft and tough it must be melted with a strong heat, and afterwards cooled very slowly.

In applying saline substances to gold, it is found that no one of the acids, in its ordinary state, produces the

* A small earthen oven made and sold by the crucible manufacturers.

least effect on it in its metallic state. Upon this depends the trial of gold by the lapis lydius, or touchstone; which is of a dark colour and pretty fine grain, but when polished has sufficient roughness, so that when the metal is rubbed over it a mark is left, which mark will be affected by any of the common acids, aqua fortis for instance, in proportion to the impurities the metal contains, but not at all if the gold is perfectly pure.

Goldsmiths use likewise two sets of needles, one for silver and the other for gold, when they want to examine the fineness of different parcels. The sets of needles for gold are alloyed with different proportions of copper; one is made with twenty-three parts of gold to one of copper, another with twenty-two parts of gold to one of copper, and so in proportion. When they have a piece of gold to be tried, they first examine its colour to determine what quantity of alloy it contains. To know this the better, they mark the touchstone with it, and then make another mark with the needle, which they think to be of nearly similar purity. Thus they compare them; and after this, to be certain that the metal is gold, they apply to the mark on the stone a drop of aqua fortis. If it is copper tinged with zinc, or any other imitation of gold, the aqua fortis immediately dissolves it. If it contains gold and some other metal, it dissolves the other metal and leaves the gold.

The only saline fluid which dissolves gold in its metallic state is aqua regia, or a mixture of the nitrous and muriatic acids. It is prepared in various ways: 1st, By mixing the two acids in their pure state. 2dly, By adding common salt, or sal ammoniac, to aqua fortis, and then distilling the mixture. A part of the nitrous acid decomposes the muriatic salt, and

detaches the muriatic acid, which rises with the remainder of the nitrous acid, and thus an aqua regia is produced. 3dly, By mixing a solution of alum with nitre and common salt, in which case the vitriolic acid of the alum disengages the nitrous and muriatic acids by its superior attraction for their basis.

It is usual to make aqua regia by dissolving sal ammoniac in about four times its weight of strong nitrous acid: but the results of experiments or operations vary considerably according to the proportion of the ingredients made use of.

The theory of the operation of this compound acid does not seem difficult. In the course of this work it has been more than once remarked, that the easy solution of metallic matters in acids does not depend merely on the degree of attraction which exists between the metal and the acid, but also on the ease with which the acid parts with oxygen to calcine the metal. From this cause it happens, that the nitrous acid, which has much less affinity with metallic matters than the vitriolic or muriatic, dissolves them more readily than either of these. Aqua regia, however, consists of the acid which has the strongest attraction for metallic bodies, and also of that which most easily parts with oxygen, and the union of these powers produces the effect of solution. That this is the true explanation of the solution of gold in aqua regia appears from several circumstances; for gold, previously reduced to the state of calx, that is, furnished already with a quantity of oxygen, is easily dissolved by muriatic acid, and gold in its metallic state, is dissolved by the oxygenated or aerated muriatic acid, and forms with it the same salt which is usually obtained by the mixed acid, or aqua regia. The muriatic acid, therefore, is the true solvent of gold, and the addition of nitrous acid

acid has no other effect than that of furnishing oxygen, since the same effect follows when the necessary quantity of oxygen is previously added either to the gold or the muriatic acid. Gold, precipitated from aqua regia by alkalis, and thus reduced to the calciform state, is soluble even in the vitriolic and nitrous acids.

The addition of water to the vitriolic acid, enables it to dissolve iron exactly on the same principle that the addition of nitrous acid to the muriatic, enables the latter to dissolve gold. The concentrated vitriolic acid has no action on iron without the assistance of heat; but by a proper addition of water the process goes on, in the ordinary temperature of the atmosphere, with considerable rapidity. The water furnishes oxygen to the iron, and its other component part, hydrogen, is set at liberty; and that the nitrous acid, in the aqua regia, answers the purpose of furnishing oxygen to the gold, is proved by the disengagement of nitrous gas.

The solution of gold in aqua regia, when first made, is always yellow, considerably caustic, corrodes animal matters, and tinges them of a deep purple colour. When applied to the surface of marble, it tinges it of a violet colour. This colour is produced by a precipitation of the gold, in consequence of the superior attraction of the calcareous earth for the acid.

The solution of gold may be made, by cautious evaporation, to afford crystals of a beautiful topaz or yellow colour. Gold may be in some measure volatilized by repeatedly distilling it with aqua regia; some of the gold rises with the acid into the neck of the retort in the form of long slender brown crystals.

Gold is precipitated from its solution by a great variety

variety of substances, but its appearances are very various, according to the nature of the matter employed. Lime and magnesia precipitate gold in the form of a yellowish powder, and the fixed alkalies have the same effect. Volatile alkali produces a more quick and copious precipitation, and forms the remarkable compound, known by the name of aurum fulminans, the nature of which has been already intimated in a note under the head of ignition. I shall in this place, however, add a few observations, which may tend still further to illustrate its nature. In the first place, it appears that the fulminating gold is a compound of about three parts of that metal with one of volatile alkali. Secondly, Fulminating gold; exposed to such a heat as is sufficient to separate the volatile alkali, without setting fire to the compound, loses its fulminating property. The same effect is produced by submitting it to the action of concentrated vitriolic acid, melted sulphur, æther, or any substance capable of abstracting the volatile alkali by superior affinity. Thirdly, When a few grains of fulminating gold are detonated in copper tubes, the extremity of which is plunged beneath the mercury of the pneumato-chemical apparatus, azote is disengaged, a few drops of water are produced, and the gold is restored to its metallic appearance. M. Berthollet, the inventor of this experiment, concludes, that the volatile alkali is decomposed, and that while one of its component parts, hydrogen, unites with the oxygen of the calx of gold, and forms water, its other component part, azote, escapes in the form of gas. The readiness with which fulminating gold explodes seems to depend on the tendency which the hydrogen of the alkali has to unite with the oxygen of the metallic calx, which tendency the weak attraction of the gold for the oxygen on the

one hand, and the azote for hydrogen on the other, are scarcely sufficient to counteract. Whenever the balance of power among these ingredients is disturbed, which happens from a moderate increase of heat, or violent friction, the hydrogen and oxygen unite and form water, the gold is reduced, and the azote escapes in the form of gas, occasioning a violent explosion.

When gold is newly precipitated, Margraff informs us, that it may be re-dissolved by the volatile alkali, or, much more readily, by the Prussian alkali. Alkaline salts precipitate gold in the form of a calx, but inflammable substances precipitate it in the metallic form. The most singular effect of inflammable substances upon the solution of gold is that of the vitriolic ether, though it does not entirely separate the gold from the acid. If into a phial of distilled water a single drop of the solution of gold is introduced, the water will become of a fine yellow colour; add to this a quantity of vitriolic ether, which will float uppermost, and remain colourless, no sensible change being produced; by shaking the mixture, however, for some time, and then allowing it to rest, the yellow colour in the lowest part of the phial will leave the water, and rise up into the ether. By repeated agitation, in a little time the ether will draw up into it the whole of the gold, so as to leave the liquor at bottom perfectly colourless. It would be erroneous to conclude from this experiment, that ether is a solvent of gold; it does not dissolve it, but attracts the solution merely by its affinity for acids. Though the ether acts primarily on the acid, it at length separates the oxygen from the calcined gold, and precipitates it in its metallic state. All the subtile aromatic oils have a similar effect, but do not act so readily as ether.

As these inflammable fluids have no action on the
4 solutions

solutions of other metals, this process may be used as a means of refining gold; for the acid containing gold is imbibed by the inflammable fluid, while that part of it which is combined with any other metal remains behind.

Almost all metallic substances precipitate gold from its solution in aqua regia. Mercury and copper separate it in its shining metallic form; lead, iron, and silver, precipitate it of a deep and dull purple colour. A plate of tin, plunged in a solution of gold, separates the perfect metal in the form of a deep violet powder, called purple powder of Cassius, which is used in painting, in enamel, and in porcelain. This powder consists of the calces of gold and tin in combination, and is capable of communicating a fine purple colour to glass. The solution of green vitriol precipitates no other metal but gold, and the gold proves of uncommon purity, and of a very deep colour. Gold in its metallic state is incapable of uniting with sulphur alone, but if a piece of gold is dropped into a solution of hepar sulphuris, especially if the latter is prepared with equal parts of sulphur and alkali, the gold dissolves with some ebullition, and forms a mass, which dissolves in water like the combination of alkali and crude antimony.

Stahl supposes that this process was used by Moses to render the golden calf, adored by the Israelites, soluble in water.

But though gold will not unite with sulphur, it may be purified by means of it, the sulphur uniting with the metals with which it is alloyed. With this view it is usual to heat the gold with crude antimony, in which state the sulphur is more fixed than when applied in a separate state. In this process, however, the gold combines with a portion of antimony, which must be afterwards driven off by heat.

There

There are scarcely any metals with which gold will not-unite. When boiled a short time with mercury, it forms an amalgam which is gritty and rigid at the first, but which becomes by grinding more soft and tender; this is often made use of for gilding the surface of silver and copper, as was more particularly mentioned when treating of the latter metal.

Gold readily unites with zinc, and produces a mixed metal, whiter than might be expected from the quantity of zinc which is employed; this alloy, made with equal parts of the two metals, is remarkably splendid, is of a fine grain, and is not liable to tarnish: on account of these properties it has been recommended for constructing the mirrors of telescopes.

All the metals, except silver and copper, take away the ductility of gold, but none more remarkably than tin, a grain of which added to a thousand of gold is said to deprive it entirely of ductility. Copper is commonly used to alloy gold, as silver renders it very pale. Copper rather heightens the colour of gold, but inclines it to red.

Goldsmiths denote the fineness of gold by the word carrat. It is supposed to be divided into twenty-four parts, called carrats; and gold, which is quite free from alloy, is said to be twenty-four carrats fine; that which contains one twenty-fourth of alloy is called gold of twenty-three carrats; that which contains two twenty-fourths, of twenty-two carrats, and so on. In England, the standard of gold coin is twenty-two carrats fine gold and two carrats of alloy, which latter is half silver and half copper. The French, Spanish, and Flemish gold are nearly of the same fineness.

C H A P. XXXVI.

P L A T I N A.

Natural History of this curious Metal.—Its Properties.—The most ponderous Body in Nature.—Its Hardness and Infusibility.—Soluble only in Aqua Regia and oxygenated muriatic Acid.—Its Union with other Metals.—Crucibles formed of it.—Might be applied to various Uses which no other Metal can answer.

IN the beginning of the year 1749, the first specimen of this metal was brought into England from Jamaica. It was said to have been originally brought from the Spanish West Indies, and it is still almost exclusively found in the gold mines of Spanish America. It is brought over in the form of small smooth grains, irregularly figured, with round edges, and is often mixed with ferruginous sand and grains of quartz or crystal. The grains of platina are whiter than iron, but less so than silver, and their flat form is probably owing to the pressure they undergo in the mills in which the gold is amalgamated.

In confirmation of this opinion, small particles of gold and mercury are usually found mixed with the grains of platina. In the state in which they are brought over, they fall short of the weight of gold, but by purification, which is performed by washing with the muriatic acid, and by exposing them for a long time to the heat of the most violent furnaces, which, however, are said to be insufficient to melt them*,

* This is the opinion of the generality of mineralogists; but my friend and chemical preceptor, Dr. Higgins, assured me, he had melted platina in his furnace.

they exceed it. The specific gravity of gold is about nineteen times that of water; whereas platina, which still contains so much iron as to render it magnetical, is upwards of twenty-one times the weight of that fluid. It is extremely difficult to free platina from the last portions of iron, but some minute particles, which have been fused by the focus of a burning glass, and so far purified as not to be attracted by the magnet, appear to exceed twenty-two times the weight of water.

Platina is, perhaps, the most perfect of all the metals. As it so considerably exceeds even gold in weight, it is therefore to be considered as the most ponderous body in nature.

It has several properties in common with the most useful of metals, iron. In hardness it approaches to that metal in the state of steel; and in infusibility it exceeds it even in the state of soft iron; it also considerably resembles iron in appearance, and it is the only metal, besides iron, which has the property of welding.

Platina resembles gold in being soluble only in aqua regia, and it even requires a larger quantity of that compound acid for its solution than gold. The solution is of a deep yellow or reddish colour. The proportions of acids best adapted to the solution of platina, are equal parts of the nitrous and muriatic acids; but the solution does not then take place with rapidity. This compound is very corrosive, and tinges animal substances of a blackish brown colour.

The vegetable alkali added to this solution, only occasions the precipitation of a part of the metal in the form of a sparkling powder, which is soluble in a large quantity of water. A very remarkable circumstance is, that the fossil alkali does not produce any precipitation,

tation, unless added in very considerable quantity. Common sal ammoniac, applied to the solution of platina, produces a precipitation like the fixed vegetable and volatile alkalis. It separates a part of the metal in a sparkling red powder, and a part remains dissolved, which it cannot separate; but if vegetable alkali is added after the sal ammoniac, it precipitates the rest of the platina; and on the contrary, sal ammoniac, added to the solution containing the remainder, which the fixed alkali could not separate, precipitates it, so that by adding both the vegetable alkali and sal ammoniac, the whole of the platina is separated. Platina, like gold, is also soluble by the oxygenated muriatic acid.

The subtile inflammable substances, as spirits of wine and aromatic oils, do not produce any separation from the solution of platina in aqua regia, as they do from that of gold. Tin precipitates it, but the precipitation is not purple like that of gold. Most of the metals precipitate platina, but it does not in general fall down in the metallic state. The precipitation of platina, from its solution by sal ammoniac, affords a method of separating this metal from the gold which is mixed with it, as the gold is not separated by the addition of that salt; if, on the contrary, we wish to precipitate the gold, and leave the platina in solution, this may be effected by sal martis.

The precipitates of platina may be reduced to a metallic button, by heating them with the common fluxes; but these cannot be rendered malleable unless they are completely fused, which can scarcely be effected, unless with the heat of the most powerful burning glasses.

A mixture of copper with platina forms a metallic body of intermediate colour and great density, so that

it receives a very fine polish. A mixture of three or four parts of copper to one of platina possessed all the above properties in great perfection, and was not tarnished in the air in the space of ten years. With iron it also produces a compound of great density, which is hard, strong, and tough, and admits of a good polish. Most metals increase the fusibility of platina so much, that the mixture may be melted in ordinary furnaces.

Gold is greatly injured in appearance by a mixture of platina, and becomes of the colour of bell metal by the addition of no more than one twenty-fourth part, though half that quantity produces little change.

Platina with bismuth and tin forms alloys, which are brittle, but easily fused. Platina and lead unite very well by fusion, but the ductility of the lead is destroyed, and the compound quickly tarnishes on exposure to air. Platina partly destroys the ductility of silver, augments its hardness, and impairs its colour.

Platina completely resists the action of mercury, with which it shews no disposition to unite. On this account it does not mix itself with the gold, which is extracted from the substances with which it is mixed by amalgamation.

From the extreme infusibility of platina, it is excellently fitted to contain other matters, which it is intended to submit to a violent heat. M. Achard succeeded in making crucibles of platina, by fusing equal parts of platina, white arsenic, and vegetable alkali. This matter, when cooled, was reduced to a powder, and rammed into a mould. A strong heat, quickly raised, and continued for some time, fused the mass, and after dissipating the arsenic and alkali, left the platina in the desired form.

Platina, when thoroughly purified, by coction in the muriatic acid and precipitation from aqua regia, may be fused into a mass nearly as malleable as soft iron. This property, united to those of resisting acids, its great infusibility, and welding, seem to render platina applicable to purposes which no other metal is capable of answering.

C H A P. XXXVII.

OF INFLAMMABLE SUBSTANCES IN
GENERAL.

Ignition and Combustion defined.—Acids formed by the Combustion of Inflammable Substances.—Flame, how produced.—The Object of the present Inquiry limited.—What Substances are commonly termed inflammable.

THE difference between ignition and combustion was briefly mentioned in the early part of this work; but after what has been advanced concerning the elastic fluids, and the nature of acids, the reader will be prepared for a more philosophical view of the subject. All bodies which can support a certain degree of heat, without the destruction of their texture, emit light, and this is called ignition; but combustion or inflammation is a property which belongs to such bodies only as are capable, when placed in proper circumstances, of augmenting their own temperature. Simple ignition produces no permanent change in bodies, but combustion entirely alters the properties of such as have undergone that process. From being mild and nearly insoluble in water, they become acrid, pungent, and extremely soluble, and are converted into acids, which differ according to the substance, by the inflammation of which they were formed. The terms combustible substance and acidifiable basis are, therefore, in the French nomenclature, synonymous.

It has already been remarked, that inflammation is the disengagement of the matter of heat or caloric contained in vital air or oxygenous gas, in con-

sequence of the basis of this gas becoming combined with other bodies. All bodies, therefore, which are capable of decomposing vital air, change a quantity of latent heat into sensible heat, and are said to be inflammable from the light and heat which seem to proceed from them, but which, in fact, are derived from the oxygenous gas, which is one of the component parts of the atmosphere.

The necessity of the presence of air to combustion is strongly maintained by M. Lavoisier, and an experiment related by him (to the latter part of which I feel some reluctance to give an unqualified assent) seems, indeed, to prove it to be essential in all cases. He successively placed a quantity of phosphorus, of sulphur, and of gunpowder, under the receiver of an air-pump, making as perfect a vacuum as the machine would admit. He then threw the focus of a lens of eight inches diameter on the different substances, which were not at all ignited, only bubbled up, and at length sublimed. The gunpowder was decomposed, the sulphur of it only subliming, and it neither took fire nor exploded.

In ordinary language, no bodies are said to be inflammable but such as burn easily, or which, in other words, are capable of decomposing vital air in the diluted state in which it exists in the atmosphere. In a more strict sense, however, the property of inflammability belongs to other bodies, though they possess it in a less eminent degree; as to zinc, which, when made extremely hot, burns with a dazzling white light, and to iron, which when heated to a proper degree, burns in pure oxygenous gas. The oxygenation which all metals, except the perfect, undergo from the conjoined operation of heat and air, must also be considered

as a slow combustion. In short, all substances may be said to be inflammable which are capable, in any circumstances, of decomposing vital air, or which have a stronger attraction for the basis of that air than that basis has for caloric or fire.

In all instances of inflammation a certain degree of heat is necessary to begin the process. Different inflammable substances require different degrees of heat for this purpose. Phosphorus is fully inflamed at the heat of 86 degrees of Fahrenheit, but undergoes a more gradual combustion at a much lower temperature. Sulphur requires much more heat than phosphorus, and charcoal still more than sulphur. There are some substances in nature which are so combustible, or have so strong an attraction for oxygen, as never to have been found uncombined with that principle; of this kind are the unknown bases of the boracic, fluoric, and muriatic acids.

Though an acid is always formed by the combustion of every inflammable substance, this fact was never attended to, or at least never properly apprehended, till within these few years. In ordinary cases, indeed, this circumstance was likely to pass unobserved; for the acid produced by the inflammation of charcoal, which is the principal ingredient in all kinds of fuel, is the carbonic acid gas, or fixed air, which escapes without leaving any traces. In the combustion of sulphur also, the acid flies off in fumes, unless collected by a particular process, which was described in treating of the sulphuric or vitriolic acid. The phosphoric acid, however, is a concrete body, and therefore cannot easily be overlooked. When inflammable bodies are united with oxygen they become acids, and having no longer sufficient attraction for

oxygen to decompose vital air, they lose their inflammability. According to the old chemical doctrine, the heat and light afforded by inflammable substances were supposed to derive their origin from the disengagement of phlogiston; but, according to the doctrine of M. Lavoisier, the vital air of the atmosphere is the repository of light and heat, from which all artificial supplies are derived, by means of inflammable substances.

There is one striking difference among inflammable substances, which is, that some burn with and some without flame. Of the former kind are oils, spirit of wine, and most others; to the latter kind belong the different species of charcoal. The cause of this difference is, that some inflammable bodies afford an inflammable vapour, the burning of which produces flame; others are entirely fixed, and produce no such vapour. The vapour, however, as it rises is not wholly consumed; the reason of which is, that the air does not find access to the center of the column of vapour as was formerly explained. In large flames, the surface on which the air acts is less in proportion to the quantity of vapour than in small flames; hence the quantity of smoke and soot produced by small flames is proportionably less than that produced by large; for smoke and soot are only that part of the vapour which is unconsumed.

In treating of inflammable substances it will be necessary to confine the inquiry to those which possess that property in a more remarkable degree. I shall, therefore, first treat of the simple inflammable substances, phosphorus, sulphur, and coal, or the carbon of the French philosophers. Hydrogen, or inflammable air, has already been described under the head of elastic or aeriform fluids. With respect to the
compound

compound inflammable substances, such as oils, resins, fat, &c. it will be found that they consist of different proportions and states of combination, of carbon, hydrogen, and oxygen. The inflammable matter of charcoal and coke consists of carbon only; pitcoal and wood, in their crude state, contain also some hydrogen, which is driven off, together with water and oil, in the process of charring.

C H A P. XXXVIII.

P H O S P H O R U S.

Phosphorus of Kunkel.—Light from putrescent Substances.—Curious Facts.—Light from the Sea Water, &c.—Lights about the Beds of Sick Persons.—Phosphorus exhaled with the Sweat.—Phosphorated Hydrogen Gas.

PHOSPHORUS* is a simple combustible substance, which was unknown to chemists till 1667, when it was discovered by Brandt, a German chemist, who kept the process a secret; soon after Kunkel found out Brandt's method of preparation, and made it public. It has ever since been known by the name of Kunkel's phosphorus. The appearance of phosphorus is that of a transparent substance, of a colour inclining to yellow, like clear horn; it is specifically heavier than water, is tough, and cuts like bees' wax, and like it melts with a gentle heat into a transparent fluid. With this heat it may be melted in water; but if the same degree of heat is applied in the open air, it melts, takes fire, and burns, producing a bright white flame with intense heat. Phosphorus should be handled with great caution, as should any of it adhere to the skin, or get under the nails, the heat of the human body is sufficient to inflame it. The process for obtaining phosphorus from bones was described in treating of the phosphoric acid.

When a quantity of phosphorus is burnt in small pieces under a bell, the phosphoric acid attaches itself to the internal surface of the bell, in the form of a

* Derived from the Greek—"A substance affording light."

downy mass. This concrete acid has so strong an attraction for water as to imbibe it from the atmosphere with astonishing rapidity, till it is converted into a liquid considerably more dense, and of greater specific gravity than water.

From the experiments detailed in M. Lavoisier's elementary work on chemistry, it appears that one pound of phosphorus requires one pound eight ounces of oxygen gas for its combustion, and that two pounds eight ounces of concrete phosphoric acid are produced.

The phosphoric acid may be obtained by three other processes besides this. If phosphorus is melted in hot water, and a stream of vital air passed through it, it becomes oxygenated. The same thing happens by plunging it in nitrous acid, from which it abstracts the oxygen. It may be also acidified by simple exposure to the atmosphere, which ought not at the time to exceed the temperature of sixty degrees, from the danger of inflammation; in this situation, by a gradual combustion, it attracts the oxygen of the atmosphere, and becomes converted into an acid.

The caustic fixed alkalies dissolve phosphorus by the assistance of heat. During this combination a fetid gas is disengaged, which has the singular property of exploding as soon as it comes in contact with atmospherical air, and still more rapidly by contact with vital air.

The phosphoric acid forms peculiar salts with the alkalies and some of the earths, and has the property of corroding glass. With the mineral alkali it forms a salt, the taste of which is less unpleasant than that of other neutral salts, and which is well calculated to answer the purposes for which neutral salts are used in medicine. The phosphoric acid acts only on a small number

number of metallic substances, but readily dissolves, in its fluid state, iron, zinc, and copper, with which it forms salts not crystallizable.

Phosphorus seems to be almost universal in the animal kingdom, and is also found in some minerals, and in a very minute proportion in most vegetables. The bones of animals are a true phosphat of lime, or an earthy salt composed of phosphoric acid and calcareous earth. The urine also contains a considerable quantity of phosphoric acid, chiefly combined with volatile alkali, but partly also with calcareous earth. This compound salt, afforded by the evaporation of urine, was formerly known by the names of essential salt of urine, or microcosmic salt. Brandt, Kunkel, and Margraff, and all chemists, till lately, prepared their phosphorus from that substance, but it is now almost entirely obtained from bones, which afford it more plentifully and with less trouble. Phosphorus does not yet seem to have been applied to any important uses.

From the remarkable ease with which phosphorus is inflamed, several experiments may be exhibited by means of it, which appear like the effects of magic to persons unacquainted with the nature of this substance. Thus, for example, if the outside of a bottle is rubbed with phosphorus, and then surrounded with tow, and hot water poured into it, the phosphorus takes fire, and communicates the inflammation to the tow. If a stick of phosphorus is used to write on a piece of paper, or on a wall, a quantity of phosphorus is abraded, and, undergoing a slow combustion, renders the strokes visible in the dark, while in the light they can only be perceived to exhale a whitish vapour.

A fluid called liquid phosphorus is prepared by digesting

digesting some phosphorus in the heat afforded by horse-dung for two days, in oil of cloves, oil of turpentine, or any similar substance. After dissolution, the oil will be so impregnated with it, that when the phial is opened, it will appear luminous. Any thing moistened with this fluid will in the dark seem to be on fire.

Many natural phenomena, which in the ages of superstition served to astonish and affright mankind, have received a satisfactory solution from the discovery of the phosphorus of Kunkel. We learn from Fabricius ab aquapendente, that three young men at Padua, having bought a lamb, and eaten part of it on Easter Day, 1592, several pieces of the remainder, which were kept till the day following, shone like so many candles when casually viewed in the dark. It appears by his account, that the astonishment of the whole city was excited by this phenomenon, and a part of the flesh was sent to him, who was professor of anatomy, to be examined by him. He observed, that those parts which were soft to the touch and transparent in candle light were the most resplendent. A philosopher of not less note, has furnished us with a very pompous account of a similar phenomenon, which occurred at Montpelier in 1641. A poor old woman had bought a piece of flesh in the market, intending to make use of it the day following; but happening not to sleep well that night, and her pantry being adjoining to her bed, she observed that a quantity of light proceeded from the meat, so as to illuminate almost the whole place where it hung. We may easily judge of the terror and astonishment of the poor woman herself, since we find that a part of the flesh was carried, as a very extraordinary curiosity, to Henry Duke of Conde, who viewed it with the utmost surprize for several

several hours. The light was as if gems were scattered over the surface, and continued till the flesh began to putrify, when it vanished, which it was believed to do in the form of a cross.

The attention of a more philosophic age was directed to experiments to ascertain the cause of this light. Mr. Boyle found, that the light of rotten wood was extinguished in vacuo, and revived again by the admission of air, even after a long continuance in vacuo. The extinction of the light was not so complete immediately on exhausting the receiver, as some little time afterwards. The wood was not much affected by condensed air; but the light of a shining fish, when put into the condensing engine, was rendered more vivid by that means. As air is therefore necessary to combustion, these experiments clearly indicate, that this light is the effect of a slow combustion, or something analogous to it; and, indeed, the experiments upon the phosphorus of Kunkel have since placed this matter beyond a doubt. The combustion, however, in these cases, is so very slow, that no change of air appeared necessary for the maintenance of this light, for it continued for a long time, even though the wood was confined within a glass hermetically sealed.

To explain the cause of this combustion it is only necessary to repeat what has been just stated, that there exists in every animal body, and in most vegetables, a certain quantity of phosphorus. This principle, we have seen, is extremely active, and has the strongest tendency to unite with the pure part of our common air. During that separation, therefore, of the parts of bodies, which takes place in an incipient putrefaction, these phosphoric particles are detached from those with which they are combined, and by the action of the air;

a degree

a degree of combustion takes place, but so extremely faint, that light only is produced, without the least appearance of sensible heat.

This short explanation of the cause will, I flatter myself, correspond with most of the phenomena of this kind noticed by philosophers. Mr. Boyle found that the light of rotten wood was in most respects analogous to that of putrescent substances. The light of the former, however, differed in some respects; it was presently quenched with water, spirit of wine, and several other fluids; but the light of some shining veal was not entirely quenched by water, though its virtue was instantly destroyed by spirit of wine*. The same philosopher was sometimes disappointed in his experiments on shining fishes; particularly he observed, that they failed to become luminous in cold and frosty weather, which is perfectly agreeable to the nature of phosphorus, since its combustion is exactly in proportion to the heat which is applied to it. He remarks also in another place, that the light of shining wood was completely extinguished by extreme cold.

Some bodies have a much greater tendency to produce this light than others. A foreign philosopher remarked, that on opening a sea polypus it was so luminous as to startle most of the persons who saw it; the nails and the fingers of those who touched it became luminous also. The light of the glow worm, and other luminous insects, must depend upon some slimy or fluid matter which they emit, and which is probably a combination of phosphorus with oil. There is a remarkable shell-fish, called *pholes*, which forms for itself holes in different kinds of stone. This fish illuminates the mouth of

* *Priest. Op.* 565.

the person who eats it; and it is remarked, that contrary to the nature of other fish, which give light when they tend to putrescence, this is more luminous the fresher it is, and when dried its light will revive on being moistened either with salt water or fresh; brandy, however, immediately extinguishes it*.

The luminous appearance of the sea in the night time cannot have escaped the observation of any person in the least conversant with that element. The light occasioned by the dashing of oars, or by the motion of the waves by night, is extremely beautiful. Father Bourzes, in his voyage to the Indies in 1704, remarked particularly the luminous appearance of the sea. The light was sometimes so great, that he could easily read the title of a book by it, though nine or ten feet from the surface of the water. Sometimes he could easily distinguish, in the wake of the ship, the particles which were not luminous from those that were. The luminous particles also appeared of different forms; some appeared like points of light, others like stars; some of them resembled globes of a line or two diameter, and some appeared as large even as a man's head; they assumed square and triangular as well as globular forms, and not only the wake of the ship, but fishes in swimming, produced these luminous appearances. All these phenomena he attributes, and rightly, to the fat or putrescent state of the water, and observed, that when the wake of the ship was brightest, the water was most clammy and glutinous. In some parts of the sea, he saw a substance like yellow and red dust, and the sailors told him it was the spawn of whales which produced all these appearances †. Later experiments have proved, that the luminous appearance of

* *Priest. Op.* 567.† *Ibid.* 572.

the sea entirely proceeds from the putrescent parts of marine animals*.

Human bodies, as well as those of other animals, emit light just when they begin to putrify; and the walls and roofs of places in which dead bodies have often been exposed have been observed to have a slimy matter deposited on them, which was luminous in the dark. The lights which are sometimes seen in burial grounds undoubtedly proceed from this cause alone †. Similar appearances have been observed about the beds of sick persons, probably in putrid diseases: one of these was observed about the body and the bed of a sick woman at Milan, which fled from the hand that approached it, but was at length dispersed by a stream of air. It is well known that the sweat often contains a considerable quantity of phosphoric matter; and the fact, which has now been stated, is strongly confirmed by a circumstance related by Henckel, in his *Pyritologia*. One of his friends, who was of a sanguine temperament, had indulged himself in the exercise of dancing to such excess, and his perspiration was so profuse, that he imagined his life in danger. While he undressed, traces of phosphoric light were seen on his shirt, and in those parts were a number of reddish yellow spots, exactly resembling the concrete phosphoric acid.

In all those animal exhalations, which exhibit phosphoric appearances, the phosphorus in the state of a gas is mixed with hydrogen, and the compound is called *phosphorated hydrogen gas*. Of this nature, probably, are many of those phenomena, which are classed under the general name of *ignes fatui*, and of those which were described in a former volume as igneous or luminous meteors.

* *Priest. Op.* 576.† *Ibid.*

C H A P. XXXIX.

S U L P H U R.

General Properties of Sulphur.—Natural History of Sulphur.—Union with Earths.—With Alkalies.—Liver of Sulphur.—Artificial sulphureous Waters.—Uses of Sulphur.

SULPHUR is another simple inflammable substance, which agrees in some properties with phosphorus. Like that it melts with a gentle heat, and is capable of a gradual as well as of a rapid combustion, in proportion to the degree of heat applied to it. Heated to 170° of Fahrenheit it generally evaporates; it melts at 185° and then appears red; it inflames at 302° . Its flame is blue, and accompanied with a sharp suffocating smell, which is the sulphureous or volatile vitriolic acid.

In treating of other bodies, particularly the metallic, several have been mentioned with which sulphur is found united in the bowels of the earth: few substances are indeed more abundant in nature than sulphur; it also enters into the composition of animal matters, and, in a very small proportion, into that of vegetables.

The sulphur of commerce is extracted, by distillation, from the substance which has been so often mentioned under the name of pyrites, in which state it is combined with iron, and is so hard as to strike fire with steel. Pyrites in colour and appearance resemble brass; some pieces are cubical, but in general this mineral has no determinate form. The sulphur obtained by the first distillation is seldom pure, from the
 \ steam

streams of other volatile substances which rise and are condensed with it. It is purified by being melted in a ladle, and kept in that state till the impurities settle at the bottom. If it is an object to obtain sulphur of the greatest purity, this must be effected by sublimation; and in this state it is commonly sold under the name of flowers of brimstone. Even these, however, are sometimes rendered impure by the sulphur taking fire, which produces a mixture of vitriolic acid. This is effectually removed by boiling the flowers in water, which dissolves the acid, and leaves the sulphur in a pure and mild state.

Sulphur is sometimes found, more or less pure, in the neighbourhood of volcanos, in which case it seems to have been separated, by subterraneous heat, from some substance with which it was previously combined.

The method of burning sulphur for the preparation of the vitriolic acid has already been described when treating of that acid.

Sulphur has no action on siliceous earths, but very readily unites with the calcareous. It is also capable of combination with magnesia, ponderous earth, and volatile alkali. It unites, however, with much more violence with the fixed alkalies. All these combinations are of a liver colour, and are therefore called livers of sulphur. By M. Lavoisier they are much more properly denominated sulphurets of these several substances, as sulphuret of lime, sulphuret of magnesia, &c. These substances are soluble in water, and have considerable action on several other bodies. The combinations of sulphur with earths and alkalies may be all decomposed by means of acids, and the earthy sulphurets by means of the fixed alkalies. These substances, when dissolved in water, disengage a peculiar

gas called hepatic gas. This gas is precisely the same, from whatever kind of fulphuret it proceeds ; but none of them afford it unless mixed with water. This gas, therefore, proceeds from a decomposition of water, and is found to consist of sulphur dissolved in inflammable air. When this gas comes in contact with vital air it is decomposed, the vital air and hydrogen uniting to form water, while the sulphur is precipitated in small flakes. This gas is capable of solution in water, and by these means natural sulphureous waters may be imitated.

The chief uses to which sulphur is applied are, the making of gunpowder and vitriolic acid. It is also used in bleaching, and is an article of some importance in the *materia medica*.

C H A P. XL.

THE CARBONACEOUS PRINCIPLE.

Nature of the Carbonaceous Principle.—In what Substances principally found.—Charcoal.—Lamp black.—Strong Attraction of the Carbonaceous Principle for Oxygen.—Its Use in the Reduction of Metals.—Plumbago, or Black Lead.—Its various Uses in the Arts.

THE word carbon is adopted from the nomenclature of the French chemists, to express an inflammable matter which constitutes the chief part of the weight of charcoal, pit coal, &c. and which, with certain proportions of hydrogen, or the basis of inflammable gas, forms the different kinds of oil.

By the combustion of carbon a peculiar acid is formed, which is soluble in water, unites with alkaline bases, and possesses all the properties of acids in general, though in a weak degree. This acid has already been treated of under the name of carbonic acid gas, or fixed air.

Carbon exists in great quantities, in fossils, as the greater number of calcareous stones and earths are found united with it; it is also one of the constituent parts of the atmosphere, in both which states it is combined with oxygen. It is found united with earthy matter and oil in the extensive strata of pit-coal, and with iron in the matter which is called plumbago, or black lead. Carbon also exists in all vegetable and animal substances, and constitutes a considerable part of their weight, particularly of those vegetable matters which are the most firm. The state of greatest purity to which carbon can be reduced is, by burning wood

in such a manner as to reduce it to charcoal, which, when well made, contains carbon united with only a very small proportion of such matter contained in vegetable substances as cannot be driven off by heat, such as earthy and saline matter, with a very minute portion of iron. In order to convert wood into charcoal, the only circumstances necessary are the application of heat while the air is nearly excluded. The only elementary substances which seem to be universal in the vegetable kingdom are, carbon, hydrogen, and oxygen. The former of these substances has very little attraction for caloric, or the matter of heat, and therefore cannot be driven off in vapour, at least by the heat of ordinary fires; the two latter, however, have a strong attraction for that principle, and therefore easily assume a gaseous state. In the ordinary temperature of the atmosphere the carbon, hydrogen, and oxygen, which constitute the woody fibre, seem to exist in a state of triple combination; but this is not the case when the temperature is altered. According to M. Lavoisier, if a heat, not exceeding that of boiling water, is applied, one part of the hydrogen combines with oxygen, and forms water, the rest of the hydrogen combines with a part of the carbon, and forms volatile oil, while the remainder of the carbon remains fixed at the bottom of the vessel. If a red heat, however, is applied, no water comes over, carbon having a stronger attraction at that temperature for oxygen than hydrogen has, and therefore carbonic acid is produced; and the hydrogen being left free from other combinations, unites with caloric, and comes over in the form of hydrogen gas. In this high temperature no oil is produced.

The solidity of charcoal depends on that of the wood from which it is procured, and the care with which
the

the process is conducted. In general it preserves the form of the vegetable, unless that was very succulent. Pure oils, when decomposed by heat, afford a coal in very fine particles, called lamp black.

In whatever manner the volatile matters can be dispelled from vegetable or animal substances without the admission of vital air, which would consume the carbon, charcoal is produced, which contains no ingredient capable of inflammation except carbon, and therefore, with respect to that process, may be considered as carbon itself.

Charcoal, exposed to the greatest heat without the presence of vital air, remains unconsumed and unchanged. This fact has been denied by the advocates for the phlogistic hypothesis, who maintain that the purest charcoal, treated in this way, affords a quantity of inflammable gas. It is now, however, I believe, commonly admitted, that if the charcoal is first accurately dried, no inflammable gas is produced, and therefore that which has been observed by other chemists, is to be attributed to the presence of a small quantity of water, which, in a high temperature, is decomposed by charcoal. Dr. Priestley has observed, that charcoal has a strong disposition to attract humidity from the atmosphere. He found that charcoal prepared in the evening, and kept till the morning, became sensibly moist, and unfit for nice experiments. This remarkable attraction for water is, perhaps, to be attributed to the alkaline salts usually contained in charcoal.

From the very strong attraction which the carbonaceous principle has for oxygen, there is no substance that can be applied to separate it from that matter. Carbon, on the contrary, is capable of decomposing all the acids except the boracic, the fluoric, and the

muriatic, the unknown bases of which have a stronger attraction for oxygen than it has.

Charcoal readily decomposes the phosphoric and sulphuric acids, the bases of which burn at a lower temperature; and this fact evinces, that the degree of heat at which the combustion of a body begins does not accurately mark its degree of attraction for oxygen.

From the strong affinity of the carbonaceous principle for oxygen, charcoal is the most powerful substance which can be used in the reduction of metals. Charcoal has also another advantage over other inflammable substances in these operations, which is, that it bears a great degree of heat without volatilization.

According to the experiments of Lavoisier, in the combustion of one pound of charcoal, two pounds nine ounces one drachm ten grains of oxygen gas are absorbed, and three pounds nine ounces one drachm ten grains of carbonic acid gas are formed.

The carbonaceous principle, or carbon, is one of the most important substances in nature. It is one of the necessary constituent parts of animal substances, and enters into the composition of all alimentary matters, flour, sugar, mucilage, oil, &c. It is also the chief ingredient in all kinds of fuel.

PLUMBAGO, or black lead, is found to consist of carbon combined with about one tenth of its weight of iron. It appears to be scarcely inflammable, but may, however, be almost entirely consumed with the production of carbonic acid gas, by keeping it heated to a great degree, and agitated so as to expose it thoroughly to the air. It may be also deflagrated with a large proportion of nitre in a red heat. It is found in a separate state in a variety of places; but the species best adapted for making pencils comes chiefly from Burrowdale, in Cumberland. For this purpose it

is cut into a thin plate, the edge of which, being fitted into a groove in a semi-cylinder of wood, is then sawed off, so as to leave the cavity entirely filled. The black lead is retained in its place by the other half of the cylinder, which is glued on. The makers of small shot polish and blacken its surface by agitating or rolling it in a cask with powder of plumbago. This mineral is likewise used in the manufacture of razor-traps.

C H A P. XLI.

PIT COAL.

Different Species of Coal.—Newcastle Coal.—Culm.—Slate Coal.—Cannel Coal.—Kilkenny Coal.—Bovey Coal.—Peat.—Coke.—Coal Tar.—Natural History of Coal.—Observations relative to the Deluge.

PIT COAL is a substance of which there are many varieties, the causes of which have not been ascertained, as all the kinds afford very nearly the same results by chemical analysis. But before the different species of this mineral are mentioned, it is necessary to notice a substance which agrees in all its chemical properties with charcoal, possessing at the same time most of the external characters of pit coal, and which Mr. Kirwan considers as the natural carbonic principle. Its colour is black or greyish black, with a lustre approaching to the metallic. It is without transparency, and its fracture is foliated or flaty. It stains the fingers. This description is taken from the purest specimens which have yet been procured; namely, those found near Strido in the territory of Florence. This substance is insoluble in acids. In a strong heat it reddens, but does not flame. Exposed to a porcelain heat for several hours in covered crucibles, it entirely, or almost entirely, evaporates like the diamond*. Distilled it yields a small quantity of water, but no air, oil, acid, or alkali. Kilkenny coal is nearly allied

* The reader will find that the diamond itself is probably a substance of this nature, by consulting Chap. 44, where the diamond is treated of as an inflammable substance.

to this substance, and may perhaps be considered as of the same species. The most remarkable varieties of pit coal are,

1. **NEWCASTLE** coal, which is of a black colour and shining appearance, where it has been lately broken. This substance undergoes an imperfect fusion when heated, so as to cohere or cake. It burns with a lively flame, and is nearly consumed in the fire. It does not break equally in all directions, and is composed of laminæ.

2. **CULM** coal. This contains a large proportion of argillaceous earth, so that after being burned its bulk is scarcely diminished. It burns with a lively flame, but its appearance is more dull and earthy than that of the former. This kind of coal is found in Sweden, and in some parts of England.

3. **SLATE** coal. This has very much the appearance of some of the common kinds of slate, but it burns very easily, with a copious and bright flame. It consists chiefly of argillaceous earth, and seems to have only been penetrated with bituminous or coaly matter.

4. **CANNEL** coal is of a dull black colour, breaks easily in any direction, and in its fracture presents a smooth chonchoidal surface, if broken transversely. It is nearly consumed in the fire, burns with a lively flame, but if suddenly heated flies in pieces with considerable violence. This inconvenience is said to be removed by previously immersing it in water for some hours*. Cannel coal does not soil the fingers,

* It is customary in Lancashire to sprinkle salt upon cannel coal, to prevent its flying; but I cannot speak decisively as to its effects, having never seen the experiment accurately made. Possibly the water contained in the salt may have some influence in preventing the cracking of the coal.

and admits of being turned into snuff boxes, inkstands, trinkets, &c.

The word lithonthrax, used by some mineralogists, properly denotes stone coal, and seems most applicable to cannel coal, as this, from its dull and uniform fracture, has most resemblance to a stony substance.

5. KILKENNY coal. This is perhaps the most free from earthy matter of all the different species of coal; the earth contained in it not exceeding the twentieth part of its weight. This coal burns with less flame and smoke*, and more slowly and intensely than the cannel coal.

6. SULPHUREOUS coal. All those kinds of coal are called by this name, which are mixed with particles of a yellow and metallic appearance, and which are in fact a species of pyrites. In consequence of this admixture they emit, when burned, a sulphureous smell, and fall to pieces when exposed to the action of air and moisture.

7. BOVEY coal, xylanthrax, is of a brown or brownish black colour, and of a laminar texture. The laminæ are frequently flexible when fresh dug, though they generally harden on exposure to air. Mr. Fabroni discovers its organic structure by boiling it in dilute nitrous acid, by which its fibres are laid bare. It seems to consist of wood penetrated by petroleum or bitumen, and frequently contains pyrites, alum, and vitriol.

8. PEAT or turf, geanthrax. It may admit of doubt

* Kilkenny, the town in Ireland where this coal is produced, is pleasantly situated; it is watered by a clear and beautiful river, and produces also a black marble variegated with white spots. The place has therefore been proverbially characterised—"Fire without smoke, air without fog, water without mud, and the streets paved with marble."

how far it is proper to consider peat among the species of coal; but as some philosophers of great authority have attributed every kind of coal to a vegetable origin, and as some kinds are decisively so, the reason of this arrangement will be obvious. What is properly called peat is formed by the growth of a particular vegetable matter, peat moss, which increases to such a degree in moorish grounds as to form strata of many feet in thickness. When peat is fresh dug from below the surface, it is of a viscid consistence, but hardens by exposure to the air. It is often mixed with pyrites and stony matters, which are separated from it while soft, in which state it is formed into oblong masses for fuel. When distilled, it affords water, oil, and volatile alkali, which are precisely the products afforded by the distillation of pit-coal. A kind of peat is found near Newbury, in Berkshire, which contains but little earth, and consists of wood, branches, twigs, roots, with leaves, grass, straw, and weeds. What is dug on moors, under the name of turf, frequently contains a mixture of peat.

Coal, when heated and inflamed to such a degree as to expel the more volatile parts, forms a kind of mineral charcoal, called COKE, which is highly useful in the property of affording a strong, clear, and lasting fire, without forming a cohesive mass, which would prove very prejudicial in the smelting of metals. It is also used in drying those substances which would be injured by the thick smoke of common coal.

Lord Dundonald was the first person who improved this process, by collecting the tar and volatile alkali, which are driven off from the coal, while it is converted into coke. His method has been adopted with much advantage in several parts of Britain. The coal is put into ovens, which are heated by fires lighted
beneath,

beneath, and the liquid matter is forced through an iron pipe inserted into the top of the oven, and which communicates with proper condensing vessels. By this process a corrosive watery liquor and two sorts of oil are obtained. Six barrels of the mixed oily matter produce about five barrels of oil of a thicker consistence; of the oil thus thickened, one part is lighter than the other, which is drawn off, and is not at present applied to any use*. The thicker part is used as an inferior kind of tar.

Coal, like most other considerable masses of matter found near the surface of the earth, is disposed in beds or strata, which are sometimes parallel with the horizon, but generally form different angles with respect to it; the same stratum uniformly preserves the same direction. The strata of coal are disposed between strata of other matters. The following strata are usually found in those districts of country, both in England and Scotland, where coal abounds: whinstone, freestone, sandstone or freestone of a coarser texture, metalstone, which is a hard argillaceous substance containing balls of iron ore, and shiver, which is the most common of them all, and is an indurated bole, usually of a blackish colour.

These strata do not bear on each other in the same order in different collieries, nor are they of any uniform thickness. The strata of coal themselves are divided by other partings, called *backs* and *cutters*, into innumerable cubic, prismatic, and rhomboidal figures.

In all places where the strata lie regularly, they are divided and subdivided in the manner above mentioned, and sometimes extend uninterruptedly through

* See Bishop Watson's Essays.

a considerable district. This regularity, however, is frequently broken by gaps filled by other matter, which has evidently fallen in, in consequence of the strata having been separated from each other by some violent convulsion. The largest gaps are called dykes, and descend from the surface of the earth, sometimes perpendicularly, sometimes obliquely, to the greatest depths ever tried. On each side of these gaps the strata correspond, but they are often sunk several feet or fathoms lower on one side than the other, and this is called a dip.

With respect to the origin of pit coal, it is the opinion of Dr. Black, Bishop Watson, and other philosophers of high reputation, that the strata of coal were formerly large collections of vegetable matter at the surface of the earth. In distant ages, Britain was probably almost entirely covered with immense forests and collections of peat moss, which (according to the opinion of these naturalists) being covered with quantities of sand or earth brought by floods, or by more gradual causes, as the falling of the substance of the neighbouring hills, has been pressed and consolidated, in course of time, into the substance called pit coal. The surface of the earth has also been probably rendered unequal in various places by the action of earthquakes; this would give rise to the formation of lakes in those places which were depressed. In this manner, a quantity of vegetable matter would become covered by deposition from water. Volcanic eruptions must often also have overwhelmed large collections of vegetable matters. We even find vegetable matter in an intermediate state between organized vegetable substances and coal; for peat has still some small remains of organic texture, but seems chiefly to consist of oily and inflammable matter, which only requires time and the pressure of superincumbent strata to convert it into the
firm

firm and compact texture of coal. In some places, the remains of forests have been observed converted into an imperfect pit coal, in which the trunks, branches, bark, and roots of trees, are discernible. In most of the varieties of coal, impressions of vegetable matters, and particularly of fern, are usually observable. Now it is remarkable, that both peat moss and fern are produced on wild and uncultivated lands, and this renders it still more probable, that coal in general owes its origin to peat moss. Coal is found in thin and broad strata, such as might be expected on the supposition of its being derived from the decay of peat moss, or collections of other vegetables on the surface of the earth. Coal is often covered with matter which cannot be supposed to have been created in its present state, as sandstone, the particles of which are evidently owing to the motion and friction occasioned by water. It has been already mentioned, that the products afforded by the distillation of peat moss and pit coal are precisely the same. We know of no substance purely and unquestionably mineral, which affords products at all similar, and it therefore on the whole seems probable, that the strata of coal found in different countries, however extensive, owe their origin to vegetable matter. The bituminous matters seem also to be exudations from vegetable substances buried in the earth.

In confirmation of the same opinion, I add the following extract from the late ingenious Mr. Whitehurst's Inquiry into the original State of the Earth.

‘ All the strata incumbent on coal, whether argillaceous stone or clay, contain figured stones, representing a vast variety of vegetables, or the impressions of them, as reeds of various kinds, striated and jointed at different distances, the euphorbia of the East Indies, the

the American ferns, corn, grass, and many other species of the vegetable kingdom. They are inclosed in the solid substance of the stone, &c. These vegetable forms, and the strata containing them, are the certain indication of coal, not only in Derbyshire, but in every part of the kingdom which I have visited; and I am informed, that the same phenomenon holds equally true in every other part of the world yet explored.' In general, the stone which holds fossil plants is either very hard and close, or bituminous, so as to afford no access to water.

The great difficulty in this hypothesis results from the immense quantities of these matters which are found in the earth, and this difficulty can only be removed by referring to a fact, which is supported by the traditions of every nation upon earth, the universal deluge.

Among many other curious observations, relating to the deluge and its remains, made by Dr. Scheuchzer and his brother, the Doctor informs us of the trunk of a tree, nine Paris feet in length, with some part of its branches still left upon it, which is lodged upon the summit of mount Stella, the chief of all the Alps of Switzerland, which, according to the barometer, is more than two English statute miles perpendicular in height, and four thousand feet higher than any trees or vegetables are observed to grow; he concludes, therefore, that it was left there by the subsidence of the waters of the deluge. Another modern writer also very properly remarks, 'When we find on any stones an exact resemblance of a plant, a leaf, or some fruit, that we are acquainted with, if these leaves are bent or folded, if they cross each other, or lie one upon another, they are certain indications that the plant or fruit so represented is an impresson made by a natural body.'

body*.' Specimens of this description are frequently found.

Not only vegetables, however, but parts of animals also, are met with, deeply plunged in the strata of the earth, for the presence of which, in such situations, we cannot account, except by supposing, that they were deposited during the deluge, when not only the windows of heaven were opened, but the fountains of the great deep were broken up; expressions which denote, in the strong style of oriental imagery, the extensiveness of that vast disturbance or convulsion which happened to this globe. A fossil skeleton of an alligator, twelve or fourteen feet in length, was discovered in the cliff of an alum rock, near Whitby, in Yorkshire. In a gravel pit of Suffolk, abounding with fossil shells, the entire skeleton of a whale was discovered, the bones of which, when they became friable by exposure to the air, were employed by a farmer for the manuring of his land. Fragments of an elephant's tooth were dug from a gravel pit at the end of Gray's Inn Lane, at the depth of twelve feet. From these and other facts it seems probable at least, that this part of the world, before the flood, contained animals as well as plants which now are very rarely found, or are totally incapable of existing in such a climate. This consideration will lead us to conclude, that the deluge not only destroyed the greater part of the animals then existing, but produced a considerable alteration in the constitution of the globe, and a permanent revolution in some of the laws of nature, of which the change that took place in the length of human life is one striking instance. The earth, and almost every part of it, is stored with the remains of trees, plants,

* Le Pluche *Speçt. de la Nature*, Dial. 25.

and fruits; of fish, testaceous, crustaceous, and squamous, and of other occasional inhabitants of the waters. The spoils of land animals are also met with, but in much smaller quantities, which it is not difficult to account for, when we consider, that the waters of the sea occupy more than twice as much of the globe as the land, and that the waters are much more copiously supplied with animals of considerable magnitude, than the land. Add to this, that the classes of corallines, lithophuta, and many of the testaceous kinds, are of a substance as hard as stone, and of a much more durable texture; whence it is not to be accounted a matter of surprize that they abound so much in the earth in the form of petrifications. We are to recollect also, that the catastrophe of a deluge would soon corrupt, destroy, and disperse the parts of such living creatures as die in the waters; while the natives of the sea would struggle with the difficulties of an inundation, and be at last deposited, perhaps alive, in the earth, when the settlement of the strata took place, and the waters retreated, as it is evident that many of them actually were, from the postures and circumstances in which they have been discovered*.

* See Jones's *Physiological Disquisitions*.

C H A P. XLII.

NAPHTA, PETROLEUM, BARBADOES TAR, &c.

Nature and Properties of Naphta.—Burning Fountains.—Petroleum.—Mineral Pitch, or Barbadoes Tar.—Lake Asphaltés.—Asphaltum; how collected.—Elastic Bitumen.—Component Principles of these Substances.

ALL these substances are of the bituminous kind, and are, indeed, all of the same nature, but differ in consistence. NAPHTA is an oily fluid, which, in its greatest degree of purity, is nearly colourless, is extremely volatile and subtile, and so light as to float even on spirits of wine. It has a strong oppressive smell, and evaporates spontaneously. Like other oils, it burns with smoke. It does not congeal at 0 of Fahrenheit. It is said to be gathered at the surface of certain wells in Persia, and is rarely found in Europe.

The vapour of naphta, which issues through the crevices of the earth, is generally supposed to be the cause of the flame which is sometimes observed on waters, fountains, &c. At Chittagon, in the East Indies, there is a fountain which bursts into flame of its own accord, whenever it has been extinguished by accident; this fountain has its deity and its priests; and some Europeans, suspecting the whole to be a pious fraud, pulled down the wall, &c. but found that the vapour actually kindled spontaneously when put out. It is possible, however, that this flame may be fed by inflammable air instead of naphta.

PETROLEUM, which is of a thicker consistence, and
more

more weighty than naphtha, is much more common. It is of a yellow or brown colour, and is found in Switzerland, Sicily, Italy, and France. It issues from the crevices of rocks, or is found floating on the surface of springs. The different kinds of petrolea, on distillation, yield naphtha, while a coaly residuum remains in the retort.

BARBADOES TAR is of a thicker consistence than petroleum, and is also called mineral pitch; it was formerly found near Babylon, and constituted, according to Vitruvius, when mixed with lime, the cement which was used in building the walls of that city. It is at present found in several parts of Europe and in America, where it drops, or distils, gradually from rocks.

ASPHALTUM is a substance much resembling Barbadoes tar; it is also called Jews pitch, and is thrown up in a liquid form from the bottom of the lake where Sodom and Gomorrah antiently stood. From the production of this substance this was called the Lake Asphaltes, from a Greek word denoting bitumen. The bitumen floating on the surface of the water is hardened by the heat of the sun, and is in that state collected by the Arabs on the shore, where it is thrown. The eastern asphaltum is seldom brought to Europe, but is used by the inhabitants as pitch.

All these thicker bitumens may be rendered thinner by distillation, and may be converted into an oily fluid, the tenuity of which is increased by the repetition of the process; at every distillation a quantity of charcoal, earthy matter, and carbonic acid gas, being separated from them.

In *Observations sur la Physique*, for January, 1788, vol. xxxii. M. de la Metherie makes mention of a mineral elastic bitumen analogous to the caoutchouc, or

elastic gum, and which is found near Castletown in Derbyshire. Its colour is brown, partly soft, flexible and elastic, and this when cut appears internally of a greenish yellow colour; partly brittle, with a conchoidal fracture. Both varieties are frequently united in the same specimen. Both are insoluble in spirit of wine, ether, and oil of turpentine, but yield to that of olives.

The production of all these bitumens is attributed to the action of subterraneous fire on strata of pit-coal, by which the oily parts are separated and sublimed in the same manner as by artificial heat.

A curious experiment is mentioned by Bishop Watson, which illustrates the relation of these four bitumens to each other. The most transparent oil of turpentine, resembling naphtha, may be changed into an oil resembling petroleum, by mixing it with a small portion of vitriolic acid; with a larger proportion of the acid the mixture becomes black and tenacious like Barbadoes tar, and the proportions of the ingredients may be so adjusted, that the mixture will even acquire a solid consistence like asphaltum.

All these substances become more tenacious, and acquire a darker colour by exposure to air. This seems to be owing to the absorption of oxygen, which, like oils, they possess the property of attracting from the atmosphere.

It appears that on distillation bitumens leave scarcely any residuum, the earthy part being merely accidental, and that the carbonic substance is by much the smallest in their composition, as their concretion seems wholly owing to the absorption of air, and not to the prevalence of the carbonaceous principle, since no coal appears, when they are burned on a hot iron.

C H A P. XLIII.

JET, AMBER, AMBERGRIS, AND MINERAL TALLOW.

General Properties of Jet.—Its Nature and Origin.—Amber.—Acid of Amber.—Natural History of Amber.—Different Opinions of its Origin.—Ambergris.—Its Natural History.—Mineral Tallow.

JET is a very compact bitumen, harder than asphaltum, always black, and susceptible of a good polish. It is so light as to swim on water, becomes electrical when rubbed, and is called black amber. When burned it emits a bituminous smell. Jet seems nearly allied to coal, and particularly to that species which is called cannel coal; it is distinguished chiefly by its structure, being composed of fibres parallel to each other like those of wood. It seems in fact to be wood, which has been long buried in the earth, and penetrated by mineral steam, so as to assume the appearance and solidity of coal.

AMBER is the substance known to the ancients under the name of electrum and succinum. In this substance the property, which certain bodies have, of attracting light substances, when rubbed, was first observed, and was therefore called electricity. The most valuable amber is perfectly transparent, of a pale yellow, and is much more esteemed when it happens to contain any extraneous substance, such as leaves, insects, &c. When broken it presents a polished surface at the place of the fracture. Amber does not readily dissolve in any fluid we are yet acquainted with. Spirit of wine has some small effect upon it, and from this combination a tincture is produced,

but the quantity it dissolves is very small. When applied to the flame of a candle it readily takes fire, and burns with a bright white flame and thick smoke, and leaves a considerable quantity of charcoal. Amber exposed to heat, without the action of flame, softens and swells very considerably. Distilled in a retort by a heat gradually raised, it affords a watery fluid of a red colour, manifestly acid; this acid spirit retains the strong smell of amber; an acid volatile salt afterwards passes over, which crystallizes in small white or yellowish needles in the neck of the retort. This salt is succeeded by a white and light oil much resembling naphtha; by continuance of the process, and in proportion as the heat is increased, the oily matter which comes over is coloured and more viscid, like petroleum. What remains at the bottom of the retort is a black mass resembling asphaltum. It appears, therefore, from distillation, that the analogy of amber with the other bitumens is very strong.

A gentle heat is sufficient to raise the concrete volatile salt of amber, and care must be taken to regulate it so as not to force up the oil, when it is required to have the salt in a separate state. This saline matter was for some time supposed to be an alkaline salt, but has been since found to be an acid of peculiar properties, and capable of combination with alkalies, earths, and metallic calces.

Amber is usually dug out of the earth, and abounds particularly in the Prussian dominions. Wood is generally found near it, and it is therefore believed to be of vegetable origin. Its analysis seems to shew, that it consists of an oil rendered concrete by combination with an acid. The most transparent specimens are usually found on the sea-shore, particularly on the shores of the Baltic, in Ducal Prussia. Amber is not
always

always of a yellow colour; it is sometimes brown, sometimes quite opake, and sometimes black. Some have supposed that it is entirely of mineral origin, but this is disproved by its distillation, and by the foreign bodies which are frequently contained in it, and which seem to demonstrate that it was once in a fluid state.

Hoffinan and Newman say, that it is sometimes found upon the sea-shore, or upon the surface of waters, particularly after great storms, when it is collected by means of nets; but that the greater part of it is dug out of pits. The first stratum is sand, then clay, then a layer of branches and trunks of trees, then a considerable quantity of pyrites, whence vitriol is prepared, and lastly, a bed of sand, through which the amber is dispersed in small pieces, or collected together in heaps. This account greatly favours the idea of the vegetable origin of amber; but Wallerius asserts, that the black and dark coloured amber is often found in the bowels of cetaceous fishes. M. Girtanner has a peculiar opinion on this subject; he thinks that amber is a vegetable oil rendered concrete by the acid of ants; it is that kind of ants called *formica rufa* by Linnæus, which prepares it, according to this author. These insects dwell in old forests of fir trees, where the fossil amber is found, which, when first dug, is ductile like wax, and becomes hard on exposure to air. No insect is so commonly found in amber as the ant.

AMBERGRIS is of much the same nature as amber, but differs from it by its particular consistence, which nearly approaches to that of bees wax. Its structure is sometimes like bees wax, but sometimes it is granulated, and appears opake, or of a dark grey. Experiments prove that it resembles amber in its nature. When analyzed it is found to consist of phlegm, a volatile acid partly fluid, oil, and a little coaly mat-

ter. It dissolves more readily in spirit of wine than amber.

It is most common in the Indian seas, on the eastern coast of Africa, Madagascar, &c. and is found either floating on the sea, or cast on the sea-shore. In this substance animal and vegetable remains are sometimes found, as for instance, parts of birds, &c.

The origin of this substance is probably the same with that of amber. According to M. Aublet (in his *Histoire de la Guiane*) it is nothing more than the juice of a tree inspissated by evaporation; and if this is true, it is a substance which belongs properly to the vegetable kingdom. The tree which is said to produce it grows in Guiana, and is called *cuma*, but has not been examined by other botanists. When a branch is broken by high winds, a large quantity of the juice exudes; and if it chances to have time to dry, various masses (some of which have been so large as to weigh one thousand two hundred pounds and more) are carried into the rivers by heavy rains, and through them into the sea; afterwards they are either thrown on the shore, or eaten by some fish, chiefly the spermaceti whale, known by the name of *physiter-macrocephalus* among ichthyologists. This kind of whale is extremely voracious of this gum-resin, and swallows such large quantities when it meets with it, that it generally becomes sick; so that those employed in the fishery of these whales always expect to find some amber mixed with the excrements and remains of other food in the bowels of those whales which are lean. Various authors, among whom is Father Santes, in his *Ethiopia Orientalis*, who travelled to various places on the African coast, and Bomare, say, that some species of birds are also fond of eating this substance, as well as whales and other fishes. This accounts very well for the
claws,

claws, beaks, bones, and feathers of birds, parts of vegetables, shells, and bones of fish, and particularly for the beaks of the cuttle-fish, *sepia octopodia*, which are sometimes found in the mass of this substance. M. Aublet brought specimens of this gum-resin, which he collected on the spot, from the cuma tree at Guiana. It is of a whitish brown colour, with a shade of yellow, and melts and burns like wax in the fire. M. Rouelle examined very carefully this substance, brought over by M. Aublet, and found that it produced exactly the same results as good amber. These observations seem to place it beyond a doubt, that both amber and ambergris are vegetable products, and that those who, from having found these substances in the intestines of whales, concluded that it was a faecal matter of those animals, were mistaken.

MINERAL TALLOW is a very peculiar substance. It was found on the coasts of Finland, in the year 1736. Its specific gravity is 0.770, whereas that of tallow is 0.969. Its colour is white; its consistence is that of tallow, and like it it is brittle; it feels greasy, and stains paper just as tallow does, and the traces thus left on paper melt on the approach of flame. It burns with a blue flame and a smell of grease, leaving a black viscid matter, which is more difficultly consumed. It is found in some rocky parts of Persia, but seems mixed with petroleum. Dr. Herman, of Strasburgh, mentions a spring, in the neighbourhood of that city, which contains a substance of that nature diffused through it, which separates on ebullition, and may then be collected. The origin of this substance is unknown.

C H A P. XLIV.

OF THE DIAMOND, CONSIDERED AS AN
INFLAMMABLE SUBSTANCE.

Natural History of Diamonds.—Varieties.—Internal Structure.—Experiments proving the inflammable Nature of the Diamond.—Experiments of M. Cadet—Of D'Arcet.—Vital Air necessary to the Combustion of the Diamond.—Experiments of Lavoisier.—Further Experiments.—Experiments of Mr. Tennant.—The Diamond proved to be crystallized Charcoal.

THE diamond, though slightly mentioned when treating of gems, belongs properly to the class of inflammables. It is the hardest and most brilliant of all substances. Its specific gravity is 3,445, hence it refracts the rays of light very powerfully; but it possesses this power even in a much greater degree than might be supposed from its density, and hence proceeds its singular brilliancy. The diamond, properly so called, is colourless; but it also retains this name when it is slightly tinged either with red or yellow. It is therefore not the colour of the stone, but its hardness and lustre, which obtain for it the denomination of a diamond.

Diamonds are found in the East Indies, particularly in the kingdoms of Golconda and Visapour: they likewise come from the Brasils; but these last appear to be of an inferior quality, and are known in commerce by the name of Portuguese diamonds.

Diamonds are usually found in an ochreous yellow earth, under rocks of grit-stone and quartz; they are likewise found detached, in torrents which have carried them from their beds. They are seldom found
above

above a certain size. The sovereigns of India reserve the largest, in order that the price of this article may not fall. Diamonds have no brilliancy when dug out of the earth, but are covered with an earthy crust, which incloses a second crust, of the nature of calcareous spar, according to M. Romé de Lisle. Bright diamonds are occasionally found in waters.

These gems very often have no regular form, but are flat; or worn round. Sometimes they are regularly crystallized in octahedrons, formed by two quadrangular pyramids, united at their base; they are likewise found with twelve, twenty-four, and forty-eight faces.

Diamonds appear to be composed of laminæ, laid upon each other; and they are easily divided, by striking them in the direction of these laminæ with a good steel instrument. There are, however, some diamonds which do not appear to be formed of distinct laminæ, but of twisted fibres, like those of knots in wood. These last are exceedingly hard, and cannot be wrought; lapidaries call them diamonds of nature.

Diamonds are shaped by first cleaving them in the direction of their lamellæ, and then rubbing them with other diamonds. They are then polished by an horizontal steel wheel, dusted with their own powder mixed with olive oil.

Sir Isaac Newton having observed that inflammable substances had a stronger power of refracting the rays of light, in proportion to their densities, than other bodies, and observing also the strong refractive power of the diamond, conjectured, upon these principles, that it must belong to this class of minerals. The reasonings of Newton were so correct, that many of his conjectures, though made only on theory, have been since confirmed by actual experiment.—Thus it has since been discovered that diamonds, exposed to a high

a high degree of heat, entirely disappear at the instant that an appearance of combustion is observed. M. Cadet exposed diamonds, in covered and luted* crucibles to the violent heat of a forge during two hours, by which the diamonds only lost one sixteenth part of their weight, he was therefore of opinion, that the consumption of diamonds in open vessels is not a true volatilization, but merely an exfoliation occasioned by the expansion of the air contained between the laminæ of the diamond, by which it is broken into portions so minute as to escape observation. M. D'Arcet opposed to the above explanation, the escape of the substance of the diamonds through the most solid porcelain crucibles, and the luminous appearance noticed by Macquer, and which was afterwards observed by M. Roux to be an actual flame. It was, indeed, even found, that diamonds inclosed in a ball of porcelain earth, and exposed to heat, were totally consumed; the space which the diamond occupied was found empty; no traces of it could be discovered, and yet the ball of porcelain, which was hardened by the heat, was apparently entire. This experiment, according to Fourcroy, was frequently repeated with the same extraordinary result. It was found, however, that if the diamond was embedded in charcoal, and carefully inclosed in several crucibles placed within each other, and the whole covered with cement, it did not disappear from exposure to a very violent heat; it was only rendered black at its surface, and when this crust was taken off, it appeared in its original splendor. It was therefore very justly concluded, that perfect exclusion from vital air is sufficient to prevent the consumption of the diamond, as well as of all other in-

* Luting is a kind of earthy cement used by chemists, and formed in different ways.

flammable substances; and it was therefore necessary to suppose, that the porcelain earth, in which the other diamonds were inclosed, suffered some small separation from exposure to heat, which, though so minute as to escape observation after the ball was cold, was yet sufficient to admit the air. This opinion was fully confirmed by the experiments of M. Lavoisier, who found, that diamonds are only consumed in proportion to the quantity of vital air to which they are exposed. He also found, that the combustion of the diamond was attended with the formation of carbonic acid gas; but at the time he made his experiments, the nature of that fluid does not seem to have been sufficiently understood, to enable this great philosopher to draw a correct conclusion relative to the composition of the diamond.

The experiments of Lavoisier were pursued by Mr. Tennant, and their result may be found in the first part of the Philosophical Transactions for the year 1797. He observed that, from the extreme hardness of the diamond, a stronger heat was required to inflame it, when exposed merely to air, than could easily be supplied in close vessels, except by means of a strong burning glass; but that with nitre* its combustion could be effected in a moderate heat. To expose it to this process, without any danger from the intrusion of extraneous matters, Mr. Tennant inclosed the nitre and the diamond in a tube of gold, and took every necessary precaution to prove that no carbonic acid gas, or fixed air, could be included, except what the diamond itself afforded. When the diamond was entirely destroyed in the gold vessel by the inflammation of the nitre, the substance which remained precipitated lime from lime

* The use of the nitre is obviously to supply a quantity of pure air to effect the combustion.

water, and with acids afforded nitrous and fixed air; and appeared, in fact, to consist of nitre partly decomposed, and of alkali united with fixed air.

In order to estimate the quantity of carbonic gas which might be obtained from a given weight of diamond, two grains and an half were inclosed in a tube with a quarter of an ounce of nitre. After the process, the alkaline matter contained in the tube was dissolved in water, and the whole of the diamonds was found to be consumed. Into the alkaline solution a quantity of saturated solution of marble in marine acid was poured, and after the fixed air had united with the calcareous earth, the alkali remained in solution with the marine acid. The clear liquor was then poured off from the calcareous precipitate, and was found to contain no fixed air. The carbonic acid gas being then expelled from the calcareous matter by the addition of an acid, occupied a space equal to about 10 ounces of water, which, according to the calculations of Lavoisier, is exactly the quantity that would be produced by the conversion of $2 \frac{1}{2}$ grains of pure and solid charcoal into an aerial form. That the fixed air, thus produced, consisted of the same matter as that of charcoal, Mr. Tennant proved by combining it with lime, and exposing it to heat with phosphorus, when he found that it afforded charcoal in the same manner as any other calcareous substance.

Mr. Tennant repeated the experiment with $1 \frac{1}{2}$ grains of diamond, and the result was the same. Upon these evidences therefore he concludes, and apparently with reason, that this peculiar and beautiful substance, so valued by the highest classes of mankind, the decoration of royalty, and the emblem of all that is pure and excellent in nature, is no other than that despised matter, *charcoal*, in a state of crystallization.

C H A P. XLV.

THE STRUCTURE OF THE EARTH.

The Curiosity of Man on this Topic limited by the Weakness of his Powers.—The Body of the Earth disposed in Strata.—Declivities of Mountains.—Disposition and Order of the Strata.—Caldy Island.—Where Metals are usually found.—Probable State of the Earth at its Creation.—Laws by which Alterations would be produced.—Fossil Shells, &c. accounted for.—Formation of Islands, &c.—Other Irregularities of the Earth's Surface explained.

AFTER the preceding survey of the natural contents of this globe of earth, and of their component principles, the next object of attention is the earth itself, and the general arrangement of those substances of which it is composed. These are neither disposed in a regular series, according to their specific gravities, nor yet thrown together in total disorder, as if by accident or chance. Human industry has hitherto been able to penetrate but a very little way into the bowels of the earth, and we can but know little of its interior parts. The depth of the earth, from the surface to the center, is more than four thousand miles, and yet the deepest mine in Europe, that at Cottéberg; in Hungary, is not more than one thousand yards deep; “the greatest depth, therefore,” says an excellent writer, “to which avarice has ever yet penetrated, may be compared to the puncture made in the body of an elephant by the proboscis of a gnat.”

From what has been discovered, however, of those parts which lie most contiguous to our observation, naturalists have compared the structure of the earth to the leaves of a book, or the coats of an onion. Ex-
cept,

cept, indeed, in some of those immense mountains, which have existed from the creation, or at least from the deluge, where the matter, from whatever cause, is more homogeneous, the earth is found to consist of various strata; or layers, which differ according to the circumstances of climate and situation. The surface, in general, evidently consists of a confused mixture of decayed animal and vegetable substances and earths rudely united together; but when we have penetrated below the surface, we find the materials of the globe arranged in a more regular manner. Sometimes, indeed, we find heaps of stone, which do not consist of layers, but are confused masses of unequal thickness, and are called rocks. The strata are, in general, extended through a whole country, and, perhaps, with some interruptions and varieties, through the globe itself. These extensive bodies are found most regular when the country is flat, being, in that case, nearly parallel to the horizon, though frequently dipping downwards in a certain angle; in many places the beds have a wave, as where the country consists of gently waving hills and vales; here too they generally dip. In travelling a mile we, perhaps, pass through ground composed mostly of sand, in another mile we find it, perhaps, composed of clay; and this is occasioned by the edges of the different strata lying with an obliquity to the horizon. By the same kind of projection, mountains, or ridges of mountains, are produced, which, in general, have what is called a back and a face, the former smoother and the latter more rugged. We generally find too, on one side of a mountain, a more gradual ascent than on the other, which is occasioned by the strata, which have risen above the general level of the country, being abruptly broken off. Mountains are in general more abrupt
towards

towards the west, and have a more gentle declivity towards the east; hence the western coast of countries is almost always steeper than the eastern. The back of a mountain shews the obliquity with which the strata sink into the ground; the abrupt edge of the strata becomes more sloping, as time, producing a gradual decay, draws the rubbish from above. Where the face of a country is so irregular, its appearance depends on the different hardness or softness of the strata. The abrupt rocks, which we observe in many parts, seem to have been composed of an adventitious mixture of different strata, which have resisted the injuries of time with unequal force.

Between the strata, layers of different clays are interposed, which are called by the miners way-boards; they are seldom more than four or five, and in some instances not more than one foot thick; they serve to mark and distinguish the different strata, for in fact the strata are themselves composed of different laminæ*.

Every part of a stratum may be considered as equally thick when covered with an incumbent bed; but when exposed to the action of the air, and other external agents, a great part of it, whether grit, lime-stone, or toad-stone, is decomposed and converted into earth or mould. Immediately under the soil the fragments of stone are small, and gradually increase to the depth of fifteen or twenty feet, where it commonly appears solid, and fit for the mason. Strata are usually interrupted by clefts or fissures at different distances, which seem to have been the effects of violence. In these fissures only the ores of metals are to be found.

It has been remarked, that we cannot, by digging into the earth, obtain a view of the position and nature

* Whitehurst, Chap. XVI.

of the strata for more than some few hundreds of yards. There is, however, one curious instance of an island, near the coast of Pembrokehire, called *Caldy Island*, where the earth suffered the action of so unusual a disruption, that the strata, of which the whole island is composed, are placed in a vertical position, so that their edges are all exposed to view, and they may be observed in succession from one end of the island to the other. Here then we have the singular opportunity of observing in what order they were originally placed, to the depth of two miles. At one end of the island they are not more than a foot thick, but increase, as we proceed, till they terminate in a stratum of red stone, more than a mile in thickness, which, with good reason, is supposed to have been the lowest of them all before they were elevated and thrown upon their edges. The thinner strata, which were originally uppermost, have fossil shells and corallines in them; but I have not heard that any thing like the traces of lava are to be found to countenance the supposition, that this singular accident was occasioned by the explosive force of a volcano.

The order of the strata in Derbyshire is as follows:

1. Millstone-grit, a coarse sand-stone composed of granulated quartz and quartz pebbles.
2. Shale or shiver, or black-laminated clay, much indurated.
3. Lime-stone, in various laminæ.
4. Toad-stone, a black porous substance, hard, resembling scorixæ, and apparently a volcanic production.
5. Lime-stone.
6. Toad-stone.
7. Lime-stone.
8. Toad-stone.
9. Lime-stone again. Such (the toad-stone excepted) appears to be the general order in which the strata appear through the different regions of the earth, or at least wherever the lime-stone predominates, which is in a considerable proportion, though it must be

*

remarked

remarked that the largest mountains are chiefly granite. Wherever, therefore, the first of these strata appears on the surface, the second lies certainly under it, the third under the second, &c. still excepting the toad-stone, which, being a volcanic production, may be supposed to be in some measure casually interposed.

The toad-stone intersects all the mineral veins, and cuts off all communication between the upper and lower parts of the fissures, being continued horizontally in one uninterrupted mass. Toad-stone is of an extremely hard and close texture, so much so as even to prevent water from filtering through it, at least in any quantity. It is perfectly similar to Iceland lava in appearance, and in being unaffailable by acids. It has no fissures, and frequently fills up the fissures of the other strata; in fine, it being not universal, but only an occasional appearance, there is the utmost probability that it is a species of lava. It being inserted between the other strata seems also to afford a proof, that it originally flowed from a volcano, the funnel or shaft of which did not approach the open air, but discharged its fiery contents between the strata in all directions. When the toad-stone is dug through, however, and the vein or fissure pursued, the miner is never disappointed in meeting it again, as soon as he arrives at the stratum of lime-stone*.

The strata of coal, argillaceous stones, clay, &c. are always incumbent on the strata of grit, shale, and lime-stone. The former are seldom in strata of above twenty feet thick, and generally not more than four or five; the latter are in strata of from fifty to one hundred and fifty feet in thickness or depth †.

* Whitehurst, Chap. XVI.

† *Ib.*

All beds of gravel are supposed to have been deposited either by rivers or by the action of the sea, and the stones that compose them to have been rounded by attrition. It is no inconsiderable proof in favour of such a conjecture, that sea-shells, &c. are so frequently found with gravel.

The argillaceous strata are only productive of iron and coal. The ores of copper, lead, zinc, &c. are confined entirely to the lime-stone strata, a few instances excepted, where they are found in shale.

The disposition of the superficial strata, however, differs in mountainous and champaign countries. In a well which was dug at Amsterdam, to the depth of two hundred and thirty feet, the following substances were found in succession*: seven feet of vegetable earth, nine of turf, nine of soft clay, eight of sand, four of earth, ten of clay, four of earth, ten of sand, two of clay, four of white sand, one of soft earth, fourteen of sand, eight of clay mixed with sand, four of sea-sand mixed with shells, then an hundred and two feet of soft clay, and then thirty-one feet of sand.

In a well dug at Marly, to the depth of an hundred feet, M. Buffon gives us a still more exact enumeration of its layers of earth. Thirteen feet of a reddish gravel, two of gravel mingled with a vitrifiable sand, three of mud or slime, two of marle, four of marly stone, five of marle in dust mixed with vitrifiable sand, six of very fine vitrifiable sand, three of earthy marle, three of hard marle, one of gravel, one of eglantine, a stone of the hardness and grain of marble, one of gravelly marle, one of stony marle, one of a coarser kind of stony marle, two of a coarser kind still, one of

* Varenus, as quoted by M. Buffon, p. 358.

vitriifiable sand mixed with fossil shells, two of fine gravel, three of stony marle, one of coarse powdered marle, one of stone, calcinable like marble, three of grey sand, two of white sand, one of red sand streaked with white, eight of grey sand with shells, three of very fine sand; three of a hard grey stone, four of red sand streaked with white, three of white sand, and fifteen of reddish vitriifiable sand.

The direction too in which the strata are found is also exceedingly different in different situations. 'When the continuity,' says Mr. Jones, 'of the strata is interrupted by a fracture, the strata are throw out of that horizontal position which is natural to them; and make an angle with the horizon; which may be called the angle of their elevation or depression; the miners call it their *dip*. In this case, if the succession of strata is accurately noted on one side of the fracture, where a vein of coal or metal is found amongst them, it may thence be learned where the same vein will occur again on the other side of the fracture; because it will be found adjacent to the same strata as before. When the edges of the strata, on each side of a fissure, are thus parted and mismatched, they are said to *trap*; and the space between them is filled up with rubble, or stones, or minerals, &c. Sometimes these fissures are the richest parts of the soil, containing such matters as are not to be found elsewhere*.' In fig. I. plate I. F. repre-

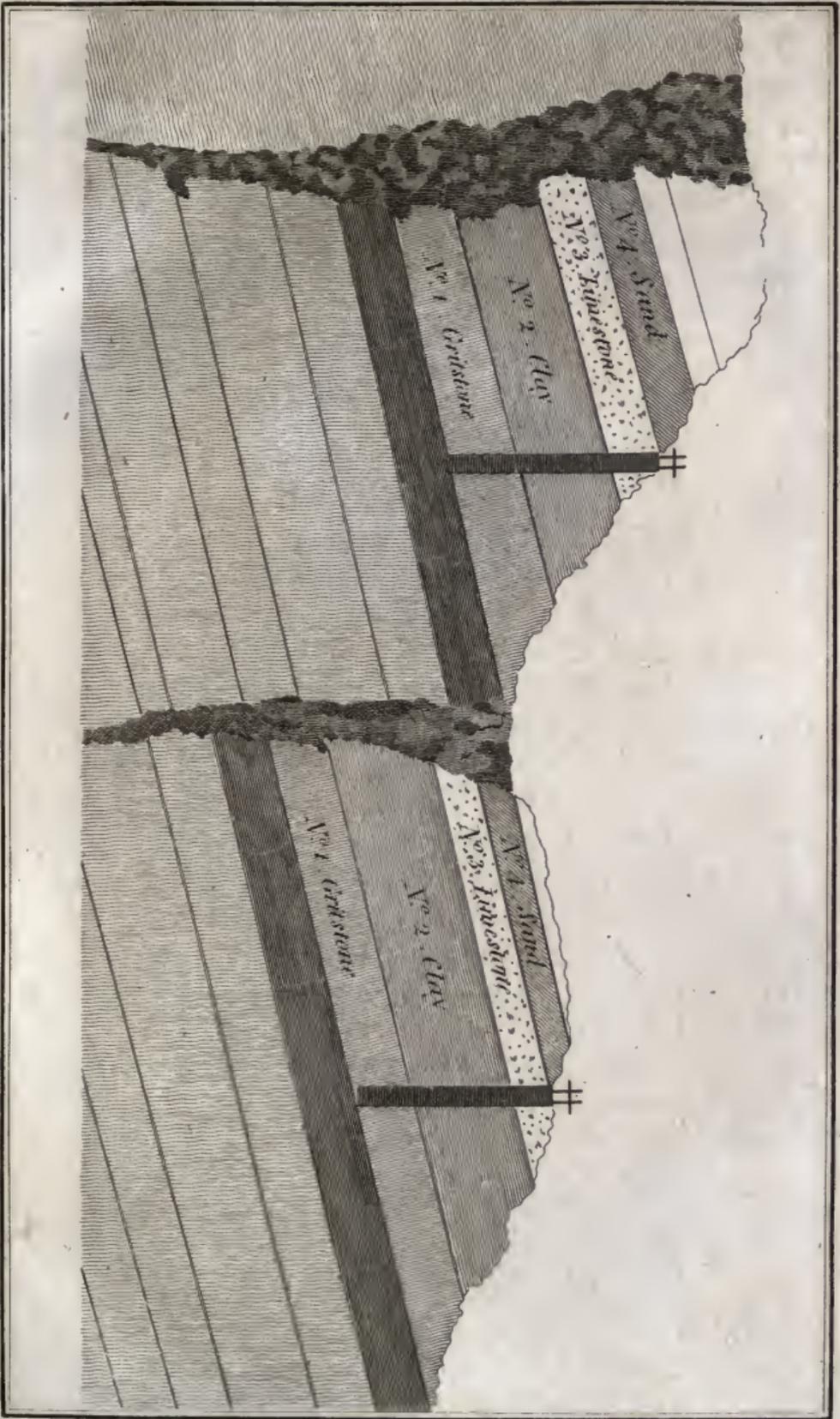
* Some of the fissures in Cornwall are near twenty feet over, and commonly full, or near it, of metallic and mineral matter. The fissures at the greatest depth are generally largest; as we ascend they become gradually less, but more frequent and numerous: infomuch that if the globe was divided in two, and the strata viewed upon the face of the section, the figures would appear after the manner of a tree: at the bottom a large trunk, which higher up is divided into branches, which break into lesser,

F. represents the fissure, by which the strata are parted, and which is filled up with extraneous rubbish, carried in after the strata were parted. The black vein of coal on the left side is found with five other strata above it; but being interrupted by the fissure F. where it comes out to the day, the stratum of sand, No. 4, on the right side, on account of the trapping, is found opposite to it; thence it is to be collected, that the fourth stratum below that sand will be coal; and when the angle of the *dip* is observed, it may be known where to sink a pit, and where the coal will again appear to the day; provided the figure of the surface of the ground will permit it to shew itself. When I was once at the bottom of a lead mine in Derbyshire, a miner informed me, that the veins of the metal always make a greater angle with the horizon than the sides of the mountain do, in which they are found and come out to the day; which was probably occasioned by the descent of the waters of the flood, tearing away much of the matter from the summit, and lodging it upon the sides and in the vallies beneath, after the strata had received their inclination.

With respect to the more internal parts of the earth, for the reasons assigned in the beginning of this chapter, nothing can be advanced with certainty, and hypotheses cannot be relied on.

By some it has been supposed, that the center of the earth consists of fire. Mr. Kirwan, however, has satisfactorily proved, that the notion of a central fire or heat is void of foundation. Since no authentic obser-

and at the top into twigs. But the branches are not continued in a straight line: they start afresh, at some little distance on one side, as in fig. 2. that by an intervening boundary the metallic matter might be detained in its descent, and prevented from sinking away to the bottom of the earth. See Mr. Hutchinson's Observations in the year 1706, p. 316, 317.





vation assures us, that this heat increases in proportion as we penetrate below the surface of the earth; on the contrary, many experiments serve to evince, that it rather decreases, (though never to less than thirty-six degrees) and that its variation at the same distance below the surface constantly bears a proportion with the variation of the solar heat at the surface.

The more general opinion is, that the strata originally lay horizontally, and were formed by a deposition from water. The arguments for this opinion are forcible. The relics of a variety of substances, which we now find only in the sea, are found in rocks and mountains, at a very great distance from it. In strata of lime-stone, every where distant from the sea, we find the remains of shells, &c. the productions of the ocean. Other circumstances prove, that the sea has covered parts of the earth, which are now at a great distance from it, and that the various directions which the strata now have were not their direction at their first formation. That the frame of this earth has undergone some violent concussion is evident, as was already stated, from the traces which still remain. The strata we have seen are often broken in different directions, in general perpendicularly; so that the parts of the strata are separated from each other. The width of these rents is different, sometimes a few inches, sometimes many yards. They are very commonly filled up with substances different from the composition of the strata. In mountains there is sometimes observed the appearance of a white stone, which passes through it like a vein. This has been a rent filled up with a particular kind of stone. These are very common in the strata of coal. They are generally of considerable hardness, and in them metallic substances are usually found. When any of

these are not filled up with extraneous matter, the internal surface is set with very beautiful and regular crystals of the sparry kind, projecting into the cavity.

Some have attributed these irregularities to frequent earthquakes; others have imagined that the globe, before the deluge, contained an immense body of water, covered over with a crust of earth, which at the deluge was broken through, and partly sunk in the waters, the elevated edges forming the mountains and high lands, while the lower were overflowed by the ocean; others have supposed, that the near approach of a comet has thrown the materials of the globe into confusion. Buffon imagines, that the sea is continually changing its bed, and is constantly washing away the ground from one place to another*.

But

* A short sketch of the most remarkable theories of the earth is given by a popular writer, and it may be amusing to some readers to trace these vagaries of the human imagination.

The first who formed this amusement of earth-making into system was the celebrated Thomas Burnet, a man of polite learning and rapid imagination. His *Sacred Theory*, as he calls it, describing the changes which the earth has undergone, or shall hereafter undergo, is well known for the warmth with which it is imagined, and the weakness with which it is reasoned, for the elegance of its style, and the meanness of its philosophy. The earth, says he, before the deluge, was very differently formed from what it is at present: it was at first a fluid mass; a chaos composed of various substances, differing both in density and figure: those which were most heavy sunk to the center, and formed in the middle of our globe an hard solid body; those of a lighter nature remained next; and the waters, which were lighter still, swam upon its surface, and covered the earth on every side. The air, and all those fluids which were lighter than water, floated upon this also; and in the same manner encompassed the globe; so that between the surrounding body of waters, and the circumambient air, there was formed a coat of oil, and other unctuous substances, lighter than water. However, as the air was still extremely impure, and must have carried up with it many

of

But the arguments and observations of Mr. Whitehurst are more deserving attention, since he is almost the

of those earthy particles with which it once was intimately blended; it soon began to defecate, and to depose these particles upon the oily surface already mentioned, which soon uniting, the earth and oil formed that crust, which soon became an habitable surface, giving life to vegetation, and dwelling to animals.

This imaginary antideluvian abode was very different from what we see it at present. The earth was light and rich; and formed of a substance entirely adapted to the feeble state of incipient vegetation: it was an uniform plain, every where covered with verdure; without mountains, without seas, or the smallest inequalities. It had no difference of seasons, for its equator was in the plain of the ecliptic, or, in other words, it turned directly opposite to the sun, so that it enjoyed one perpetual and luxuriant spring. However, this delightful face of nature did not long continue in the same state, for, after a time, it began to crack and open in fissures: a circumstance which always succeeds when the sun exhales the moisture from rich or marshy situations. The crimes of mankind had been for some time preparing to draw down the wrath of Heaven; and they, at length, induced the Deity to defer repairing these breaches in nature. Thus the chasms of the earth every day became wider, and, at length, they penetrated to the great abyss of waters; and the whole earth, in a manner, fell in. Then ensued a total disorder in the uniform beauty of the first creation, the terrene surface of the globe being broken down: as it sunk the waters gushed out in its place; the deluge became universal; all mankind, except eight persons, were destroyed, and their posterity condemned to toil upon the ruins of desolated nature.

It only remains to mention the manner in which he relieves the earth from this universal wreck, which would seem to be as difficult as even its first formation. "These great masses of earth falling into the abyss, drew down with them vast quantities also of air; and by dashing against each other, and breaking into small parts, by the repeated violence of the shock, they, at length, left between them large cavities filled with nothing but air. These cavities naturally offered a bed to receive the influent waters; and in proportion as they filled, the face of the earth became once more visible. The higher parts of its broken surface, now become the tops of mountains, were the first that appeared; the plains

the only writer on this subject, who has united observation with theory.

With

plains soon after came forward, and, at length, the whole globe was delivered from the waters, except the places in the lowest situations; so that the ocean and the seas are still a part of the ancient abyfs that have not had a place to return to. Islands and rocks are fragments of the earth's former crust; kingdoms and continents are larger masses of its broken substance; and all the inequalities that are to be found on the surface of the present earth, are owing to the accidental confusion into which both earth and waters were then thrown."

'The next theorist was Woodward, who, in his *Essay towards a Natural History of the Earth*, which was only designed to precede a greater work, has endeavoured to give a more rational account of its appearances; and was, in fact, much better furnished for such an undertaking than any of his predecessors, being one of the most assiduous naturalists of his time. His little book, therefore, contains many important facts, relative to natural history, although his system may be weak and groundless.

'He begins by asserting that all terrene substances are disposed in beds of various natures, lying horizontally one over the other, somewhat like the coats of an onion; that they are replete with shells, and other productions of the sea: these shells being found in the deepest cavities, and on the tops of the highest mountains. From these observations, which are warranted by experience, he proceeds to observe, that these shells and extraneous fossils are not productions of the earth, but are all actual remains of those animals which they are known to resemble; that all the beds of the earth lie under each other, in the order of their specific gravity; and that they are disposed as if they had been left there by subsiding waters. All these assertions he affirms with much earnestness, although daily experience contradicts him in some of them; particularly we find layers of stone often over the lightest soils, and the softest earth under the hardest bodies. However, having taken it for granted, that all the layers of the earth are found in the order of their specific gravity, the lightest at the top, and the heaviest next the center, he consequently asserts, and it will not improbably follow, that all the substances of which the earth is composed were once in an actual state of dissolution. This universal dissolution he takes to have happened at the time of the flood. He supposes that at that time a body
of

With respect to the form of the earth, it is scarcely necessary to mention, that it is nearly round; a circumstance,

of water, which was then in the center of the earth, uniting with that which was found on the surface, so far separated the terrene parts as to mix all together in one fluid mass; the contents of which afterwards sinking according to their respective gravities, produced the present appearances of the earth. Being aware, however, of an objection that fossil substances are not found dissolved, he exempts them from this universal dissolution, and for that purpose, endeavours to shew that the parts of animals have a stronger cohesion than those of minerals; and that, while even the hardest rocks may be dissolved, bones and shells may still continue entire.

So much for Woodward; but of all the systems which were published respecting the earth's formation that of Whiston was most applauded, and most opposed. Nor need we wonder; for being supported with all the parade of deep calculation, it awed the ignorant, and produced the approbation of such as would be thought otherwise, as it implied a knowledge of abstruse learning, to be even thought capable of comprehending what the writer aimed at. In fact, it is not easy to divest this theory of its mathematical garb; but those who have had leisure, have found the result of our philosopher's reasoning to be thus. He supposes the earth to have been originally a comet; and he considers the history of the creation, as given us in scripture, to have its commencement just when it was, by the hand of the Creator, more regularly placed as a planet in our solar system. Before that time, he supposes it to have been a globe without beauty or proportion; a world in disorder; subject to all the vicissitudes which comets endure; some of which have been found, at different times, a thousand times hotter than melted iron; at others, a thousand times colder than ice. These alternations of heat and cold, continually melting and freezing the surface of the earth, he supposes to have produced, to a certain depth, a chaos entirely resembling that described by the poets, surrounding the solid contents of the earth, which still continued unchanged in the midst, making a great burning globe of more than two thousand leagues in diameter. This surrounding chaos, however, was far from being solid: he resembles it to a dense though fluid atmosphere, composed of substances mingled, agitated, and shocked against each other; and in this disorder he describes the earth to have been just at the eve of creation.

cumstance, however, which, though now so universally known, remained undiscovered for many thousand

‘ But upon its orbit’s being then changed, when it was more regularly wheeled round the sun, every thing took its proper place; every part of the surrounding fluid then fell into a situation, in proportion as it was light or heavy. The middle, or central part, which always remained unchanged, still continued so, retaining a part of that heat which it received in its primæval approaches towards the sun; which heat, he calculates, may continue for about six thousand years. Next to this fell the heavier parts of the chaotic atmosphere, which serve to sustain the lighter: but as in descending they could not entirely be separated from many watery parts, with which they were intimately mixed, they drew down a part of these also with them, and these could not mount again after the surface of the earth was consolidated: they, therefore, surrounded the heavy first descending parts, in the same manner as these surround the central globe. Thus the entire body of the earth is composed internally of a great burning globe: next which is placed an heavy terrene substance, that encompasses it; round which also is circumfused a body of water. Upon this body of water, the crust of earth on which we inhabit is placed: so that, according to him, the globe is composed of a number of coats, or shells, one within the other, all of different densities. The body of the earth being thus formed, the air, which is the lightest substance of all, surrounded its surface; and the beams of the sun darting through, produced that light which, we are told, first obeyed the Creator’s command.

‘ The whole œconomy of the creation being thus adjusted, it only remained to account for the risings and depressions on the surface of the earth, with the other seeming irregularities of its present appearance. The hills and vallies are considered by him as formed by their pressing upon the internal fluid, which sustains the outward shell of earth, with greater or less weight: those parts of the earth which are heaviest, sink into the subjacent fluid more deeply, and become vallies: those that are lightest, rise higher upon the earth’s surface, and are called mountains.

‘ Such was the face of nature before the deluge; the earth was then more fertile and populous than it is at present; the life of man and animals were extended to ten times its present duration; and all these advantages arose from the superior heat of the central globe, which ever since has been cooling. As its heat was then in full

land years. That its form is spherical, was first conjectured from the curved line which bounds the earth's

full power, the genial principle was also much greater than at present; vegetation and animal increase were carried on with more vigour; and all nature seemed teeming with the seeds of life. But these physical advantages were only productive of moral evil; the warmth which invigorated the body increased the passions and appetites of the mind; and, as man became more powerful, he grew less innocent. It was found necessary to punish this depravity; and all living creatures were overwhelmed by the deluge in universal destruction.

This deluge, which simple believers are willing to ascribe to a miracle, philosophers have been long desirous to account for by natural causes: they have proved that the earth could never supply from any reservoir towards its center, nor the atmosphere by any discharge from above, such a quantity of water as would cover the surface of the globe to a certain depth over the tops of our highest mountains. Where, therefore, was all this water to be found? Whiston has found enough, and more than a sufficiency, in the tail of a comet; for he seems to allot comets a very active part in the great operations of nature.

He calculates with great seeming precision, the year, the month, and the day of the week on which this comet (which has paid the earth some visits since, though at a kinder distance) involved our globe in its tail. The tail he supposed to be a vapourous fluid substance, exhaled from the body of the comet, by the extreme heat of the sun, and increasing in proportion as it approached that great luminary. It was in this that our globe was involved at the time of the deluge; and, as the earth still acted by its natural attraction, it drew to itself all the watery vapours which were in the comet's tail; and the internal waters being also at the same time let loose, in a very short space the tops of the highest mountains were laid under the deep.

The punishment of the deluge being thus completed, and all the guilty destroyed, the earth, which had been broken by the eruption of the internal waters, was also enlarged by it; so that upon the comet's recess, there was found room sufficient in the internal abyss for the recess of the superfluous waters; whither they all retired, and left the earth uncovered, but in some respects changed, particularly in its figure, which, from being round, was now become oblate. In this universal wreck of nature Noah survived, by

earth's shadow in lunar eclipses. We have a still plainer proof of its rotundity, from the appearance of objects

a variety of happy causes, to re-people the earth, and to give birth to a race of men slow in believing ill-imagined theories of the earth.

After so many theories of the earth, which had been published, applauded, answered, and forgotten, M. Buffon ventured to add one more to the number. This philosopher was in every respect better qualified than any of his predecessors for such an attempt, being furnished with more materials, having a brighter imagination to find new proofs, and a better style to cloath them in. However, if one so ill qualified as I am may judge, this seems the weakest part of his admirable work; and I could wish that he had been content with giving us facts instead of systems; that, instead of being a reasoner, he had contented himself with being merely an historian.

He begins his system by making a distinction between the first part of it and the last; the one being founded only on conjecture, the other depending entirely upon actual observation. The latter part of his theory may, therefore, be true, though the former should be found erroneous.

The planets, says he, and the earth among the number, might have been formerly (he only offers this as conjecture) a part of the body of the sun, and adherent to its substance. In this situation, a comet falling in upon that great body might have given it such a shock; and so shaken its whole frame, that some of its particles might have been driven off like streaming sparkles from red hot iron; and each of these streams of fire, small as they were in comparison of the sun, might have been large enough to have made an earth as great, nay many times greater than ours. So that in this manner the planets, together with the globe which we inhabit, might have been driven off from the body of the sun by an impulsive force: in this manner also they would continue to recede from it for ever, were they not drawn back by its superior power of attraction; and thus, by the combination of the two motions, they are wheeled round in circles.

Being in this manner detached at a distance from the body of the sun, the planets, from having been at first globes of liquid fire, gradually became cool. The earth also having been impelled obliquely forward, received a rotatory motion upon its axis at the very

objects on the surface of the earth, but still more remarkably on that of the sea. As we depart from
objects

very instant of its formation; and this motion being greatest at the equator, the parts there acting against the force of gravity, they must have swollen out, and given the earth an oblate or flattened figure.

As to its internal substance, our globe having once belonged to the sun, it continues to be an uniform mass of melted matter, very probably vitrified in its primæval fusion. But its surface is very differently composed. Having been in the beginning heated to a degree equal to, if not greater, than what comets are found to sustain, like them it had an atmosphere of vapours floating round it, and which, cooling by degrees, condensed and subsided upon its surface. These vapours formed, according to their different densities, the earth, the water, and the air; the heavier parts falling first, and the lighter remaining still suspended.

Thus far our philosopher is, at least, as much a system-maker as Whiston or Burnet; and, indeed, he fights his way with great perseverance and ingenuity through a thousand objections that naturally arise. Having, at last, got upon the earth, he supposes himself on firmer ground, and goes forward with greater security. Turning his attention to the present appearance of things upon this globe, he pronounces from the view that the whole earth was at first under water. This water he supposes to have been the lighter parts of its former evaporation, which, while the earthy particles sunk downwards by their natural gravity, floated on the surface, and covered it for a considerable space of time.

“The surface of the earth,” says he *, “must have been in the beginning much less solid than it is at present; and, consequently, the same causes, which at this day produce but very slight changes, must then, upon so complying a substance, have had very considerable effects. We have no reason to doubt but that it was then covered with the waters of the sea; and that those waters were above the tops of our highest mountains, since, even in such elevated situations, we find shells and other marine productions in very great abundance. It appears also that the sea continued for a considerable time upon the face of the earth: for as these layers of shells are found so very frequent at such great depths, and in such prodigious

* *Theorie de la Terre*, vol. i. p. 111.

objects on the ocean, they seem to subside gradually below the visible horizon. Ships at a distance on the water are not visible in their hulls; at a greater distance, their mainsails disappear; and at a greater still, their topails; which could not be, if they sailed on a plain. But that the earth is really globular was at length practically demonstrated by the adventurous project of sailing round it, which has several times been accomplished.

This fact being premised, let us consider in what quantities, it seems impossible for such numbers to have been supported all alive at one time; so that they must have been brought there by successive depositions. These shells also are found in the bodies of the hardest rocks, where they could not have been deposited all at once, at the time of the deluge, or at any such instant revolution; since that would be to suppose, that all the rocks in which they are found were, at that instant, in a state of dissolution, which would be absurd to assert. The sea, therefore, deposited them where ever they are now to be found, and that by slow and successive degrees.

“ It will appear, also, that the sea covered the whole earth, from the appearance of its layers, which lying regularly one above the other, seem all to resemble the sediment formed at different times by the ocean. Hence, by the irregular force of its waves, and its currents driving the bottom into sand-banks, mountains must have been gradually formed within this universal covering of waters; and these successively raising their heads above its surface, must, in time, have formed the highest ridges of mountains upon land, together with continents, islands, and low grounds, all in their turns. This opinion will receive additional weight by considering, that in those parts of the earth where the power of the ocean is greatest, the inequalities on the surface of the earth are highest: the ocean’s power is greatest at the equator, where its winds and tides are most constant; and, in fact, the mountains at the equator are found to be higher than in any other part of the world. The sea, therefore, has produced the principal changes in our earth: rivers, volcanoes, earthquakes, storms, and rain, having made but slight alterations, and only such as have affected the globe to very inconsiderable depths.”

GOLDSMITH’S *History of the Earth and animated Nature*,
Vol. I. p. 22, &c.

manner

manner the known laws of nature were likely to act upon a mass of materials such as enter into the composition of this globe.

The first principle of the law of gravitation is, that the constituent particles of all bodies attract each other mutually, whence arise their common centers of gravity. Hence all fluids assume a spherical form, from the particles mutually attracting each other; and no bodies but fluids being capable of obeying the laws of gravitation, so as to become spherical, it is presumed that the earth was originally in a fluid state. The earth revolves round its center, and the centrifugal force increases in proportion to the distance from the axis of motion; all bodies, therefore, revolving round their axis in a state of fluidity, will necessarily depart from the spherical form, and assume that of an oblate spheroid. Such, by actual mensuration, is found to be the form of the earth; and this is also demonstrated, by astronomical observations, to be the case with all the other planets. It is therefore highly probable, that all these bodies were originally fluid, and only departed in some measure from the spherical form, in consequence of a revolution on their axis.

It is not natural or easy to suppose, that the earth and planets have, since their existence, been reduced, by any solvent principle, from a solid to a fluid state. It is much more obvious to believe, that such was their state at their first creation. It follows of consequence, that they had a beginning, and have not existed from eternity, as some fantastical-writers have been inclined to imagine.

If such was the original state of the earth, it follows, that it was at first absolutely unfit for animal and vegetable life; and, therefore, these must have been

after-creations. This account, it is observable, agrees admirably with the Mosaic account of the creation, as well as with the opinions of the most ancient philosophers, historians, poets, &c. that is, with the traditions of the first ages.

It is the opinion of Mr. Whitehurst, that the component parts of the earth, at its first formation, existed in a state of actual solution, and that they subsided partly into solid bodies, and partly into fluids, by the mutual action of these particles upon each other.

We have seen that there exists between different particles of matter what is called elective or chemical attraction, by which substances having certain properties in common are disposed to unite; and by the combinations thus formed (whether by an immediate act of omnipotence, or whether by some more gradual process) the suspension of the component parts of the chaotic mass would be effectually destroyed, and bodies would approach towards their center of gravity in proportion to their respective densities. That the laws of elective attraction have prevailed in the formation of the earth is evident from the sameness of quality which is observed in different strata of minerals.

It has been, I think, demonstrated, that the presence of heat, caloric, or fire is the efficient cause of fluidity. When the permanently elastic fluids, therefore, which constitute the atmosphere, assumed their aeriform state, and rose from the chaotic mass, a great quantity of heat must have become latent, while the remaining substances, from which the caloric was abstracted, must have been considerably cooled, and it might, therefore, be expected, that those kinds of matter, which had least attraction for caloric, would assume a solid form; while others, whose attraction for that substance

was intermediate, would remain in the state of common fluids. It is therefore, perfectly agreeable to sound philosophy to suppose, that the abstraction of a considerable quantity of caloric, or the matter of fire, from the chaotic mass, would effectually destroy its fluidity, and would almost instantly produce all the different mineral substances, which are observed in the bowels of the earth. Not that we are under any necessity of believing, that the whole internal substance of the earth exists at this hour as it existed when creation was completed. There are a variety of processes going on continually in the interior parts of the globe, beside those more sudden and violent changes, which have been produced by earthquakes, floods, and volcanoes.

By the subsiding of the denser and more solid bodies, a considerable portion of the fluid matter would be left in a separate state, and would form large masses, or oceans of water.

With respect to the formation of islands, nothing more was necessary than the unequal and irregular subsiding of the different parts of matter, which may have happened from a variety of causes; from the effects of elective attraction and crystallization; from the motion of the earth, and the flux and reflux of the tides. The latter cause would necessarily remove the solid masses, as they were formed, from place to place, till these solid masses, meeting with others, or increasing their bulk by their action upon congenial particles, would, from their increased gravity and density, at length become stationary. Thus the surface of the earth is all irregular, and an island is no other than a hill or mountain, the adjacent vallies of which are filled with water. Some islands, however, we know, are of more recent origin. Some have

been thrown up by volcanic eruptions; and some have apparently been formed by that extraordinary insect which produces rocks of coral. The islands Delos and Rhodes are said to have *grown* out of the sea. Pliny mentions a number of other islands, which were produced by subterraneous fires. In 1628, one of the islands of the Azores rose up out of the bottom of the sea, which in that place was one hundred and sixty fathoms deep; and this island, which is three leagues long, one league and an half broad, and three hundred and sixty feet above the level of the water, rose in fifteen days*.

On the 20th of November, 1720, a subterraneous fire burst out of the sea near Tercera, one of the Azores, which threw up such a quantity of stones, in the space of thirty days, as formed an island two leagues in diameter, and nearly circular †.

The Isle of Sheppey contains a great variety of fossil bodies, as well animal as vegetable, which evidently prove it to be an assemblage of adventitious matter.

In every instance upon record, the fragments of sea shells are infinitely more numerous than the bones and teeth of fish. The latter too are but seldom deposited in any other matter than in beds of sand and gravel, and not in the solid beds of lime-stone, as the shells of fish generally are, even to the depth of many hundred yards, and disposed throughout the whole extent of the strata ‡.

There is no occasion to suppose, that the whole

* Sir William Hamilton's Observations on Vesuvius and Ætna.

† Philosophical Transactions, quoted by Whitehurst.

‡ Whitehurst, p. 44.

surface of the earth was at once rendered habitable. From the scripture account we have reason to believe, that only a very small part of it was inhabited for a long series of time, *viz.* the regions about the Euphrates, supposed to constitute the Garden of Eden. Here the terrestrial animals were chiefly assembled, while the marine animals were dispersed through the great abyss of waters; and, from the extreme fecundity of those animals, they would, in a very short space of time “replenish the waters” from pole to pole. If, therefore, we suppose (as is most probable) that the greater part of the earth was gradually forming itself according to the laws of nature and creation, in other words, according to the usual processes of attraction and combination, it is easy to conceive, that a part of these animals, especially those which are least active, would be gradually intombed in the increasing mass, and this, as well as the deluge, will account for the great quantities of the exuviae and bones of marine animals, especially shell fish, which are found in beds of lime-stone, gravel, &c. even on the tops of mountains.

We shall cease to be astonished at the immense quantities of shells, which are thus found imbedded in the earth, if we only consider the amazingly prolific nature of these animals. It is not uncommon to take away a bed of these shell fish several fathoms in thickness; and, though the places whence they are removed appear entirely exhausted, yet in the ensuing season there shall be as many found in all these places as there were before*.

The bones or teeth of fish, Mr. Whitehurst affirms, as far as his knowledge extends, have never been found mixed with shells in the solid substance of lime-stone.

* Whitehurst, p. 47.

That at different periods the earth must have suffered very violent convulsions and dislocations of the solid parts, we may reasonably conclude from the rugged and uncouth appearance of many of the mountainous parts of the world. We see rocks in some places torn asunder, or, in appearance cut with a saw. Mr. Whitehurst remarks, that at Stafford and Newport, in Shropshire, there are detached blocks of Cornish moor-stone, or granite, of considerable magnitude, though no such stratum is known to exist nearer than Cornwall. It is fair, therefore, to conclude, that they have been thrown there by some violent commotion or subterraneous convulsion.

To the general deluge, that fact recorded with so much precision in the writings of Moses, and confirmed by the traditions of every nation, we must attribute much of the irregularities of the earth's surface. It would in some instances have the effect of reducing great masses of matter to a second state of solution. Many eminences would be levelled, and some of the vallies would be filled up. Some parts, which before were sea, might receive such an accession of foreign matter as to fill up their beds, and on the subsiding of the waters to present to the eye a vast level plain. Those elevations, on the contrary, which consisted of solid masses of the harder stones, would have the lighter portions of earth washed away from their bases, and their height would receive a proportional increase. If pit coal, indeed, is of vegetable origin, it is difficult to account for the deposition of such a quantity of vegetable matter beneath the surface of the earth, on any other hypothesis than that of a deluge; and though much of the exuviae of shell-fish might be involved in the first ages succeeding the creation, in the manner Mr. Whitehurst supposes, much greater quantities

quantities would be inhumed at the deluge. The other animal matters found in a fossil state, particularly the horns, skeletons, and bones of animals, which are much larger than any now found upon the earth, can only be accounted for upon this hypothesis. Such are those mentioned by Buffon, which were dug up in America, near the river Ohio, a single tooth of which, belonging to a large row, weighed upwards of eleven pounds, and a single thigh bone was upwards of four feet in length. In the year 1783, a skeleton of an immense animal of the deer kind was found on an estate belonging to Dr. Percy, Bishop of Dromore. It was dug out of a marle pit, under a peat moss, and was found surrounded by shells and other marine productions. The horns were seven feet and one inch in height, the length of the scull nearly two feet, the breadth of the forehead nearly a foot, and the bones of an enormous size. In Siberia, in America, and even in England, the bones and teeth of the elephant, hippopotamus, and other animals, which never have existed in those climates, have been found, and even these were larger than those of any such animals now existing.

To the deluge, therefore, much of the present inequalities of the earth may be rationally attributed. But there are other causes which may have operated both before and since. It is a fact, which will scarcely admit of dispute, that volcanic eruptions were much more frequent in the early ages of the world than at present; the vestiges of volcanoes, and, even the exhausted craters, are often found, where there is now not the least appearance of subterraneous fire. This fact is also easily accounted for on philosophical principles. The imperfect, and, if I may so speak, accidental mixture of different bodies, would in many

cases produce spontaneous inflammation in the early ages of the world, whereas, as the earth grows older, these materials must be exhausted, or rather formed into other combinations. Many mountains, we know, are of volcanic origin, and therefore many of them of a date long posterior to the æra of creation.

Such appears to be the most rational account of the structure of the earth, as far as we are warranted by actual experiment, or well authenticated observation. The succeeding chapters of this book will serve to explain more satisfactorily the different appearances of various portions of the globe. I shall therefore proceed, without further digression, to treat more particularly of mountains, volcanoes, and the other phenomena more immediately connected with this branch of natural history.

C H A P. XLVI.

MOUNTAINS.

Distinction between Hills and Mountains.—Mountains primæval or secondary.—Granite Mountains only supposed in general primæval.—Some Lime-stone Mountains primæval.—Alluvial Mountains.—Entire and stratified Mountains.—Mountains homogeneous and heterogeneous.—Confused Mountains.—Volcanic Mountains.—Height of Mountains, how measured.—Computed Heights of the most remarkable Mountains.—Line of Congelation in different Parts of the World.

ELEVATIONS, consisting chiefly of clay, sand, or gravel, are called hills. Those which consist chiefly of stone are called mountains. Mountains are divided into primæval, that is, of equal date with the formation of the globe, and secondary or alluvial. Among primæval, those of granite hold the first place. The highest mountains and most extensive ridges throughout the globe are of that kind; as the Alps and Pyrenees, in Europe; the Altuischan, Uralian, and Caucasus, in Asia; and the Andes, in America. The highest of them never contain metallic ores; but some of the lower contain ores of copper and tin. The granite next the ore always abounds in mica. Petrifications are never found in these primæval mountains.

That the formation of these mountains preceded that of vegetables and animals, is justly inferred from their containing no organic remains, either in the form of petrification or impresson. Naturalists are agreed, that granites were formed by crystallization. This operation probably took place after the formation of the atmosphere, and the gradual excavation

of the bed of the ocean, when the dry land appeared. For, as was remarked in the preceding chapter, by means of the separation of the aeriform fluids, which constitute the atmosphere, the evaporation of part of the water into the atmosphere, and the gradual retreat of the remainder, the various species of earths, before dissolved or diffused through this mighty mass, were disposed to coalesce, and among these the siliceous must have been the first, as it is the least soluble; but as the siliceous earth has an affinity to the other earths with which it was mixed, some of these must have united in various proportions, and thus have formed, in distinct masses, the felt spar, shoerl, and mica, which compose the granite. Calcareous earth enters very sparingly into the composition of this stone; but as it is found in shoerl, which is frequently a component part of granite, it follows that it must be one of the primitive earths, and not entirely derived from marine exuviae, as some have supposed. Quartz can never be supposed to be a product of fire; for in a very low heat it bursts, cracks, and loses its transparency, and in the highest degree of heat that we can produce, is infusible, so that in every essential point it is different from glass, to which some have compared it. As granite contains earths of every genus, we may conclude, that all the simple earths are original. This, however, is no proof that they are in reality simple and uncompounded of other principles; but they must be considered as such in the present state of our knowledge. Though water undoubtedly dates from creation, yet late experiments have shewn it to be a compound, as was formerly stated.

Mountains, which consist of lime-stone or marbles of a granular or scaly texture, and not disposed in strata, seem also to have preceded the creation of animals,

animals, for no organic traces are found in them. Some of those, which consist of argillaceous stones, and some of the siliceous, contain also no organic remains. These often consist of parallel strata of unequal thickness, and the lower are harder and less thick than the upper, and therefore seem to have been formed earlier than the upper.

Alluvial mountains are evidently of posterior formation, as they contain petrifications and other vestiges of organic substances, and these are always stratified.

Mountains, as to structure are entire, stratified, and confused. Entire mountains are formed of huge masses of stone, without any regular fissures, and are mostly homogeneous. They consist chiefly of granite, sometimes gneiss*, schistus, flag-stone, sand-stone, limestone, gypsum, porphyry or trapp. Some in Sweden and Norway consist of iron ore.

The stratified mountains are those whose mass is regularly divided by joints or fissures; these are called horizontal, rising, or dipping. Homogenous stratified mountains consist chiefly of stones of the argillaceous genus, or of the fissile compound species of the siliceous genus, as metallic rock; sometimes of limestone of a granular or scaly texture, in which no animal vestiges appear. This limestone reposes on the argillaceous or siliceous strata: sometimes the argillaceous are covered with masses of granite, sometimes of lava. These mountains, particularly those of gneiss, metallic rock, and horn-stone, are the chief seat of metallic ores. When covered with limestone, the ore is generally between the limestone and the argillaceous stones. These ores run in veins, not in strata.

* A rock consisting of mica, lapis ollaris, and quartz.

Petrifications are found upon, but not in, these mountains.

Heterogeneous, or compound stratified mountains, consist of alternate strata of various species of stones, earths, sands, &c. The lime-stone here is always of the laminar, and not of the granular or scaly kind, and when it contains any ore, it is placed between its laminae. Stones of the siliceous genus seldom form strata in these mountains, except lavas; but the strata are frequently interrupted by siliceous masses, as jasper, porphyry, &c. Coal, bitumen, petrifications, and organic impressions, are found in these mountains, also salts and calamine.

There are other mountains, which cannot properly be called stratified, as they consist only of three immense masses, the lowest granite, the middle argillaceous, and the upper lime-stone. Metallic ores are found in the argillaceous part, or between it and the lime-stone.

Confused mountains consist of stones heaped together without order, their interstices filled with clay, sand, and mica. They scarcely ever contain any ore.

Besides these, there are many mountains in different parts of the world, which derive their origin from volcanoes; but of these it will be necessary to treat in the succeeding chapter.

The height of mountains is usually calculated by means of the barometer, upon the principles already explained. For this purpose two columns of mercury, or barometers, are provided, and one is kept at the foot of the mountain while the other is carried to its summit. The degree of heat, if not equal, is reduced by calculation to an equality, and for this purpose a thermometer is attached to each of the barometers. The degree of heat, to which both are reduced, is commonly

commonly 55° ; if, however, either of the barometers stands at 30 inches, and the annexed thermometer at 55° , no reduction is to be made in the degrees indicated by that barometer; but if either of them is at 30° , and the thermometer below 55° , we must add the expansion the mercury in the barometer would have experienced at the heat of 55° . If the heat should, on the contrary, be above 55° , we must subtract the degree of expansion which it gains by that heat. Every degree of Fahrenheit's scale produces an expansion of 00.304 of the barometrical inch, when the barometer is at 30; when, therefore, the thermometer is at 11° below or above 55° , we must add in the former, or subtract in the latter case, eleven times that number from the barometrical height. In the same manner it may be calculated, whatever is the height of the barometer. When this matter is ascertained, the height is easily found by comparing the two barometers and calculating the density of the air in the higher regions according to the principles of geometrical progression.

The highest mountains are those which are situated at or near the equator; and the Andes are generally allowed to be the highest of these. Catopaxi, one of the Andes, which was measured by Ulloa and the French academicians, was found to be rather more than three miles above the level of the sea; whereas the highest point of the Alps is not above a mile and a half. Mount Caucasus approaches nearest to the height of the Andes of any of the Asiatic mountains. The Pike of Teneriff, which has been so much celebrated, is about a mile and a half in height. It is an extraordinary circumstance, that the moon, which is a body so much smaller than our earth, should so greatly exceed it in the irregularities of its surface;

some

some of the mountains in that planet being calculated to exceed nine miles in height.

The line of congelation, or perpetual frost, on mountains, is calculated at 15,400 feet, at or near the equator; at the entrance of the temperate zone, at 13,428; on Teneriff, at 1,000; in Auvergne (lat. 45.) 6,740; with us (lat. 52.) 5,740. On the Andes, vegetation ceases at 14,697 feet; and on the Alps, at 9,585. The air is so dry in these elevated situations, that M. D'Arcel observed, that on the Pic de Midi, one of the Pyrenees, salt of tartar remained dry for an hour and a half, though it immediately moistened in the same temperature at the bottom of the mountain.

C H A P. XLVII.

VOLCANOES.

General Observations on Volcanoes.—Their Connection with the Sea.—Immense Force of subterraneous Fires exemplified in various Instances.—Theory of Volcanoes.—Great Depth.—Traces of Volcanoes in different Parts of the World.—Description of Ætna.—Eruption of Vesuvius, in 1794.

VOLCANOES are peculiar to no climate, and have no necessary or regular connection with any other mountains, but seem to have some with the sea, for they are generally in its neighbourhood. It has been remarked by those who have observed them, that volcanoes often throw out matters which belong to the sea, as the relics of fish, sea-weed, and often immense quantities of sea-water itself. Sir William Hamilton observes, in the Philosophical Transactions for the year 1776, “that the operations of Vesuvius are very capricious and uncertain, except that the smoke increases considerably and constantly when the sea is agitated, and the wind blows from that quarter.”

There are ancient extinguished volcanoes, it is true, which are inland; but this is only one of many proofs that the sea covered those countries at some remote period. Volcanic mountains are of all heights; some so low as four hundred and fifty feet, as that of Tanna; Vesuvius is three thousand six hundred feet high, and Ætna eleven thousand. They in general form lofty spires, and the volcano itself is internally shaped like an inverted cone, placed on a broader basis. This cone is called the crater, or bowl, and through it the lava

lava generally passes; though sometimes it bursts through the sides, and even proceeds occasionally from the bottom of the mountain. Sometimes the crater falls in and is effaced, sometimes, in extinguished volcanoes, it is filled with water. Sub-marine volcanoes have been observed, and from these some islands have derived their origin. Volcanic fires, taking place at the bottom of the ocean, would frequently, by the expansive force of the steams which are generated, elevate those parts which were once at the bottom of the deep, and overflow those which were habitable earth. It is very probably conjectured, as was noticed in a preceding chapter, that subterraneous convulsions operated more powerfully in the early ages of the world than at any later period; and indeed such an hypothesis is supported by the most probable reasoning, since we may well conceive, that at the first consolidation of the earth, much heterogeneous matter would be included in the different masses, which might produce more frequent fermentations than at any after periods, when these have been, if I may so express it, purged off by frequent eruptions, and in many parts, perhaps, rectified and assimilated by slow and secret processes in the bowels of the earth. But history was not cultivated till a very late period, and the most eventful ages of nature have passed unrecorded.

The force of subterraneous fires, or rather of the steam which is generated by them, is so great, that considerable rocks have been projected by Vesuvius to the distance of eight miles. A stone was once thrown from the crater of that volcano twelve miles, and fell upon the Marquis of Lauro's house at Nola, which it set on fire. One also, which measured twelve feet in height and forty-five in circumference, was carried

ried, in 1767, by the projectile force of the steam, a quarter of a mile from the crater. In an eruption of *Ætna*, a stone, fifteen feet long, was ejected from the crater to the distance of a mile, and buried itself eight feet deep in the ground.

A volcano broke forth in Peru, in 1600, accompanied with an earthquake, and the sand and ashes which were ejected covered the fields ninety miles one way and one hundred and twenty another. Dreadful thunders and lightning were heard and seen for upwards of ninety miles round *Araquapa* during this eruption, which seemed to denote some connection between the electric matter and these volcanic fires*; and this fact is strongly confirmed by the very accurate observations of Sir William Hamilton, which I shall afterwards have occasion to notice more at large.

Both the inside of the crater and the base of many volcanoes consist of lava, either entire or decomposed, nearly as low as the level of the sea, but they finally rest either on granite, as in Peru, or schistus, as the extinguished volcanoes of Hesse and Bohemia, or on lime-stone, as those of Silesia, Mount Vesuvius, &c. No ore is found in these mountains, except that of iron, of which lava contains from twenty to twenty-five parts in the hundred, and some detached fragments of the ores of copper, antimony, and arsenic. Vesuvius ejected, from the year 1779 to 1783, 309,658,161 cubic feet of matter of different kinds; we must therefore conclude the seat of these fires to be several miles, perhaps hundreds of miles, below the level of the sea; and as iron makes from one-fourth to one-fifth of these ejections, we may infer that

* Dr. Hooke's posthumous Works, p. 304.

the internal parts of the earth abound much in this metal.

The origin of these subterraneous fires is not easily explained. Iron filings mixed with powdered sulphur, and the whole moistened with water into a paste, we have formerly seen, will swell, become hot, and, if the quantity is considerable, will throw out a blue flame. It is a mixture of this kind which is used for making an artificial earthquake, for such a quantity of inflammable gas is produced during the fermentation, that if the mass is buried in the earth, the gas will force a passage for its escape, and exhibit, on a small scale, the phenomena of an earthquake. M. Lemery seems to have been the first person who illustrated, in this manner, the origin of volcanic fires and earthquakes. He mixed twenty-five pounds of iron filings with an equal weight of sulphur, and having made them into a paste with the addition of water, he put them into a pot, covered them with a cloth, and buried them a foot under ground. In about eight or nine hours time the earth swelled, became warm, and cracked, and hot sulphureous vapours were perceived*. Now, large beds of martial pyrites, which
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* That part of this experiment (says Bishop Watson) which relates to the production of fire, by the fermentation of iron filings and sulphur when made into a paste, has been frequently repeated since the Time of Mr. Lemery. I myself have made it more than once, but I have nothing material to add to his account, except that the flame, when the experiment is made in the open air, is of very short duration; and that the whole mass, after the extinction of the flame, continues at intervals, for a longer or shorter time, according to its quantity, to throw out sparks; and that a ladle full of the ignited mass, being dropped down from a considerable height, descends like a shower of red-hot ashes, much resembling the paintings of the eruptions of Mount Vesuvius, which may be seen at the British Museum. It has been observed, that large quantities

are natural combinations of iron and sulphur, are known to exist in different parts of the earth; the only difficulty which attends this explanation of the origin of volcanoes, as well as of earthquakes, is, that the presence of air is in general necessary for the production of actual flame. It is well known, however, that martial pyrites, when moistened, acquire heat; and if we suppose the heated pyrites to have been in contact with black wad and petroleum, we may suppose the flame to arise, as we see it produced by art, from the desiccation of the former substance, and its mixture with mineral oil. Many minerals, when heated, afford vital air, a very small quantity of which is sufficient to produce flame; this flame, once produced, may be supported from other ores, and the combustion be maintained by the presence of bituminous schistus, bitumen, and coal. Marl, schistus, hornstone, shoerl, with a further addition of iron, are the

quantities of the materials are not requisite to make the experiment succeed, provided there be a due proportion of water: half a pound of steel filings, half a pound of flowers of brimstone, and fourteen ounces of water, will, when well mixed, acquire heat enough to make the mass take fire.

That heat and fire should be generated from the spontaneous actions of *minerals* upon each other, is a phenomenon by no means singular in nature, how difficult soever it may be to account for it. The heat of putrescent dunghills, of the fermenting juices of vegetables, and, above all, the spontaneous firing of hay not properly dried, are obvious proofs that *vegetables* possess this property as well as minerals. In both vegetables and minerals, a definite quantity of moisture is requisite to enable them to commence that intestine motion of their parts, which is necessary for the production of fire. Iron and sulphur would remain mixed together for ages without taking fire, if they were either kept perfectly free from moisture, or drenched with too much water; and vegetables in like manner, which are quite dry, or exceedingly wet, are incapable of taking fire whilst they continue in that state.

true sources of lava. It seems, however, after all, difficult to conceive that such extensive and intense fires should be maintained without the access of considerable quantities of air; that fluid may therefore be possibly supplied by a communication with some extensive caverns, which may themselves receive it by openings at the distance of many miles from the crater of the volcano. It does not seem improbable that the volcanoes, which now burn, may have a communication with the cavities and craters of extinguished volcanoes, and thence derive a supply of air sufficient to account for the inflammation of large beds of pyrites and bituminous matters. M. Buffon supposes, that the seat of volcanic fires is situated but a very little way below the bed of the mountains; but it appears more probable, that it is in general many miles below the surface of the earth, for the quantity of matter discharged from *Ætna* alone is supposed, on a moderate calculation, to exceed twenty times the original bulk of the mountain, and therefore could not have been derived from its contents alone, but must come from the deeper recesses of the earth.

M. Condamine asserts, that all the mountains in the neighbourhood of Naples exhibit undoubted marks of a volcanic origin. He says, he could trace the lava, and other productions of subterraneous fire, from Naples to the very gates of Rome, pervading the whole soil, sometimes pure and sometimes differently combined. "Wherever I see," says he, "on an elevated plain, a circular basin, surrounded with calcined rocks, I am not deceived by the verdure of the adjacent fields; I can discover, beneath the snow itself, the traces of an extinguished fire. If there is a breach in the circle, I usually find out, by following the declivity of the ground, the traces of a rivulet, or the bed
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of a torrent, which seems as if it was hollowed in the rock, and this rock appears frequently to be pure lava. If the circumference of the basin has no breach, the rain and spring waters, which are collected there, generally form a lake in the very-mouth of the volcano." The Apennines, as well as the Cordeliers of Peru and Chili, he supposes to have been a chain of volcanoes. The chain in both instances is interrupted, and many of the fires either extinguished or smothered, but many remain still actually burning. This intelligent author is, however, far from attributing to all mountains the same origin; and adds, that in that part of the Alps, which he travelled over, he could observe no such appearances.

The traces of volcanoes have been observed in Ireland by Mr. Whitehurst. Though no visible crater is remaining between Port Rush Strand and Balley Castle eastward, yet, he observes, that whole space, about twenty English miles, is one continued mass of lava. The cliffs, he says, are truly stupendous, and bear every possible mark of having been originally liquid fire. The elevation of that, at the foot of which the Giant's Causeway is situated, he presumes cannot be less than five or six hundred feet perpendicular above the level of the Atlantic ocean, and yet composed entirely of lava; the same appearances extend towards the south upwards of twenty miles.

The most remarkable volcanoes in Europe are *Ætna* and *Vesuvius*, and as these are not too far distant, we have the most accurate descriptions of them from travellers of the first talents and reputation.

Ætna, which is the most striking object in Sicily, and indeed one of the most magnificent productions of nature, arises from an immense base, and mounts equally on all sides to its summit. The ascent on

each side is computed at about thirty miles, and the circumference of its base, at one hundred and thirty-three; but as it has never been measured with any great degree of accuracy, its dimensions are but imperfectly known.

‘ The whole mountain is divided into three distinct regions, called *La Regione Culta*, or *Piedmontese*, the fertile regions; *La Regione Sylvosa*, or *Nemorosa*, the woody region; and *La Regione Deserta*, or *Scoperta*, the barren region. These differ as materially both in climate and production as the three zones of the earth, and perhaps with equal propriety might have been stiled the torrid, the temperate, and the frigid zone.

‘ The first region of *Ætna* surrounds the base of the mountain, and constitutes the most fertile country in the world on all sides of it, to the extent of fourteen or fifteen miles, where the woody region begins. It is composed almost entirely of lava, which, in time, becomes the most fertile of all soils, but the roads, which are entirely over old lavas, now converted into orchards, vineyards, and corn-fields, are execrable. The lavas, which form this region, arise from a number of beautiful little mountains, every where scattered over the immense declivities of *Ætna*. These are all either of a conical or semispherical figure, and are in general covered with beautiful trees, and the most luxurious verdure. The formation of them is owing to the internal fires of *Ætna*, which raging for a vent. at so vast a distance from the great crater that it cannot possibly be carried to the height of twelve or thirteen thousand feet, which is probably the height of the summit of *Ætna*, must necessarily be discharged at some other orifice. After shaking the mountain, and its neighbourhood for some time, at length the
fire

fire bursts open its side; and this is called an eruption. At first it emits only a thick smoke and showers of ashes. These are followed by red hot stones, and rocks of a great size, which are thrown to an immense height in the air. These stones, together with the quantities of ashes discharged at the same time, form those mountains, which cover all the declivities of *Ætna*. The size of them is in proportion to the duration of the eruption. When it continues a considerable time, it sometimes forms an elevation of one thousand feet in perpendicular height, which at its base is seven or eight miles in circumference.

‘ After the formation of the new mountain, the lava commonly bursts out from its lower side, and, sweeping every thing before it, is generally terminated by the sea. Sometimes it issues from the side of the mountain, without these attending circumstances, which is commonly the case with the eruptions of *Vesuvius*, in which the elevation being so much smaller, the melted matter is carried up into the crater, where it is dislodged without forming any new mountain, but only adding to the height of the old one; till at length the lava, rising near the summit, bursts the side of the crater. But *Ætna* being upon a much larger scale, one crater is not sufficient to give vent to such immense oceans of liquid fire.

‘ At *Nicolosi*, which is only twelve miles up the mountain, the climate appears totally changed. When the heats at *Catania* are insupportable, and the harvest entirely over, the temperature of the air is moderate at *Nicolosi*, and in many places the corn quite green. Mr. Brydone, in travelling over *Ætna*, was struck with the degree of wildness and ferocity which appeared in the inhabitants of the mountain, and which reminded him of an observation made by the Padre

della Tore, the historiographer of Mount Vesuvius, that in places where the air is most impregnated with sulphur and hot exhalations, the people are always most wicked and vicious. It was with great difficulty he could persuade the people of Nicolosi to suffer his guide to attend him in the prosecution of his researches. They were excessively troublesome, and extremely suspicious that his views were directed to the discovery of some hidden treasure, the only motive to which they could ascribe so fatiguing a journey. At length one of them recollected having heard many of their old people say, that the English had a queen that had burnt in the mountain for many years past, and imputed the visits of several of that nation to their respect to their deceased sovereign. Upon enquiring who this queen was, they said her name was Anna, that she was wife to a king who had been a christian, but she had made him a heretic, and was condemned to burn for ever in Mount Ætna. As this could only relate to the unfortunate Anne Bullen, Mr. Brydone asked if she was the victim alluded to, and whether her husband was not likewise condemned to the same punishment. "Certainly," said the man, "and all his heretic subjects too; and if you are of that number you need not be in such a hurry to get there, you will be sure of it at last."

The beautiful country of Hybla, in the neighbourhood of Nicolosi, after repeated vicissitudes, is now reduced to a melancholy monument of the fury of Ætna; it was so much celebrated for its fertility, and particularly for its honey, that it was called *Mel Passi*, till it was overwhelmed by the lava of Ætna, and became totally barren, when, by a kind of pun, it obtained the name of *Mal Passi*. On a second eruption, however, a fertile shower of ashes restored its pristine beauty,

beauty, and its former appellation. But in the dreadful eruption of 1669 it was again reduced to the most deplorable sterility, since which it is once more known by the name which denotes its wretchedness. The eruption that first destroyed this beautiful country, issued from Montpelieri, which it then formed. It destroyed a great number of villages and palaces, and in particular two noble churches, which are extremely regretted on account of three statues, considered, at that time, as the most perfect in the island. They have attempted to recover them, but in vain, nor is it believed they ever can; for the churches were built of lava, which is supposed to melt as soon as it comes into contact with a torrent of newly erupted matter. Massa, a Sicilian author of great credit, affirms, that in some eruptions of Ætna, the lava has poured down with such a sudden impetuosity, that, in the course of a few hours, palaces, churches, and villages, have been entirely melted down, and the whole run off in fusion. It is however probable, that the impetuous force of the torrent, rather than its incorporating with the old mass, may in many of these instances have occasioned this devastation. Thus much at least is certain, that if the lava has had any considerable time to cool, this singular effect never happens.

The contrast between the different regions of Ætna is extremely striking. On entering into the romantic forests of the *Regiona Sylviosa*, a new creation seems to arise. The air, which before was hot and sultry, is cool and refreshing, and every breeze loaded with delicious perfumes from the aromatic plants, with which the whole ground is covered. Indeed every beauty, and every horror in nature, seems to be united on this wonderful mountain, and the most opposite and dissimilar objects are promiscuously blended together.

ther. Here we observe a gulph which threw out torrents of fire, now covered with the most luxuriant verdure. Delicious fruits arising from what was but lately a black and barren rock. Delightful flowers covering the earth, the surface of which is but a few yards removed from lakes of liquid fire and brimstone. An immense gulph of fire for ever existing in the midst of snows which it has not the power to melt, and immense fields of snow and ice unceasingly surrounding this gulph of fire, which they have not the power to extinguish.

The woody region of *Ætna* ascends for about eight or nine miles, and forms a zone of the brightest green around the mountain. In this region, near the *Spelonca del Capriolo*, or goats cavern, are two of the most beautiful mountains that adorn the sides of *Ætna*. Their hollow craters are each of them considerably larger than that of *Vesuvius*. They are now filled with stately oaks, and covered with the richest soil to a great depth. A mountain at some distance, which was formed by an eruption in 1766, was, in 1770, still on fire; nor was the lava by any means cold. This region of *Ætna*, like the *Regione Culta*, is composed of lava; but this is now covered with so deep a layer of earth, that it is no where to be seen, except in the beds of the torrents, in many of which it is worn down by the water to the depth of fifty or sixty feet, and in one of them considerably more. On approaching *La Regione Scoperta*, the trees begin to assume a wintry appearance, and every object indicates the proximity of barrenness and eternal frost.

On completely bidding adieu to the vegetable regions, an expanse of ice presents itself, which is sufficient to stagger the most determined resolution. Above these the high summit of the mountain rears its tremendous

mendous head, vomiting torrents of thick smoke. The difficulty of ascending this part of the mountain, is greatly increased by the uncertainty of a secure footing; for the surface of the mountain being hot below, frequently melts the snow in particular spots, and forms pools of water where it is impossible to foresee the danger; sometimes, likewise, it happens that the surface of the water, as well as the snow, is covered with black ashes, which render it exceedingly deceitful. At first the ascent is not so steep, but it becomes so by degrees. In this region are the remains of an ancient structure called *Il Terre del Filosofo*, and supposed to have been built by Empedocles, a native of Agrigentum, who is said to have died 400 years before the christian era. His vanity, perhaps, rather than his philosophy, led him to this elevated situation. Desirous of being regarded as a god, he is recorded to have thrown himself into the great gulph of *Ætna*, in hopes that the people would imagine he had been taken up to heaven, and never supposing that his death would be discovered to mankind. But the treacherous mountain threw out his slippers, which were of brass, and announced to the world the fate of the pretended philosopher, who preferred an airy fame, which he was beyond the reach of enjoying, to the solid advantages of existence, and who was content to purchase the admiration of an ignorant multitude with the meanness of deceit, and the sacrifice of life*.

Many striking remains of the great eruption in 1669 are still to be seen, and will long continue as memorials of that dreadful event which overwhelmed Catania, and all the adjacent country. Tremendous

* See present state of Sicily and Malta.

earthquakes shook the island, and loud subterraneous bellowings were heard in the mountain. During some weeks, the sun ceased to appear, and the day seemed changed into night. Borelli, who was a witness to these terrible phenomena, says, that at length a rent, twelve miles in length, was opened in the mountain, in some places of which, when they threw down stones, they could not hear them reach the bottom. Burning rocks, sixty palms in length, were thrown to the distance of a mile, and lesser stones were carried three miles. After the most violent struggles, and a shaking of the whole island, an immense torrent of lava gushed from the rent, and sprung up into the air to the height of sixty palms, whence it poured down the mountain, and overwhelmed every object in its way in one promiscuous ruin.

This destructive torrent, which burst from the side of Ætna at a place called Ricini, rushed impetuously against the beautiful mountain of Montpelieri, and pierced into the ground to a considerable depth; then dividing and surrounding the mountain, it united again on the south side, and poured desolation upon the adjacent country. The progress of the torrent was at first at the rate of seven miles a day, but it afterwards took four days to travel sixteen; wherever it directed its course, the whole appearance of nature was changed, several hills were formed in places which were formerly valleys, and a large lake was so entirely filled up by the melted mass, as not to leave a vestige remaining. In its course it descended upon a vineyard, belonging to a convent of Jesuits, which was formed upon an ancient and probably a very thin layer of lava, with a number of caverns and crevices under it. The liquid mass entering into these excavations soon filled them up, and by degrees bore up the vineyard, which in a
short

short time, to the great astonishment of the spectators, began to move away, and was carried by the torrent to a considerable distance. In 1770 some remains of this vineyard were still to be seen, but the greater part of it was entirely destroyed.

In vain did the terrified inhabitants of Catania recur for protection to the miraculous veil, or expect defence from the lofty walls of their city. After destroying several convents, churches, and villages, this fiery current directed its course to Catania, where it poured impetuously over the ramparts, which are near sixty feet in height, and covered up five of its bastions, with the intervening curtains. After laying waste a great part of this beautiful city, and entirely destroying several valuable remains of antiquity, its further progress was stopped by the ocean, over whose banks it poured its destructive current. In its course from the rent in the mountain, till its arrival in the sea, it is said to have totally destroyed the property of near thirty thousand persons.

Still however did the infatuated inhabitants of Catania adhere to the remains of their almost ruined city, nor did even the more dreadful calamity with which they were afterwards visited, abate their attachment. Twenty-four years after the fatal eruption of 1669, a violent earthquake, which extended along all the eastern coast, and destroyed in one hour more than sixty thousand persons, overthrew the remaining buildings of Catania, and buried a very considerable number of its inhabitants under the ruins of their houses and churches; but again the place was rebuilt, a new and elegant plan was adopted, and the city is now much handsomer than before. The principal streets are wide, strait, and well paved with lava. The cathedral, which was founded in the year 1094, has suffered so
greatly

greatly from earthquakes, that a very small part of the original structure remains. The other religious edifices are profusely ornamented, but in a bad taste.

But if the united effects of attachment to their native soil, of contempt for dangers to which they are habituated, and of confidence in the miraculous veil, have occasioned the wonderful adherence of the Catanians to this dangerous situation from which they have so severely suffered, it must, however, be confessed, that they have sometimes derived advantages from the very evils which they have so much reason to dread. They were always in great want of a port, with which they were furnished by one of those capricious changes which nature so frequently makes in this ever varying spot. A stream of lava running into the sea, formed a mole, which no expence could have furnished them with. This advantage, however, proved but temporary; there remained for some time a safe and commodious harbour, but by a subsequent eruption it was entirely filled up and demolished.

The celebrated Bishop Berkeley has described an eruption of Mount Vesuvius, of which he was a witness in the year 1717, and the reader will find his narrative in the first volume of Dr. Goldsmith's *History of the Earth and Animated Nature*, p. 94. But the most complete and philosophical account of this most formidable phenomenon, a volcanic explosion, is that with which Sir William Hamilton has favoured the public, in describing the late dreadful eruption of that mountain in 1794; and this I shall endeavour to give, as nearly as possible, in his own words.

• Sir William begins his narrative with remarking, that the frequent slight eruptions of lava for some years

years past had issued from near the summit, and ran in small channels in different directions down the flanks of the mountain, and from running in covered channels, had often an appearance as if they came immediately out of the sides of Vesuvius, but such lavas had not sufficient force to reach the cultivated parts at the foot of the mountain. In the year 1779, the whole quantity of the lava in fusion having been at once thrown up with violence out of the crater of Vesuvius, and a great part of it falling, and cooling on its cone, added much to the solidity of the walls of this huge natural chimney, and had not of late years allowed of a sufficient discharge of lava to calm that fermentation, which by the subterraneous noises heard at times, and by the explosions of scorixæ and ashes, was known to exist within the bowels of the volcano; so that the eruptions of late years, before this last, were simply from the lava having boiled over the crater, the sides being sufficiently strong to confine it, and oblige it to rise and overflow. The mountain had been remarkably quiet for seven months before the late eruption, nor did the usual smoke issue from its crater, but at times it emitted small clouds of smoke that floated in the air in the shape of little trees. It was remarked by the Father Antonio di Petrizzi, a capuchin friar (who printed an account of the late eruption) from his convent close to the unfortunate town of Torre del Greco, that for some days preceding this eruption, a thick vapour was seen to surround the mountain, about a quarter of a mile beneath its crater, and it was observed by him and others at the same time, that both the sun and the moon had often an unusual reddish cast,

The water of the great fountain at Torre del Greco began to decrease some days before the eruption, so

that the wheels of a corn-mill, worked by that water, moved very slowly; it was necessary in all the other wells of the town and its neighbourhood to lengthen the ropes daily, in order to reach the water; and some of the wells became quite dry. Although most of the inhabitants were sensible of this phenomenon, not one of them seems to have suspected the true cause of it. Eight days also before the eruption, a man and two boys, being in a vineyard above Torre del Greco (and precisely on the spot where one of the new mouths opened, whence the principal current of Java that destroyed the town issued) were much alarmed by a sudden puff of smoke which issued from the earth close to them, and was attended with a slight explosion.

Had this circumstance, with that of the subterraneous noises heard at Refina for two days before the eruption (with the additional one of the decrease of water in the wells) been communicated at the time, it would have required no great foresight to have been certain that an eruption of the volcano was near at hand, and that its force was directed particularly towards that part of the mountain.

- On the 12th of June 1794, in the morning, there was a violent fall of rain, and soon after the inhabitants of Refina, situated directly over the ancient town of Herculaneum, were sensible of a rumbling subterraneous noise, which was not heard at Naples.

From the month of January to the month of May, the atmosphere had been generally calm, and there was continued dry weather. In the month of May there was a little rain, but the weather was unusually sultry. For some days preceding the eruption, the Duke della Torre, a learned and ingenious nobleman, who published two letters upon the subject of the eruption, observed

observed by his electrometers, that the atmosphere was charged in excess with the electric fluid, and continued so for several days during the eruption.

About eleven o'clock on the night of the 12th of June, the inhabitants of Naples were all sensible of a violent shock of an earthquake; the undulatory motion was evidently from east to west, and appeared to have lasted near half a minute. The sky, which had been quite clear, was soon after covered with black clouds. The inhabitants of the towns and villages, which are very numerous at the foot of Vesuvius, felt this earthquake still more sensibly, and say, that the shock at first was from the bottom upwards, after which followed the undulation from east to west. This earthquake extended all over the Campagna Felice; and the royal palace at Caserta, which is fifteen miles from Naples, and one of the most magnificent and solid buildings in Europe (the walls being eighteen feet thick) was shaken in such a manner as to cause great alarm, and all the chamber bells rang. It was likewise much felt at Beneventum, about thirty miles from Naples; and at Ariano in Puglia, which is at a much greater distance; both these towns, indeed, have been often afflicted with earthquakes.

On Sunday the 15th of June, soon after ten o'clock at night, another shock of an earthquake was felt at Naples, but did not appear to be quite so violent as that of the 12th, nor did it last so long; at the same moment a fountain of bright fire, attended with a very black smoke and a loud report, was seen to issue, and rise to a great height, from about the middle of the cone of Vesuvius; soon after another of the same kind broke out at some little distance lower down; then, as is supposed by the blowing up of a covered channel full of red hot lava, it had the appearance as if

the lava had taken its course directly up the steep cone of the volcano. Fresh fountains succeeded one another hastily, and all in a direct line tending, for about a mile and a half down, towards the towns of Refina and Torre del Greco. Sir William Hamilton could count fifteen of them, but believes there were others obscured by the smoke. It seems probable, that all these fountains of fire, from their being in such an exact line, proceeded from one and the same long fissure down the flanks of the mountain, and that the lava and other volcanic matter forced its way out of the widest parts of the crack, and formed there the little mountains and craters that will be described in their proper place. It is impossible that any description can give an idea of the blazing scene, or of the horrid noises that attended this great operation of nature. It was a mixture of the loudest thunder, with incessant reports, like those from a numerous heavy artillery, accompanied by a continued hollow murmur, like that of the roaring of the ocean during a violent storm; and, added to these was another blowing noise, like that of the ascending of a large flight of sky-rockets, or that which is produced by the action of the enormous bellows on the furnace of the Carron iron foundery in Scotland. The frequent falling of the huge stones and scoriæ, which were thrown up to an incredible height from some of the new mouths, one of which having been since measured by the Abbé Tata was ten feet high, and thirty-five in circumference, contributed undoubtedly to the concussion of the earth and air, which kept all the houses at Naples for several hours in a constant tremor, every door and window shaking and rattling incessantly, and the bells ringing. This was an awful moment! The sky, from a bright full moon and star-

light, began to be obscured; the moon had presently the appearance of being in an eclipse, and soon after was totally lost in obscurity. The murmur of the prayers and lamentations of a numerous populace forming various processions, and parading in the streets, added to the horror. As the lava did not appear to have yet a sufficient vent, and it was now evident that the earthquakes already felt had been occasioned by the air and fiery matter confined within the bowels of the mountain, and probably at no small depth (considering the extent of those earthquakes) Sir William recommended to the company that was with him, who began to be much alarmed, rather to go and view the mountain at some greater distance, and in the open air, than to remain in the house, which was on the sea side, and in the part of Naples that is nearest and most exposed to Vesuvius. They accordingly proceeded to Posilipo, and viewed the conflagration, now become still more considerable, from the sea-side under that mountain; but whether from the eruption having increased, or from the loud reports of the volcanic explosions being repeated by the mountain behind them, the noise was much louder, and more alarming than that they had heard in their first position, at least a mile nearer to Vesuvius. After some time, and which was about two o'clock in the morning of the 16th, having observed that the lavas ran in abundance, freely, and with great velocity, having made a considerable progress towards Resina, the town which it first threatened, and that the fiery vapours which had been confined had now free vent through many parts of a crack of more than a mile and a half in length, as was evident from the quantity of inflamed matter and black smoke, which continued to issue from the new mouths above mentioned,

without any interruption, our author concluded that at Naples all danger from earthquakes, which had been his greatest apprehension, was totally removed, and he returned to his former station at St. Lucia at Naples.

All this time there was not the smallest appearance of fire or smoke from the crater on the summit of Vesuvius; but the black smoke and ashes issuing continually from so many new mouths, or craters, formed an enormous and dense body of clouds over the whole mountain, and which began to give signs of being replete with the electric fluid, by exhibiting flashes of that sort of zig-zag lightning, which in the volcanic language of the country is called *ferilli*, and which is the constant attendant on the most violent eruptions.

Sir William Hamilton proceeds to remark, that during thirty years that he had resided at Naples, and in which space of time he had been witness to many eruptions of Vesuvius, of one sort or other, he never saw the cloud of smoke replete with the electric fire, except in the two great eruptions of 1767, that of 1779, and during this more formidable one. The electric fire, in the year 1779, that played constantly within the enormous black cloud over the crater of Vesuvius, and seldom quitted it, was exactly similar to that which is produced, on a very small scale, by the conductor of an electrical machine communicating with an insulated plate of glass, thinly spread over with metallic filings, &c. when the electric matter continues to play over it in zig-zag lines without quitting it. He was not sensible of any noise attending that operation in 1779; whereas the discharge of the electrical matter from the volcanic clouds during this eruption, and particularly the second and third days, caused explosions like those of the loudest thunder;

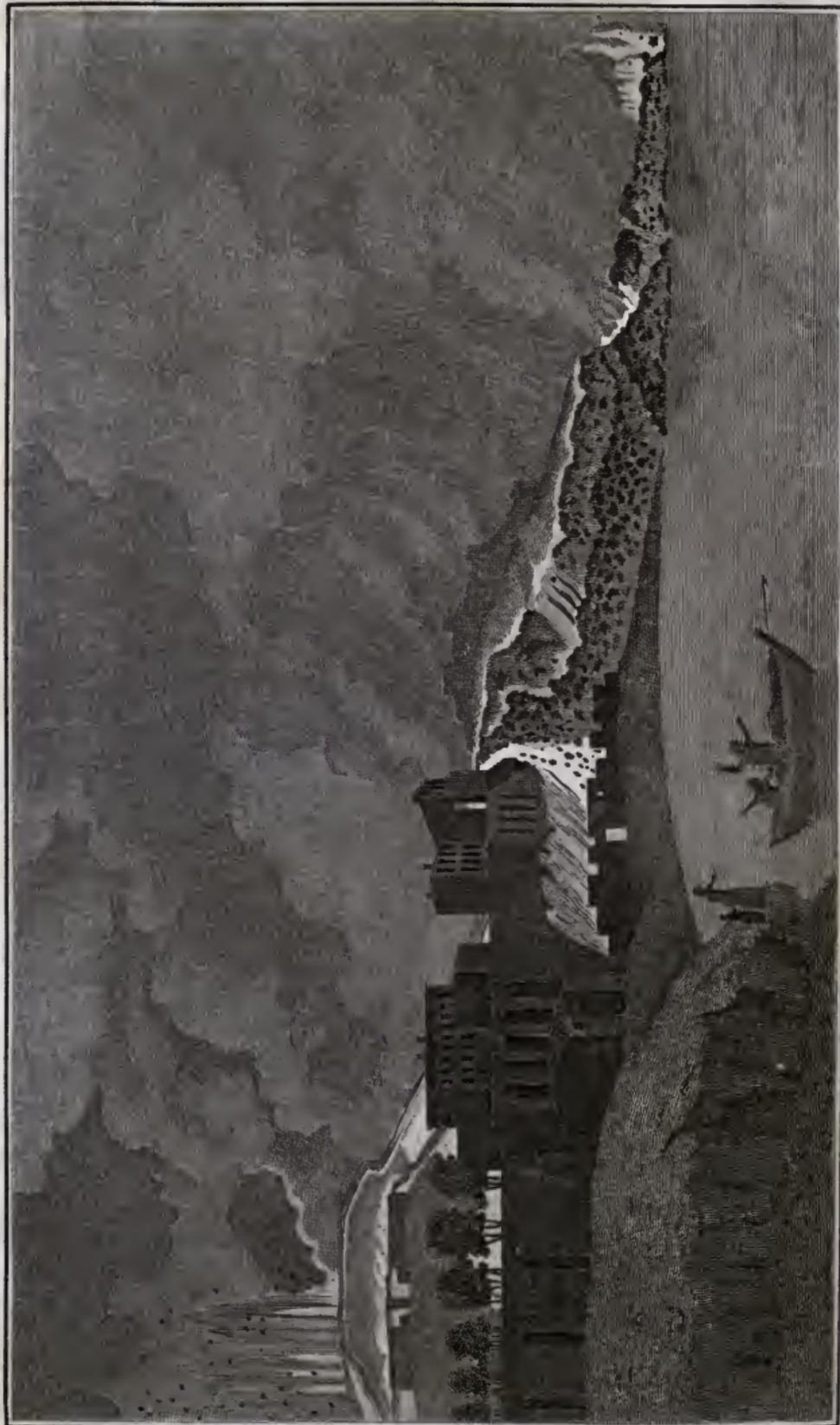
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and indeed the storms raised evidently by the sole power of the volcano, resembled in every respect all other thunder-storms; the lightning falling and destroying every thing in its course. The house of the Marquis of Berio at St. Jorio, situate at the foot of Vesuvius, during one of these volcanic storms was struck with lightning, which having shattered many doors and windows, and damaged the furniture, left for some time a strong smell of sulphur in the rooms it passed through. Out of these gigantic and volcanic clouds, besides the lightning, both during this eruption and that of 1779, the author adds, he had, with many others, seen balls of fire issue, and some of a considerable magnitude, which bursting in the air, produced nearly the same effect as that from the air-balloons in fire-works, the electric fire that came out having the appearance of the serpents with which those fire-work balloons are often filled. The day on which Naples was in the greatest danger from the volcanic clouds, two small balls of fire, joined together by a small link like a chain-shot, fell close to his Casino at Posilipo; they separated, and one fell in the vineyard above the house, and the other in the sea, so close to it that he heard the splash in the water. The Abbé Tata, in his printed account of this eruption, mentions an enormous ball of this kind which flew out of the crater of Vesuvius while he was standing on the edge of it, and which burst in the air at some distance from the mountain, soon after which he heard a noise like the fall of a number of stones, or of a heavy shower of hail. During the eruption of the 15th at night, few of the inhabitants of Naples, from the dread of earthquakes, ventured to go to their beds. The common people were either employed in devout processions in the streets, or were sleeping on the quays and open places;

the nobility and gentry, having caused their horses to be taken from their carriages, slept in them in the squares and open places, or on the high roads just out of the town. For several days, while the volcanic storms of thunder and lightning lasted, the inhabitants at the foot of the volcano, both on the sea side and the Somma side, were often sensible of a tremor in the earth, as well as of the concussions in the air, but at Naples only the earthquakes of the 12th and 15th of June were distinctly and universally felt: this fair city could not certainly have resisted, had not those earthquakes been fortunately of a short duration. Throughout this eruption, which continued in force about ten days, the fever of the mountain, as has been remarked in former eruptions, showed itself to be in some measure periodical, and generally was most violent at the break of day, at noon, and at midnight.

About four o'clock in the morning of the 16th, the crater of Vesuvius began to show signs of being open, by some black smoke issuing out of it; and at day-break another smoke, tinged with red, issuing from an opening near the crater, but on the other side of the mountain, and facing the town of Ottaiano, shewed that a new mouth had opened there from which a considerable stream of lava issued, and ran with great velocity through a wood, which it burnt; and having run about three miles in a few hours it stopped before it had arrived at the vineyards and cultivated lands. The crater, and all the conical part of Vesuvius, was soon involved in clouds and darkness, and so it remained for several days; but above these clouds, although of a great height, fresh columns of smoke were seen from the crater, rising furiously still higher, until the whole mass remained in the usual form of a pine-tree; and in that gigantic mass of heavy clouds
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the ferilli, or volcanic lightning, was frequently visible, even in the day time. About five o'clock in the morning of the 16th, the lava which had first broken out from the several new mouths on the south side of the mountain, had reached the sea, and was running into it, having overwhelmed, burnt, and destroyed the greatest part of Torre del Greco, the principal stream of lava having taken its course through the very center of the town (see plate II.)*. They observed from Naples, that when the lava was in the vineyards in its way to the town, there issued often, and in different parts of it, a bright pale flame, and very different from the deep red of the lava; this was occasioned by the burning of the trees that supported the vines. Soon after the beginning of this eruption, ashes fell thick at the foot of the mountain, all the way from Portici to the Torre del Greco; and what is remarkable, although there were not at that time any clouds in the air, except those of smoke from the mountain, the ashes were wet, and accompanied with large drops of water, which were to the taste very salt; the road, which is paved, was as wet as if there had been a heavy shower of rain. Those ashes were black and coarse, like the sand of the sea-shore, whereas those that fell there, and at Naples some days after, were of a light-grey colour, and as fine as Spanish snuff, or powdered bark. They contained many saline particles; those ashes that lay on the ground, exposed to the burning sun, had a coat of the whitest powder on their surface, which to the taste was ex-

* This view was taken from a boat on the sea near that town, about five in the morning of the 16th of June, and while the lava was still advancing in the sea. The rocks, on which are two figures near the boat, were formed by a lava that ran into the sea during a former eruption of Mount Vesuvius.

tremely salt and pungent. In the printed account of the eruption by Emanuel Scotti, doctor of physic and professor of philosophy in the university of Naples, he supposes (which appears to be highly probable) that the water which accompanied the fall of the ashes at the beginning of the eruption, was produced by the mixture of the inflammable and dephlogisticated air.

By the time that the lava had reached the sea between five and six o'clock in the morning of the 16th, Vesuvius was so completely involved in darkness, that the violent operation of nature that was going on there could no longer be discerned, and so it remained for several days; but the dreadful noise, and the red tinge on the clouds over the top of the mountain, were evident signs of the activity of the fire underneath. The lava ran but slowly at Torre del Greco after it had reached the sea; and on the 17th of June in the morning, its course was stopped, excepting that at times a little rivulet of liquid fire issued from under the smoking scoriæ into the sea, and caused a hissing noise, and a white smoke; at other times, a quantity of large scoriæ were pushed off the surface of the body of the lava into the sea, discovering that it was red-hot under that surface; and even to the latter end of August the center of the thickest part of the lava that covered the town retained its red heat. The breadth of the lava that ran into the sea, and formed a new promontory there, after having destroyed the greatest part of the town of Torre del Greco, having been exactly measured by the duke della Torre, is of English feet 1204. Its height above the sea is twelve feet, and as many feet under water; so that its whole height is twenty-four feet; it extends into the sea 626 feet. The sea water was boiling as in a cauldron, where it washed

washed the foot of this new formed promontory: and although our author was at least a hundred yards from it, observing that the sea smoked near his boat, he put his hand into the water, which was literally scalded; and by this time his boatmen observed that the pitch from the bottom of the boat was melting fast, and floating on the surface of the sea, and that the boat began to leak; he therefore retired hastily from this spot, and landed at some distance from the hot lava. The town of Torre del Greco contained about 18,000 inhabitants, all of whom (except about 15, who from either age or infirmity could not be moved, and were overwhelmed by the lava in their houses) escaped either to Castel-a-mare, which was the ancient Stabiae, or to Naples; but the rapid progress of the lava was such, after it had altered its course from Resina, which town it first threatened, and had joined a fresh lava that issued from one of the new mouths in a vineyard, about a mile from the town, that it ran like a torrent over the town of Torre del Greco, allowing the unfortunate inhabitants scarcely time to save their lives; their goods and effects were totally abandoned, and indeed several of the inhabitants, whose houses had been surrounded with lava while they remained in them, escaped from them, and saved their lives the following day, by coming out of the tops of their houses, and walking over the scorixæ on the surface of the redhot lava. Five or six old nuns were taken out of a convent in this manner, on the 16th of June, and carried over the hot lava; their stupidity was such, as not to have been the least alarmed, or sensible of their danger: one of upwards of ninety years of age was found actually warming herself at a point of redhot lava, which touched the window of her cell, and which she

she said was very comfortable; and though now apprized of their danger, they were still very unwilling to leave the convent, in which they had been shut up almost from their infancy, their ideas being as limited as the space they inhabited. Having been desired to pack up whatever they had that was most valuable, they all loaded themselves with biscuits and sweetmeats, and it was but by accident it was discovered that they had left a sum of money behind them, which was recovered for them.

The lava passed over the center and best part of the town; no part of the cathedral remained above it, except the upper part of a square brick tower, in which were the bells; and it is a curious circumstance, that those bells, although they were neither cracked nor melted, were deprived of their tone as much as if they had been cracked. When the lava first entered the sea it threw up the water to a prodigious height; and particularly when two points of lava met and inclosed a pool of water, that water was thrown up with great violence, and a loud report: at this time, as well as the day after also, a great many boiled fish were seen floating on the surface of the sea.

The lava over the cathedral, and in other parts of the town, is said to be upwards of forty feet in thickness; the general height of the lava during its whole course was about twelve feet, and in some parts not less than a mile in breadth.

When Sir William Hamilton visited it on the 17th of June, the tops of the houses were just visible here and there in some parts, and the timbers within still burning caused a bright flame to issue out of the surface; in other parts, the sulphur and salts exhaled in a white smoke from the lava, forming a white or yellow crust on the scorixæ round the spots where it issued with
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the greatest force. He often heard little explosions, and saw that they blew up, like little mines, fragments of the scorixæ and ashes into the air; these he supposes to have been occasioned either by rarefied air in confined cellars, or, perhaps, by small portions of gunpowder taking fire, as few in that country are without a gun and some little portion of gunpowder in their houses. As the church feasts there are usually attended with fireworks and crackers, a firework-maker of the town had a very great quantity of fireworks ready made for an approaching feast, and some gunpowder, all of which had been shut up in his house by the lava, a part of which had even entered one of the rooms; yet he actually saved all his fireworks and gunpowder some days after, by carrying them safely over the scorixæ of the lava, while it was red-hot underneath. The heat in the streets of the town, at this time, was so great as to raise the thermometer to very near one hundred degrees, and close to the hot lava it rose much higher. Sir William remarked in his way home, that there was a much greater quantity of the petroleum floating on the surface of the sea, and diffusing a very strong and offensive smell, than was usual; for at all times in calms, patches of this bituminous oil are to be seen floating on the surface of the sea between Portici and Naples, and particularly opposite a village called Pietra Bianca. The minute ashes continued falling at Naples; and the mountain, totally obscured by them, continued to alarm the inhabitants with repeated loud explosions.

On Wednesday June 18, the wind having for a short space of time cleared away the thick cloud from the top of Vesuvius, it was now discovered that a great part of its crater, particularly on the west side opposite Naples, had fallen in, which it probably did about four o'clock

o'clock in the morning of that day, as a violent shock of an earthquake was felt at that moment at Resina, and other parts situate at the foot of the volcano. The clouds of smoke, mixed with the ashes, were of such a density as to appear to have the greatest difficulty in forcing their passage out of the now widely extended mouth of Vesuvius, which, since the top fell in, is described as not much short of two miles in circumference. One cloud heaped on another, and succeeding one another incessantly, formed in a few hours such a gigantic and elevated column of the darkest hue over the mountain, as seemed to threaten Naples with immediate destruction, having at one time been bent over the city, and appearing to be much too massive and ponderous to remain long suspended in the air; it was, besides, replete with the ferilli, or volcanic lightning, which was stronger than common lightning, just as Pliny the younger describes it in one of his letters to Tacitus, when he says *fulgoribus illæ et similes et majores erant* *. (See plate III.)

Vesuvius was at this time completely covered, as were all the old black lavas, with a thick coat of those fine light-grey ashes already fallen, which gave it a cold and horrid appearance; and in comparison of the abovementioned enormous mass of clouds, which certainly, however it may contradict our idea of the extension of our atmosphere, rose many miles above the

* This view was taken from Naples, and gives a very good idea of the appearance of Mount Vesuvius, like a molehill, in comparison of the enormous mass that hung over it.—The black lines show the form of the top of Vesuvius, as it was before this eruption, and when the crater was only the width of the upper line. On the side of the mountain is represented the spot whence the lava first issued on the 15th of June, with its course to Torre del Greco and the sea.





mountain, it appeared like a molehill, although the perpendicular height of Vesuvius, from the level of the sea, is more than three thousand six hundred feet. The abbé Braccini, as appears in his printed account of the eruption of Mount Vesuvius in 1631, measured with a quadrant the elevation of a mass of clouds of the same nature, which was formed over Vesuvius during that great eruption, and found it to exceed thirty miles in height. Dr. Scotti, in his printed account of this eruption, says, that the height of this threatening cloud of smoke and ashes, measured from Naples, was found to be of an elevation of thirty degrees.

The storms of thunder and lightning, attended at times with heavy falls of rain and ashes, causing the most destructive torrents of water and glutinous mud, mixed with huge stones, and trees torn up by the roots, continued more or less to afflict the inhabitants on both sides of the volcano until the 7th of July, when the last torrent destroyed many hundred acres of cultivated land, between the towns of Torre del Greco and Torre dell' Annunziata. Some of these torrents, both on the sea side and the Somma side of the mountain, came down with a horrid rushing noise; and some of them, after having forced their way through the narrow gullies of the mountain, rose to the height of more than twenty feet, and were near half a mile in extent. The mud, of which the torrents were composed, being a kind of natural mortar, completely cased up and ruined some thousand acres of rich vineyards; for it soon becomes so hard, that nothing less than a pickaxe can break it up.

The laudable curiosity of our author induced him to go upon Mount Vesuvius, as soon as it was consistent with any degree of prudence, which was not until the 30th of June, and even then it was attended with some risk.

risk. The crater of Vesuvius, except at short intervals, had been continually obscured by the volcanic clouds from the 16th, and was so on that day, with frequent flashes of lightning playing in those clouds, and attended as usual with a noise like thunder; and the fine ashes were still falling on Vesuvius, but still more on the mountain of Somma. Sir William went up the usual way by Refina, and observed, in his way through that village, that many of the stones of the pavement had been loosened, and were deranged by the earthquakes, particularly by that of the 18th, which attended the falling in of the crater of the volcano, and which had been so violent as to throw many people down, and obliged all the inhabitants of Refina to quit their houses hastily, to which they did not dare return for two days. The leaves of all the vines were burnt by the ashes that had fallen on them, and many of the vines themselves were buried under the ashes, and great branches of the trees that supported them had been torn off by their weight. In short, nothing but ruin and desolation was to be seen. The ashes at the foot of the mountain were about ten or twelve inches thick on the surface of the earth, but in proportion as he ascended, their thickness increased to several feet, not less than nine or ten in some parts; so that the surface of the old rugged lavas, that before was almost impracticable, was now become a perfect plain, over which he walked with the greatest ease. The ashes were of a light-grey colour, and exceedingly fine, so that by the footsteps being marked on them as on snow, he learnt that three small parties had been up before him. He saw likewise the track of a fox, which appeared to have been quite bewildered, to judge from the many turns he had made. Even the traces of lizards and other little animals, and of insects,

fects, were visible on these fine ashes. Sir William and his companion ascended to the spot whence the lava of the 15th first issued, and followed the course of it, which was still very hot (although covered with such a thick coat of ashes) quite down to the sea at Torre del Greco, which is more than five miles. It was not possible to get up to the great crater of Vesuvius, nor had any one yet attempted it. The horrid chasms that existed from the spot where the late eruption first took place, in a strait line for near two miles towards the sea, cannot be imagined. They formed vallies more than two hundred feet deep, and from half a mile to a mile wide; and where the fountains of fiery matter existed during the eruption, were little mountains with deep craters. Ten thousand men, in as many years, could not make such an alteration on the face of Vesuvius. Except the exhalations of sulphureous and vitriolic vapours, which broke out from different spots of the line abovementioned, and tinged the surface of the ashes and scorixæ in those parts with either a deep or pale-yellow, with a reddish ochre colour, or a bright white, and in some parts with a deep green and azure blue (so that the whole together had the effect of an iris) all had the appearance of a sandy desert. Our adventurers then went on the top of seven of the most considerable of the new-formed mountains, and looked into their craters, which on some of them appeared to be little short of half a mile in circumference; and although the exterior perpendicular height of any of them did not exceed two hundred feet, the depth of their inverted cone within was three times as great. It would not have been possible to have breathed on these new mountains near their craters, if they had not taken the precaution of tying a doubled handkerchief over their mouths and nostrils;

nostrils; and even with that precaution they could not resist long, the fumes of the vitriolic acid were so exceedingly penetrating, and of such a suffocating quality. They found in one a double crater, like two funnels joined together; and in all there was some little smoke and depositions of salts and sulphurs, of the various colours abovementioned, just as is commonly seen adhering to the inner walls of the principal crater of Vesuvius.

Two or three days after they had been there, one of the new mouths, into which they had looked, suddenly made a great explosion of stones, smoke, and ashes, which would certainly have proved fatal to any one who might unfortunately have been there at the time of the explosion. We read of a similar accident having proved fatal to more than twenty people, who had the curiosity to look into the crater of the Monte Nuovo, near Puzzuoli, a few days after its formation, in the year 1538. The 15th of August, Sir William saw a sudden explosion of smoke and ashes thrown to an extreme height out of the great crater of Vesuvius, that must have destroyed any one within half a mile of it; and yet on the 19th of July a party not only had visited that crater, but had descended 170 feet within it. While they were on the mountain, two whirlwinds, exactly like those that form water-spouts at sea, made their appearance; and one of them, which was very near, made a strange rushing noise; and having taken up a great quantity of the fine ashes, formed them into an elevated spiral column, which, with a whirling motion and great rapidity, was carried towards the mountain of Somma, where it broke and was dispersed. One of our author's servants, employed in collecting of sulphur, or sal ammoniac, which crystallizes near the fumaroli, as they are called (and which
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are the spots whence the hot vapour issues out of the fresh lavas) found, to his great surprize, an exceeding cold wind issue from a fissure very near the hot fumaroli upon his leg. In a vineyard not in the same line with the new-formed mountains just described, but in a right line from them, at the distance of little more than a mile from Torre del Greco, they found three or four more of these new-formed mountains with craters, out of which the lava flowed, and by uniting with the streams that came from the higher mouths, and adding to their heat and fluidity, enabled the whole current to make so rapid a progress over the unfortunate town, as scarcely to allow its inhabitants sufficient time to escape with their lives. The rich vineyards belonging to the Torre del Greco, and which produced the wine called *Lacrima Christi*, that were buried, and totally destroyed by this lava, consisted of more than three thousand acres; but the destruction of the vineyards by the torrents of mud and water, at the foot of the mountain of Somma, was much more extensive.

In that part of the country, the first signs of a torrent that our author met with, was near the village of the *Madonna dell' Arco*, and he passed several others between that and the town of *Ottaiano*; one near *Trochia*, and two near the town of *Somma*, were the most considerable, and not less than a quarter of a mile in breadth; and, according to the testimony of eye-witnesses, when they poured down from the mountain of *Somma*, they were from twenty to thirty feet high; the matter of these torrents was a liquid glutinous mud, composed of *scoriæ*, ashes, stones (some of an enormous size) mixed with trees that had been torn up by the roots. Such torrents, as it may well be imagined, were irresistible, and carried off every thing before them;

houses, walls, trees, and not less than four thousand sheep and other cattle. At Somma, a team of eight oxen, which were drawing a large timber tree, were at once carried off, and never were heard of more.

The appearance of these torrents was like that of all other torrents in mountainous countries, except that what had been mud was become a perfect cement, on which nothing less than a pickaxe could make any impression. The vineyards and cultivated lands were here much more ruined; and the limbs of the trees much more torn by the weight of the ashes, than those which have been already described on the sea side of the volcano.

The abbé Tata, in his printed account of this eruption, has given a good idea of the abundance, the great weight, and glutinous quality of these ashes, when he says, that having taken a branch from a fig-tree still standing near the town of Somma, on which were only six leaves, and two little unripe figs, and having weighed it with the ashes attached to it, he found it to be thirty-one ounces; when having washed off the volcanic matter, it scarcely weighed three.

In the town of Somma, our author found four churches and about seventy houses without roofs, and full of ashes. The great damage on that side of the mountain, by the fall of the ashes and the torrents, happened on the 18th, 19th, and 20th of June, and on the 12th of July. The 19th, the ashes fell so thick at Somma, that unless a person kept in motion, he was soon fixed to the ground by them. This fall of ashes was accompanied also with loud reports, and frequent flashes of the volcanic lightning, so that, surrounded by so many horrors, it was impossible for the inhabitants to remain in the town, and they all fled; the darkness was such, although it was mid-day, that even with the help

help of torches it was scarcely possible to keep in the high road. On the 16th of July, signor Guiseppe Sacco went up to the crater, and, according to his account, which has been printed at Naples, the crater is of an irregular oval form, and as he supposes (not having been able to measure it) of about a mile and a half in circumference; the inside, as usual, in the shape of an inverted cone, the inner walls of which on the eastern side are perpendicular; but on the western side of the crater, which is much lower, the descent was practicable, and Sacco with some of his companions actually went down one hundred and seventy-six palms, from which spot, having lowered a cord with a stone tied to it, they found the whole depth of the crater to be about five hundred palms. But such observations on the crater of Vesuvius are of little consequence, as both its form and apparent depth are subject to great alterations from day to day.

The 22d of July, one of the new craters, which is the nearest to the town of Torre del Greco, threw up both fire and smoke, which circumstance, added to that of the lava's retaining its heat much longer than usual, seemed to indicate that there was still some fermentation under that part of the volcano. The lava in cooling often cracks, and causes a loud explosion, just as the ice does in the glaciers in Swisserland; such reports were frequently heard at this time at the Torre del Greco; and a vapour was often seen to issue from the body of the lava, and taking fire in air, fall like those meteors vulgarly called falling stars.

The darkness occasioned by the fall of the ashes in the Campagna Felice extended itself, and varied, according to the prevailing winds. On the 19th of June it was so dark at Caserta, which is fifteen miles from Naples, as to oblige the inhabitants to light can-

dles at mid-day; and one day, during the eruption, the darkness spread over Beneventum, which is thirty miles from Vesuvius.

The archbishop of Taranto, in a letter to Naples, and dated from that city the 18th of June, observes, 'We are involved in a thick cloud of minute volcanic ashes, and we imagine that there must be a great eruption either at Mount Etna, or of Stromboli.' The bishop did not suspect their having proceeded from Vesuvius, which is about two hundred and fifty miles from Taranto. Ashes also fell, during the late eruption, at the very extremity of the province of Lecce, which is still farther off; at Martino, near Taranto, a house was struck and much damaged by the lightning from one of the clouds. In the accounts of the great eruption of Vesuvius in 1631, mention is made of the extensive progress of the ashes from Vesuvius, and of the damage done by the ferilli, or volcanic lightning, which attended them in their course.

Our author in this place mentions a very extraordinary circumstance, which happened near Sienna, on the Tuscan state, about eighteen hours after the commencement of the late eruption of Vesuvius on the 15th of June, although he adds, that phenomenon must have no relation to the eruption; it was communicated to him in the following words by the earl of Bristol, bishop of Derry, in a letter dated from Sienna, July 12, 1794: 'In the midst of a most violent thunder-storm, about a dozen stones of various weights and dimensions fell at the feet of different people, men, women, and children; the stones are of a quality not found in any part of the Siennese territory; they fell about eighteen hours after the enormous eruption of Vesuvius, which circumstance leaves a choice of difficulties in the solution of this extraordinary

dinary phenomenon: either these stones have been generated in this igneous mass of clouds, which produced such unusual thunder, or, which is equally incredible, they were thrown from Vesuvius at a distance of at least two hundred and fifty miles; judge then of its parabola.' One of the largest stones, when entire, weighed upwards of five pounds. The outside of every stone that was found, and ascertained to have fallen from the cloud near Sienna, was evidently freshly vitrified, and black, having every sign of having passed through an extreme heat; when broken, the inside was found of a light-grey colour mixed with black spots, and some shining particles, supposed to be pyrites. Stones of the same nature, at least as far as the eye can judge of them, are frequently found on Mount Vesuvius; and should similar stones be found there, with the same vitrified coat on them, the question would be decided in favour of Vesuvius, unless it could be proved that there had been, about the time of the fall of these stones in the Siennese territory, some nearer opening of the earth, attended with an emission of volcanic matter, which might very possibly happen, as the mountain of Radicofani, within fifty miles of Sienna, is certainly volcanic. The celebrated father Ambrogio Soldani, professor of mathematics in the university of Sienna, has printed there a dissertation upon this extraordinary phenomenon; wherein, it is said, he has decided that those stones were generated in the air independently of volcanic assistance.

Until after the 7th of July, when the last cloud broke over Vesuvius, and formed a tremendous torrent of mud, which took its course across the great road between Torre del Greco and the Torre dell'Annunziata, and destroyed many vineyards, the eruption

could not be said to have finished, although the force of it was over the 22d of June. The power of attraction in mountains is well known; but whether the attractive power of a volcanic mountain is greater than that of any other mountain, is a question. During this eruption, however, it appeared that every watery cloud was evidently attracted by Vesuvius, and the sudden dissolution of those clouds left marks of their destructive power on the face of the country all round the basis of the volcano. After the mouth of Vesuvius was enlarged, our author says he has seen a great cloud passing over it, and which not only was attracted, but was sucked in, and disappeared in a moment.

After every violent eruption of Mount Vesuvius, we read of damage done by a mephitic vapour, which coming from under the ancient lavas, insinuates itself into low places, such as the cellars and wells of the houses situated at the foot of the volcano. After the eruption of 1767, there were several instances, as in this, of people going into their cellars at Portici, and other parts of that neighbourhood, having been struck down by this vapour, and who would have expired if they had not been hastily removed. These occasional vapours, or *mosfete*, are of the same quality as that permanent one in the Grotta del Cane, near the lake of Agnano, and which has been proved to be chiefly fixed air. The vapours, that in the volcanic language of Naples, are called *fumaroli*, are of another nature, and issue from spots all over the fresh and hot lavas while they are cooling; they are sulphureous and so suffocating, that often the birds which are flying over them are overpowered, and fall down dead. These vapours deposit a crust of sulphur, or salts, particularly of sal ammoniac, on the scorixæ of
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the lava through which they pass; and the small crystals of which they are composed are often tinged with deep or pale yellow, with a bright red like cinnabar, and sometimes with green, or an azure blue. After the late eruption, many pieces of the scorix of the fresh lava were found powdered with a lucid substance, exactly like the brightest steel or iron filings.

The first appearance of the mofete, after the late eruption, was on the 17th of June, when a peasant going with an ass to his vineyard, a little above the village of Resina, in a narrow hollow way, the ass dropped down, and seemed to be expiring; the peasant was soon sensible of the mephitic vapour himself, and well knowing its fatal effects, dragged the animal out of its influence and it soon recovered. This heavy vapour, when exposed to the open air, does not rise much more than a foot above the surface of the earth, but when it gets into a confined place, like a cellar or well, it rises and fills as any other fluid would; having filled a well, it rises above it about a foot high, and then bending over, falls to the earth, on which it spreads, always preserving its usual level. Wherever this vapour issues, a wavering in the air is perceptible, like that which is produced by the burning of charcoal; and when it issues from a fissure near any plants or vegetables, the leaves of those plants are seen to move, as if they were agitated by a gentle wind. It is extraordinary, that although there does not appear to be any poisonous quality in this vapour, which in every respect resembles fixed air, it should prove so very fatal to the vineyards, some thousand acres of which were destroyed by it after the late eruption: when it penetrates to the roots of the vines, it dries them up, and kills the plant. A peasant in the neighbourhood of Resina, having suffered by the

mofete, which destroyed his vineyards in the year 1767, and having observed then that the vapour followed the laws of all fluids, made a narrow deep ditch all round his vineyard, which communicated with ancient lavas, and also with a deep cavern under one of them; the consequence of his well planned operation was, that although surrounded by these noxious vapours, which lay constantly at the bottom of his ditch, they never entered his vineyard, and his vines were in a flourishing state, while those of his neighbours were perishing. Upwards of thirteen hundred hares, and many pheasants and partridges, overtaken by this vapour, were found dead within his Sicilian majesty's reserved chases in the neighbourhood of Vesuvius; and also many domestic cats, who in their pursuit after this game fell victims to the mofete. A shoal of fish, of several hundred weight, having been observed by some fishermen at Resina in great agitation on the surface of the sea, near some rocks of an ancient lava that had run into the sea, they surrounded them with their nets, and took them all with ease, and afterwards discovered that they had been stunned by the mephitic vapour, which at that time issued forcibly from underneath the ancient lava into the sea.

The account of Sir William Hamilton is concluded by two remarks, which as they are curious I shall insert:

1. Within a mile of Castel-a-mare, the mofete were still very active (on Sept. 2.) and particularly under the spot where the ancient town of Stabia was situated. The 24th of August, a young lad by accident falling into a well there that was dry, but full of the mephitic vapour, was immediately suffocated; there were no signs of any injury from the fall, as the well was shallow. This circumstance called to our author's
mind

mind the death of the elder Pliny, who most probably lost his life by the same sort of mephitic vapours, on this very spot, and which are active after great eruptions of Vesuvius.

2. Mr. James, a British merchant, assured our author, that on Tuesday night, the 17th of June, which was the third day of the eruption of Mount Vesuvius, he was in a boat with a sail, near Torre del Greco, when the minute ashes, so often mentioned, fell thick; and that in the dark they emitted a pale light like phosphorus, so that his hat, those of the boatmen, and the part of the sails that were covered with ashes, were luminous. Others had mentioned having seen a phosphoric light on Vesuvius after this eruption; but until it was confirmed to him by Mr. James, he did not chuse to say any thing about it*.

* See Phil. Transf. for 1795, p. 73, &c.

C H A P. XLVIII.

EARTHQUAKES.

Connection between Earthquakes and Volcanoes.—Earthquakes caused by the Progress of Steam between the Strata of the Earth.—Signs of approaching Earthquakes.—Great Earthquake at Lisbon, in 1755.—Earthquakes in Calabria, in 1783.

THE sudden explosions which take place from volcanoes, probably depend on the access of a quantity of water, which enters through some fissure communicating with the sea, or which is derived from other sources in the earth. If this mass of water is sufficiently great, it will extinguish the volcano; if not, it will be converted into steam, the expansive force of which far exceeds that of gun-powder. The elastic fluid, thus formed, either finds vent at the mouth of the volcano, or, if the super-incumbent weight should be too great, it will force a passage between the strata of the earth, and occasion that undulatory but sometimes violent motion which is called an earthquake. From various facts demonstrative of the cohesion and elasticity of bodies, we are warranted in concluding, that the different strata of which the earth is composed will adhere together, and that a freer passage will be afforded to any intervening body between the strata than directly through them. If the confined fire acts directly under a province or town, it will heave the earth perpendicularly upwards, and the shocks will be more sudden and violent. If it acts at a distance, it will raise that tract obliquely, and the motion will be more oblique, undulatory, and tremulous.

The

The great earthquake at Lisbon, in 1755, was felt as far as Scotland, and from the phenomena which attended it, it was evident that the ground had a waving motion from south to north. All the oblong lakes, that lay from north to south, were much agitated, the wave commencing at the south end, whilst all other lakes which lay across, from east to west, were much less affected.

The great distance to which earthquakes extend depends on the compressibility and elasticity of the earth, which may be understood from the vibration of the walls of houses, occasioned by the passing of carriages in the adjacent streets. Another instance is the vibration of steeples by the ringing of bells or gusts of wind. The Eddystone lighthouse often vibrates from the force of the waves which beat against its foundation.

Previous to an eruption of Vesuvius the earth always trembles, and subterraneous explosions are heard. On the 1st of November, 1755, the era so fatal to Lisbon, the island of Madeira was violently shaken by an earthquake, accompanied with subterraneous explosions. So thoroughly convinced, indeed, are the inhabitants of volcanic countries of the connection between earthquakes and volcanoes, that when a great eruption takes place from a volcano, they congratulate themselves on having escaped an earthquake.

Earthquakes as well as volcanic eruptions are always preceded by a violent agitation of the sea. Previous to the breaking out of Vesuvius, the sea retires from the adjacent shores till the mountain is burst open, and then it returns with such impetuosity as to overflow its usual boundary. About an hour after the first shocks, which alarmed the city of Lisbon in 1755, the sea was observed to come rushing to-

wards

wards the city like a torrent, though against both wind and tide; it rose forty feet higher than was ever known, and as suddenly subsided. A ship, fifty leagues off at sea, received so violent a shock as greatly to injure the deck, &c. The same effect was observed at Cadiz, and at a number of ports throughout the Mediterranean, and, indeed, more or less, all over Europe.

That earthquakes are the effect of steam generated within the bowels of the earth, and that they are produced in the manner which has been described, appears highly probable from the quantities of steam and boiling water which have occasionally been thrown up by volcanoes in different parts of the world. In 1631 and 1698 vast torrents of boiling water flowed from the crater of Vesuvius, previous to the eruption of fire: and what was, perhaps, still more remarkable, many species of sea-shells, in a calcined state, were found on the brink of the crater, and also in the channel formed by the flood. The same thing happened at *Ætna*, in 1755, when a dreadful torrent of boiling water flowed from the crater at the time of an eruption of fire. Sir William Hamilton observes, that the sea-shells emitted along with the water clearly indicate a communication with the sea. All warm springs probably receive their heat from the action of pyrites, near which the water passes.

The following account of the great Lisbon earthquake is extracted from a volume of letters, published a few years ago by the reverend Mr. Davy:

‘ There never was a finer morning seen than the first of November (1755); the sun shone out in its full lustre; the whole face of the sky was perfectly serene and clear, and not the least signal or warning of that approaching event, which has made this once flourish-

ishing, opulent, and populous city, a scene of the utmost horror and desolation, except only such as served to alarm, but scarcely left a moment's time to fly from the general destruction.

‘ It was on the morning of this fatal day, between the hours of nine and ten, that I was sat down in my apartment, just finishing a letter, when the papers and table I was writing on began to tremble with a gentle motion, which rather surprized me, as I could not perceive a breath of wind stirring; whilst I was reflecting with myself what this could be owing to, but without having the least apprehension of the real cause, the whole house began to shake from the very foundation, which at first I imputed to the rattling of several coaches in the main street, which usually passed that way, at this time, from Belem to the palace; but on hearkening more attentively, I was soon undeceived, as I found it was owing to a strange frightful kind of noise under ground, resembling the hollow distant rumbling of thunder; all this passed in less than a minute, and I must confess I now began to be alarmed, as it naturally occurred to me, that this noise might possibly be the forerunner of an earthquake, as one I remembered, which had happened about six or seven years ago, in the Island of Madeira, commenced in the same manner, though it did little or no damage.

‘ Upon this I threw down my pen, and started upon my feet, remaining a moment in suspense, whether I should stay in the apartment, or run into the street, as the danger in both places seemed equal; and still flattering myself that this tremor might produce no other effects than such inconsiderable ones as had been felt at Madeira; but in a moment I was roused from my dream, being instantly stunned with a most horrid crash,

crash, as if every edifice in the city had tumbled down at once. The house I was in shook with such violence, that the upper stories immediately fell, and though my apartment (which was the first floor) did not then share the same fate, yet every thing was thrown out of its place in such a manner, that it was with no small difficulty I kept my feet, and expected nothing less than to be soon crushed to death, as the walls continued rocking to and fro in the frightfullest manner; opening in several places, large stones falling down on every side from the cracks, and the ends of most of the rafters starting out from the roof. To add to this terrifying scene, the sky in a moment became so gloomy, that I could now distinguish no particular object; it was an Egyptian darkness indeed, such as might be felt; owing, no doubt, to the prodigious clouds of dust and lime, raised from so violent a concussion, and as some reported, to sulphureous exhalations, but this I cannot affirm; however, it is certain I found myself almost choaked for near ten minutes.

‘As soon as the gloom began to disperse, and the violence of the shock seemed pretty much abated, the first object I perceived in the room was a woman sitting on the floor, with an infant in her arms, all covered with dust, pale and trembling; I asked her how she got hither: but her consternation was so great that she could give me no account of her escape; I suppose, that when the tremor first began, she ran out of her own house, and finding herself in such imminent danger from the falling of stones, retired into the door of mine, which was almost contiguous to her’s, for shelter, and when the shock increased, which filled the door with dust and rubbish, ran up stairs into my apartment, which was then open: be it as it might, this was no time for curiosity. I remember the poor creature

creature asked me, in the utmost agony, if I did not think that the world was at an end; at the same time she complained of being choaked, and begged for God's sake I would procure her a little drink; upon this I went to a closet where I kept a large jar with water (which you know is sometimes a pretty scarce commodity in Lisbon) but finding it broken in pieces, I told her she must not now think of quenching her thirst, but saving her life, as the house was just falling on our heads, and if a second shock came, would certainly bury us both; I bade her take hold of my arm, and that I would endeavour to bring her into some place of security.

‘ I shall always look upon it as a particular providence, that I happened on this occasion to be undressed, for had I dressed myself, as I proposed, when I got out of bed, in order to breakfast with a friend, I should, in all probability, have run into the street at the beginning of the shock, as the rest of the people in the house did, and consequently have had my brains dashed out, as every one of them had; however, the imminent danger I was in did not hinder me from considering that my present dress, only a gown and slippers, would render my getting over the ruins almost impracticable: I had, therefore, still presence of mind enough left to put on a pair of shoes and a coat, the first that came in my way, which was every thing I saved, and in this dress I hurried down stairs, the woman with me, holding by my arm, and made directly to that end of the street which opens to the Tagus, but finding the passage this way entirely blocked up with the fallen houses to the height of their second stories, I turned back to the other end which led into the main street (the common thoroughfare to the palace) and having helped the woman over a vast heap
of

of ruins, with no small hazard to my own life, just as we were going into the street, as there was one part I could not well climb over without the assistance of my hands, as well as feet, I desired her to let go her hold, which she did, remaining two or three feet behind me, at which time there fell a vast stone, from a tottering wall, and crushed both her and the child in pieces: so dismal a spectacle at any other time would have affected me in the highest degree, but the dread I was in of sharing the same fate myself, and the many instances of the same kind which presented themselves all around, were too shocking to make me dwell a moment on this single object.

‘ I had now a long narrow street to pass, with the houses on each side four or five stories high; all very old, the greater part already thrown down, or continually falling, and threatening the passengers with inevitable death at every step, numbers of whom lay killed before me, or what I thought far more deplorable—so bruised and wounded that they could not stir to help themselves. For my own part, as destruction appeared to me unavoidable, I only wished I might be made an end of at once, and not have my limbs broken, in which case I could expect nothing else but to be left upon the spot, lingering in misery, like these poor unhappy wretches, without receiving the least succour from any person.

‘ As self-preservation, however, is the first law of nature, these sad thoughts did not so far prevail, as to make me totally despair. I proceeded on as fast as I conveniently could, though with the utmost caution, and having at length got clear of this horrid passage, I found myself safe and unhurt in the large open space before St. Paul’s church, which had been thrown down a few minutes before, and buried a great part
of

of the congregation, that was generally pretty numerous, this being reckoned one of the most populous parishes in Lisbon. Here I stood some time, considering what I should do, and not thinking myself safe in this situation, I came to the resolution of climbing over the ruins of the west end of the church, in order to get to the river side, that I might be removed, as far as possible, from the tottering houses, in case of a second shock.

‘ This, with some difficulty, I accomplished, and here I found a prodigious concourse of people, of both sexes, and of all ranks and conditions, among whom I observed some of the principal canons of the patriarchal church, in their purple robes and rochets, as these all go in the habit of bishops; several priests who had run from the altars in their sacerdotal vestments in the midst of their celebrating mass; ladies half dressed, and some without shoes; all these, whom their mutual dangers had here assembled as to a place of safety, were on their knees at prayers, with the terrors of death in their countenances, every one striking his breast, and crying out incessantly, *Misericordia meu Dios*.

‘ In the midst of our devotions, the second great shock came on, little less violent than the first, and completed the ruin of those buildings which had been already much shattered. The consternation now became so universal, that the shrieks and cries of *Misericordia* could be distinctly heard from the top of St. Catherine’s hill, at a considerable distance off, whither a vast number of people had likewise retreated; at the same time we could hear the fall of the parish church there, whereby many persons were killed on the spot, and others mortally wounded. You may judge of the force of this shock, when I inform you, it was so vio-

lent, that I could scarce keep on my knees, but it was attended with some circumstances still more dreadful than the former.—On a sudden I heard a general outcry, ‘The sea is coming in, we shall be all lost.’—Upon this, turning my eyes towards the river, which in that place is near four miles broad, I could perceive it heaving and swelling in a most unaccountable manner, as no wind was stirring; in an instant there appeared, at some small distance, a large body of water, rising like a mountain; it came on foaming and roaring, and rushed towards the shore with such impetuosity, that we all immediately ran for our lives as fast as possible; many were actually swept away, and the rest above their waist in water at a good distance from the banks. For my own part, I had the narrowest escape, and should certainly have been lost, had I not grasped a large beam that lay on the ground, till the water returned to its channel, which it did almost at the same instant, with equal rapidity. As there now appeared at least as much danger from the sea as the land, and I scarce knew whither to retire for shelter, I took a sudden resolution of returning back with my cloaths all dropping, to the area of St. Paul’s: here I stood some time, and observed the ships tumbling and tossing about, as in a violent storm; some had broken their cables, and were carried to the other side of the Tagus; others were whirled round with incredible swiftness; several large boats were turned keel upwards; and all this without any wind, which seemed the more astonishing. It was at the time of which I am now speaking, that the fine new quay, built of rough marble, at an immense expence, was entirely swallowed up, with all the people on it, who had fled thither for safety, and had reason to think themselves out of danger in such a place; at the same time

time a great number of boats and small vessels, anchored near it (all likewise full of people, who had retired thither for the same purpose) were all swallowed up, as in a whirlpool, and never more appeared.

This last dreadful incident I did not see with my own eyes, as it passed three or four stones throws from the spot where I then was, but I had the account as here given from several masters of ships, who were anchored within two or three hundred yards of the quay, and saw the whole catastrophe. One of them in particular informed me, that when the second shock came on, he could perceive the *whole* city waving backwards and forwards, like the sea when the wind first begins to rise; that the agitation of the earth was so great even under the river, that it threw up his large anchor from the mooring, which swam, as he termed it, on the surface of the water; that immediately upon this extraordinary concussion, the river rose at once near twenty feet, and in a moment subsided; at which instant he saw the quay, with the whole concourse of people upon it, sink down, and at the same time every one of the boats and vessels that were near it were drawn into the cavity, which he supposes instantly closed upon them, inasmuch as not the least sign of a wreck was ever seen afterwards. This account you may give full credit to, for as to the loss of the vessels, it is confirmed by every body; and with regard to the quay, I went myself a few days after, to convince myself of the truth, and could not find even the ruins of a place, where I had taken so many agreeable walks, as this was the common rendezvous of the factory in the cool of the evening. I found it all deep water, and in some parts scarcely to be fathomed.

‘ This is the only place I could learn which was swallowed up in or about Lisbon, though I saw many large cracks and fissures in different parts, and one odd phenomenon I must not omit, which was communicated to me by a friend who had a house and wine-cellars on the other side of the river, viz. that the dwelling-house being first terribly shaken, which made all the family run out, there presently fell down a vast high rock near it, that upon this the river rose and subsided in the manner already mentioned, and immediately a great number of small fissures appeared in several contiguous pieces of ground, whence there spouted out like a *jet d’eau* a large quantity of fine white sand, to a prodigious height.

‘ I had not been long in the area of St. Paul’s, when I felt the third shock, which though somewhat less violent than the two former, the sea rushed in again, and retired with the same rapidity, and I remained up to my knees in water, though I had gotten upon a small eminence at some distance from the river, with the ruins of several intervening houses to break its force. At this time I took notice the waters retired so impetuously, that some vessels were left quite dry, which rode in seven fathom water: the river thus continued alternately rushing on and retiring several times together, in such sort, that it was justly dreaded Lisbon would now meet the same fate, which a few years ago had befallen the city of* Lima.

‘ Perhaps you may think the present doleful subject here concluded; but, alas! the horrors of the first of November, are sufficient to fill a volume. As soon as it grew dark, another scene presented itself

* This happened in 1746.

little less shocking than those already described—the whole city appeared in a blaze, which was so bright that I could easily see to read by it. It may be said, without exaggeration, it was on fire at least in an hundred different places at once, and thus continued burning for six days together, without intermission, or the least attempt being made to stop its progress.

‘ I could never learn, that this terrible fire was owing to any subterraneous eruption, as some reported, but to three causes, which all concurring at the same time, will naturally account for the prodigious havock it made; the first of November being All Saints Day, a high festival among the Portuguese, every altar in every church and chapel (some of which have more than twenty) was illuminated with a number of wax tapers and lamps, as customary; these setting fire to the curtains and timber work that fell with the shock, the conflagration soon spread to the neighbouring houses, and being there joined with the fires in the kitchen chimnies, increased to such a degree, that it might easily have destroyed the whole city, though no other cause had concurred, especially as it met with no interruption.

‘ But what would appear incredible to you, were the fact less public and notorious, is, that a gang of hardened villains, who had been confined, and got out of prison when the wall fell, at the first shock, were busily employed in setting fire to those buildings, which stood some chance of escaping the general destruction.

‘ The fire, by some means or other, may be said to have destroyed the whole city, at least every thing that was grand or valuable in it; and the damage on this occasion is not to be estimated.

‘ The whole number of persons that perished, including

cluding those who were burnt, or afterwards crushed to death whilst digging in the ruins, is supposed, on the lowest calculation, to amount to more than sixty thousand; and though the damage in other respects cannot be computed, yet you may form some idea of it, when I assure you, that this extensive and opulent city, is now nothing but a vast heap of ruins, that the rich and poor are at present upon a level, some thousands of families which but the day before had been easy in their circumstances, being now scattered about in the fields, wanting every conveniency of life, and finding none able to relieve them.

‘A few days after the first consternation was over, I ventured down into the city, by the safest ways I could pick out, to see if there was a possibility of getting any thing out of my lodgings, but the ruins were now so augmented by the late fire, that I was so far from being able to distinguish the individual spot where the house stood, that I could not even distinguish the street, amidst the mountains of stone and rubbish which rose on every side. Some days after, I ventured down again with several porters, who, having long plied in these parts of the town, were well acquainted with the situation of particular houses; by their assistance, I at last discovered the spot; but was soon convinced, that to dig for any thing there, besides the danger of such an attempt, would never answer the expence.

‘On both the times when I attempted to make this fruitless search, especially the first, there came such an intolerable stench from the dead bodies, that I was ready to faint away, and though it did not seem so great this last time, yet it had nearly been more fatal to me, as I contracted a fever by it, but of which, God be praised, I soon got the better. However,
this

this made me so cautious for the future, that I avoided passing near certain places, where the stench was so excessive that people began to dread an infection: a gentleman told me, that going into the town a few days after the earthquake, he saw several bodies lying in the streets, some horribly mangled, as he supposed, by the dogs, others half burnt, some quite roasted; and that in certain places, particularly near the doors of churches, they lay in vast heaps piled one upon another.

The year 1783 was fatally marked by the desolation of some of the most fertile, most beautiful, and most celebrated provinces of Europe. The two Calabrias, with a part of Sicily, were doomed to be a scene of the most tremendous, and the most fatal earthquakes that ever were known, even in those volcanic regions. The first shock happened about noon, on the 5th of February, and was so violent as to involve almost the whole of Calabria in ruin. This was but the commencement of a succession of earthquakes, which beginning from the city of Amantea, on the coast of the Tyrrhene sea, proceeded along the western coast to Cape Spartivento, and up the eastern as far as Cape D'Alice; during the whole of which space not a town was left undestroyed.

During two years repeated shocks continued to agitate the affrighted minds of the inhabitants of Calabria and Sicily, but the principal mischiefs arose in the months of February and March in the first year. For several months the earth continued in an unceasing tremor, which at certain intervals increased to violent shocks, some of which were beyond description dreadful. These shocks were sometimes horizontal, whirling like a vortex; and sometimes by pulsations or beating from the bottom upwards, and were at

times so violent that the heads of the largest trees almost touched the ground on either side. The rains, during a great part of the time, were continual and violent, often accompanied with lightning, and furious gusts of wind. All that part of Calabria, which lay between the 38th and 39th degrees, assumed a new appearance. Houses, churches, towns, cities, and villages, were buried in one promiscuous ruin. Mountains were detached from their foundations, and carried to a considerable distance*. Rivers disappeared from their beds, and again returned and overflowed the adjacent country †. Streams of water suddenly gushed out of the ground, and sprang to a considerable height. Large pieces of the surface of the plain, several acres in extent, were carried five hundred feet from their former situation down into the bed of the river, and left standing at nearly the distance of a mile, surrounded by large plantations of olives and mul-

* Sir William Hamilton, whose ardent and laudable spirit of inquiry occasioned his visiting Calabria and Sicily during this calamitous season, accounts for the removal of a mountain of about two hundred and fifty feet in height, and about four hundred feet in diameter at its base, from the different nature of its inferior and superior strata. The under part being more solid and compact, was more strongly acted upon by the violent motion of the earth, and the volcanic vapours, which drove it to the distance of some hundred yards from its original scite, where it lay in confused blocks, after having left the superior stratum, which, with its trees and vineyards, was carried in another direction to the distance of four miles.

† The same philosopher accounts for this phenomenon by supposing the first impulse of the earthquake to have come from the bottom upwards, which raising the surface of the ground, the rivers which are not deep must naturally disappear; but the earth returning again with violence to its former level, the rivers must as naturally return and overflow their banks; at the same time the boggy grounds being suddenly depressed, would force out the water which lay hid under their surface.

berry trees, and corn growing as well upon them as upon the ground from which they were separated. Amidst these scenes of devastation, the escapes of some of the unhappy sufferers is extremely wonderful. Some of the inhabitants of houses which were thrown to a considerable distance, were dug out from their ruins unhurt. But these instances were few, and those who were so fortunate as to preserve their lives in such situations, were content to purchase existence at the expence of broken limbs and the most dreadful contusions.

During this calamitous scene, it is impossible to conceive the horrors and wretchedness of the unhappy inhabitants. The jaws of death were opened to swallow them up; ruin had seized all their possessions, and those dear connections to which they might have looked for consolation in their sorrows, were for ever buried in the merciless abyss. All was ruin and desolation. Every countenance indicated the extremity of affliction and despair; and the whole country formed a wide scene of undescribable horror.

One of the most remarkable towns which was destroyed was Casal Nuova, where the Princess Gerace Grimaldi, with more than four thousand of her subjects, perished in the same instant. An inhabitant happening to be on the summit of a neighbouring hill at the moment of the shock, and looking earnestly back to the residence of his family, could see no other remains of it than a white cloud which proceeded from the ruins of the houses. At Bagnara, about three thousand persons were killed, and not fewer at Radicina and Palma. At Terra Nuova four thousand four hundred perished, and rather more at Semnari. The inhabitants of Scilla escaped from their houses on the celebrated rock of that name, and with their prince, descended

descended to a little harbour at the foot of the hill; but, in the course of the night, a stupendous wave, which is said to have been driven three miles over land, on its return swept away the unfortunate prince, with two thousand four hundred and seventy-three of his subjects. It is computed that not less than forty thousand persons perished by this earthquake.

B O O K VII.

O F W A T E R.

C H A P. I.

O F W A T E R I N G E N E R A L.

Water a Compound Body.—Three States of Water.—Water in a fluid State.—Florentine Experiment.—Vapour.—Experiments ascertaining the Force of Vapour.—Steam Engine.—Ice.—Phenomena of Freezing.—Of Thawing.—Water expanded in the State of Ice.—Immense Force exerted by Water on passing to that State.—Why Ice is not perfectly transparent.

WA T E R was universally considered as a simple elementary substance till the chemists of the present age proved, by experiments, the substance of which has been stated in a preceding volume *, that it is in reality a compound body. Its principles have been ascertained both by composition and decomposition; and one hundred parts of water are found to consist of eighty-five parts of oxygen, and fifteen of hydrogen, or the basis of inflammable air.

This very useful and necessary fluid presents itself to our notice in three distinct forms, namely, in its liquid state, in the state of vapour or steam, and lastly

in its frozen state. Of these I shall speak in their order.

Water, when pure and in its fluid state, is transparent, colourless, and without smell. It adheres to most bodies which come in contact with it, it pervades porous substances, dissolves gummy and saline matters, and extinguishes fire.

Water, when fluid, is not in its most simple state, for its fluidity depends on a certain quantity of caloric, or the matter of heat, which enters into combination with it, and insinuating itself between the particles of the water, renders them capable of moving in all directions.

We are supplied with water either from the atmosphere, whence it descends in the form of rain, hail, or snow, or from the earth, which sends it forth in springs and rivulets. In the former case the watery exhalations drawn from the sea, and the surface of the earth by the sun's heat, form clouds, whose particles being afterwards condensed, fall back again in showers. In the latter, the water which falls on the tops of mountains, and other lofty situations, penetrates the earth, and, after passing downwards, breaks forth at some fissure or aperture at a distance from its source.

The quantity of water attracted from the surface of the globe is almost incredible. Dr. Halley has calculated that portion which is yielded by the sea, to be at the rate of one cubic inch from every ten inches of surface in twelve hours*. To form an adequate idea of this, let us suppose only half the globe to be covered by the sea. The whole surface of the earth being about 25,797,278 leagues, that of the sea will consequently be 12,898,639. Supposing the evaporation

* See Bishop Watson's Calculation, vol. i. p. 122.

which takes place in twelve hours to be that above mentioned, without having any regard to what is evaporated from the whole of the land, or from the sea during the other twelve hours, it will be found that the atmosphere has taken up no less than 20,302,535,177,834, or more than twenty millions of millions of cubic feet of water; an enormous quantity, and much more than sufficient to supply all the rivers that intersect the different quarters of the globe*.

What particularly distinguishes water, and those fluids which are of a similar consistence, and in common language are termed liquids, from those subtile fluids which were treated of at large in the preceding volume, is, that the former are not, like the others, possessed of that surprizing elasticity which admits of the volume of fluid being condensed into a small compass; but, on the contrary, may be considered as incapable of compression, or at least are compressible in a very slight degree. The Florentine academicians filled a globe of gold with water, and compressed it with immense force; the first effect of this compression was, that the ball was considerably heated by the emission of latent heat from the water, and afterwards the fluid forced its way through the pores of the gold, or

* There will possibly be apparent, in this part of the work, some degree of repetition when compared with what was said of vapour in the first book. It was then necessary to speak of vapour, in explanation of the properties of heat; it is now necessary to treat of it in connection with the fluid of which it is usually formed; and I conceive it better to do this, with the risk of some repetition, than to refer to a former volume, both because it will serve more firmly to impress on the minds of young readers some of the most important doctrines of philosophy: and because what may now appear as repetition, is, in this place, mixed with new facts, which could not be previously introduced.

through certain cavities, and appeared in drops on the surface. The conclusion, however, which was hastily drawn from this experiment, that water, in its liquid state, is absolutely void of all elasticity, is not warrantable. Since other experiments shew that water as well as mercury will yield, in a certain degree, to the pressure of the air in a condensing machine, as Mr. Canton proved by including it in a glass vessel, with a narrow neck or stem nicely graduated; its condensation appears proportioned to the force, and as soon as the pressure of the air is removed, the fluid will be observed gradually to recover its accustomed dimensions.

When water becomes heated to a degree beyond that of the air upon its surface, the matter of heat, which has a constant propensity to diffuse itself equally through all bodies with which it is in contact, rises and carries with it part of the water, which it converts into an elastic fluid or vapour. Until the water, however, arrives at the boiling point, the evaporation is very gradual; but when this happens it becomes very rapid, and the part of the water which is most heated, being converted into vapour, rises suddenly to the surface, and occasions considerable agitation.

Ebullition requires a determined degree of heat, because the steam cannot be formed within the water, unless it is strong enough to overcome the actual pressure of the fluid and air incumbent on it. But in ordinary evaporation, the vapour is formed at the surface of the water, and has therefore no other pressure to overcome than that of the atmosphere. The elastic fluid, however, which is formed by ordinary evaporation is different from that produced by ebullition, for the latter always returns to the state of water by a diminution of temperature, whereas the former is reduced

duced almost to the state of a permanently elastic fluid by mixture with air.

We find that all fluids boil more easily in proportion as the pressure of the atmosphere is removed; whether this is effected by ascending a mountain, or making use of the air pump. M. Lavoisier says, that if the weight of the atmosphere was only equal to between twenty or twenty-four inches of a column of mercury, instead of twenty-eight inches, we should never be able to obtain æther in a liquid state, at least in summer; and that the formation of æther must consequently be impossible upon mountains of a moderate degree of elevation, without employing extraordinary means of compression for its condensation. Upon the whole, it appears most probable that all bodies are capable of existing in a solid, a liquid, and an aeriform state; that the first is the most simple state of all bodies, and that the two others depend on combinations with different quantities of the matter of heat, of which the aeriform state requires by far the most.

Vapour, as it first rises from boiling water, is invisible, but as it mixes with the air it is deprived of part of its heat, returns to its fluid form, and the very minute drops of water which are produced, ascend in a copious cloud of a white or light-grey-colour. Vapour is the more readily discernable in proportion to the coldness and humidity of the atmosphere. The cloudy appearance of steam is occasioned by the difficulty with which its particles are separated and dissolved in the atmosphere; the difficulty is increased in proportion to the coldness and humidity of the air, and this is the reason that the moisture exhaled with the breath, is visible in winter and not in summer.

It was stated in a former volume, that the combination of the matter of heat or caloric, with the particles
of

of water, in that degree which constitutes steam, rarifies them so exceedingly, as to occasion them to occupy a space some hundred times greater than the original bulk of the fluid, and it is that also which volatilizes and enables them to ascend through the air, and to overcome its resistance.

But when steam is exposed to a still greater degree of heat, its volume is augmented still more considerably. That heat which makes water boil, and which rarifies it only one twenty-sixth, rarifies its vapour to eighteen hundred times the bulk of the water which produced it. This may be very readily demonstrated, by taking a glass tube, at one end of which is a bulb of two inches in diameter, and dropping into it a single drop of water, the diameter of which we will suppose to be one-tenth of an inch. The squares of these two spheres, with regard to each other, will be as 1800 are to one. Upon heating the bulb of the tube over the flame of a spirit lamp, the air will first be expelled, and afterwards the drop of water will be converted into steam, and take possession of the whole of the bulb; as may be proved by plunging the mouth of the tube into cold water, and suffering the steam within the bulb to return to its fluid state. In this case, the pressure of the atmosphere will cause the water to rush into the tube, and to occupy that space within the bulb, which before was occupied by the vapour, and thus the fact will be ascertained.

If, however, any obstacle is opposed to the expansive force of steam, the heat augments its resistance in a degree proportionate to the augmentation of its volume. The power of resistance afforded by the vapour of water is prodigious, and has of late years been made subservient to some mechanical purposes of the greatest importance. Muschenbroek has proved by experiment,

experiment, that the force of gunpowder is feeble, when compared to that of rising steam. An hundred and forty pounds of gunpowder blew up a weight of thirty thousand pounds; but on the other hand, an hundred and forty pounds of water, converted by heat into steam, lifted a weight of seventy-seven thousand pounds, and would lift a much greater, if there were means of giving the steam greater heat with safety; for the hotter the steam the greater is its force.

The steam engine, to which I had formerly occasion slightly to advert*, is a machine which may be, and is occasionally applied to various mechanical purposes where great force is required; but which has hitherto been principally used to clear mines from water, and to raise water to a proper height for the supply of cities. In these cases, the expansive power of steam is so managed as to operate on immense pumps, which could not conveniently be worked by any other means. In order to give the reader a superficial idea of this machine, let us imagine a common pump prepared, and that we want to move the handle of this pump upwards by the force of steam only. In the first place, let us suppose, that the handle of the pump, or something connected to it, was so contrived as to admit of being inserted in the barrel of a gun, or some cylindrical tube, set upright over a cauldron containing boiling water. Next let us suppose, that the steam could be admitted into the tube, through the touch-hole, and so confined as to pass only by that way. Now as the fire begins to dilate the steam, a part of it will enter the tube by the touch-hole, and this will press up the pump, which is supposed to be so fitted to the tube as to prevent any part

* See vol. i. p. 110.

of the steam from escaping. In this way the pump handle would be driven quite out at the mouth of the tube, but let us imagine, that before this can happen a valve is opened, which allows a small quantity of cold water to be spouted into the tube, which effectually and instantaneously destroys, or, more properly, condenses the steam. The tube being now left empty, there is nothing to counteract the pressure of the atmosphere, which again forces down the handle into the tube, into which no steam is permitted to enter, on account of a valve which now stops the touch-hole below; but when the handle is thus pressed down, the valve below is again opened, and new steam entering again presses the handle upwards; when the handle comes near the top, the steam is again cooled and condensed as before, and the handle is again pressed down by the weight of the atmosphere. In this manner it is alternately driven upwards and downwards by the expansive power of the steam and the pressure of the external air, and works the pump with unwearied assiduity.

Though the principle however, is plain, the machinery is complex in the steam engine; but the annexed plate IV. will probably render it tolerably intelligible.

In fig. 1. A represents the fire-place under the boiler, for the boiling of the water, and the ash-hole below it.

B, the boiler, filled with water about three feet above the bottom, made of iron plates.

C, the steam pipe, through which the steam passes from the boiler into the receiver.

D, the receiver, a close iron vessel, in which is the regulator or steam-cock, which opens and shuts the hole of communication at each stroke.

E, the

E, the communication pipe between the receiver and the cylinder; it rises five or six inches up, in the inside of the cylinder bottom, to prevent the injected water from descending into the receiver.

F, the cylinder, of cast iron, about ten feet long, bored smooth in the inside; it has a broad flanch in the middle on the outside, by which it is supported when hung in the cylinder-beams.

G, the piston, made to fit the cylinder exactly: it has a flanch rising four or five inches upon its upper surface, between which and the side of the cylinder a quantity of junk or oakum is stuffed, and kept down by weights, to prevent the entrance of air or water and the escaping of steam.

H, the chain and piston shank, by which it is connected to the working beam.

I I, the working beam or lever: it is made of two or more large logs of timber, bent together at each end, and kept at the distance of eight or nine inches from each other in the middle by the gudgeon, as represented in the plate. The arch-heads, I I, at the ends, are for giving a perpendicular direction to the chains of the piston and pump-rods.

K, the pump-rod which works in the sucking pump.

L, and draws the water from the bottom of the pit to the surface.

M, a cistern, into which the water drawn out of the pit is conducted by a trough, so as to keep it always full; and the superfluous water is carried off by another trough.

N, the jack-head pump, which is a sucking-pump wrought by a small lever or working-beam, by means of a chain connected to the great beam or lever near the arch g at the inner end, and the pump rod at the

outer end. This pump commonly stands near the corner of the front of the house, and raises the column of water up to the cistern O, into which it is conducted by a trough.

O, the jack-head cistern for supplying the injection, which is always kept full by the pump N; it is fixed so high as to give the jet a sufficient velocity into the cylinder when the cock is opened. This cistern has a pipe on the opposite side for conveying away the superfluous water.

P P, the injection-pipe, of three or four inches diameter, which turns up in a curve at the lower end, and enters the cylinder bottom; it has a thin plate of iron upon the end *a*, with three or four adjutage holes in it, to prevent the jet of cold water of the jack-head cistern from flying up against the piston, and yet to condense the steam each stroke, when the injection-cock is open.

e, a valve upon the upper end of the injection-pipe within the cistern, which is shut when the engine is not working, to prevent any waste of the water.

f, a small pipe which branches off from the injection-pipe, and has a small cock to supply the piston with a little water to keep it air-tight.

Q, the working plug, suspended by a chain to the arch *g*, of the working beam. It is usually a heavy piece of timber, with a slit vertically down its middle, and holes bored horizontally through it, to receive pins for the purpose of opening and shutting the injection and steam cocks, as it ascends and descends by the motion of the working beam.

b, the handle of the steam-cock or regulator. It is fixed to the regulator by a spindle which comes up through the top of the receiver. The regulator is a circular plate of brass or cast iron, which is moved horizontally

horizontally by the handle *b*, and opens or shuts the communication at the lower end of the pipe E within the receiver. It is represented in the plate by a circular dotted line.

i i, the spanner, which is a long rod or plate of iron for communicating motion to the handle of the regulator, to which it is fixed by means of a slit in the latter, and some pins put through to fasten it.

k l, the vibrating lever, called the Y, having the weight *k* at one end and two legs at the other end. It is fixed to an horizontal axis, moveable about its center-pins or pivots *m n*, by means of the two shanks *o p* fixed to the same axis, which are alternately thrown backwards and forwards by means of two pins in the working plug; one pin on the outside depressing the shank *o*; throws the loaded end *k* of the Y from the cylinder into the position represented in the plate, and causes the leg *l* to strike against the end of the spanner, which, forcing back the handle of the regulator or steam-cock, opens the communication, and permits the steam to fly into the cylinder. The piston immediately rising by the admission of the steam, the working beam I I rises; which also raises the working-plug, and another pin which goes through the slit raises the shank *p*, which throws the end *k* of the Y towards the cylinder, and, striking the end of the spanner, forces it forward, and shuts the regulator steam-cock.

q r, the lever for opening and shutting the injection cock, called the F. It has two toes for its center, which take between them the key of the injection-cock. When the working-plug has ascended nearly to its greatest height, and shut the regulator, a pin catches the end *q* of the F and raises it up, which opens the injection-cock, admits a jet of cold water to

fly into the cylinder, and, condensing the steam, makes a vacuum; then the pressure of the atmosphere bringing down the piston in the cylinder, and also the plug-frame, another pin fixed in it catches the end of the lever in its descent, and, by pressing it down, shuts the injection-cock, at the same time the regulator is opened to admit steam, and so on alternately; when the regulator is shut the injection is open, and when the former is open the latter is shut.

R, the hot-well, a small cistern made of planks, which receives all the waste water from the cylinder.

S, the sink-pit to convey away the water which is injected into the cylinder at each stroke. Its upper end is even with the inside of the cylinder bottom, its lower end has a lid or cover moveable on a hinge, which serves as a valve to let out the injected water, and shuts close each stroke of the engine, to prevent the water being forced up again when the vacuum is made.

T, the feeding-pipe, to supply the boiler with water from the hot-well. It has a cock to let in a large or small quantity of water, as occasion requires, to make up for what is evaporated; it goes nearly down to the boiler bottom.

U, two gage cocks, the one larger than the other, to try when a proper quantity of water is in the boiler: upon opening the cocks, if one gives steam and the other water, it is right; if they both give steam, there is too little water in the boiler; and if they both give water, there is too much.

W, a plate which is screwed on to a hole on the side of the boiler, to allow a passage into the boiler for the convenience of cleaning or repairing it.

X, the steam-clack or puppet valve, which is a
brass

brass valve on the top of a pipe opening into the boiler, to let off the steam when it is too strong. It is loaded with lead, at the rate of one pound to an inch square; and when the steam is nearly strong enough to keep it open, it will do for the working of the engine.

f, the snifting valve, by which the air is discharged from the cylinder each stroke, which was admitted with the injection, and would otherwise obstruct the due operation of the engine.

t t, the cylinder-beams; which are strong joists going through the house for supporting the cylinder.

v, the cylinder cap of lead, foldered on the top of the cylinder, to prevent the water upon the piston from flashing over when it rises too high.

w, the waste-pipe, which conducts the superfluous water from the top of the cylinder to the hot-well.

x x, iron bars, called the catch-pins, fixed horizontally through each arch head, to prevent the beam descending too low in case the chain should break.

y y, two strong wooden springs, to weaken the blow given by the catch-pins when the stroke is too long.

z z, two friction-wheels, on which the gudgeon or center of the great beam is hung; they are the third or fourth part of a circle, and move a little each way as the beam vibrates. Their use is to diminish the friction of the axis, which in so heavy a lever, would otherwise be very great.

When this engine is to be set to work, the boiler must be filled about three or four feet deep with water, and a large fire made under it; and when the steam is found to be of a sufficient strength by the puppet-clack, then by thrusting back the spanner, which opens the regulator or steam-cock, the steam is admitted into the cylinder, which raises the piston to the top of the cylinder, and forces out all the air at

the snifting valve; then by turning the key of the injection-cock, a jet of cold water is admitted into the cylinder, which condenses the steam and makes a vacuum; and the atmosphere then pressing upon the piston, forces it down to the lower part of the cylinder, and makes a stroke by raising the column of water at the other end of the beam. After two or three strokes are made in this manner, by a man opening and shutting the cocks to try if they are right, then the pins may be put into the pin-holes in the working plug, and the engine left to turn the cocks of itself, which it will do with greater exactness than any man.

Many important improvements have been lately made in the steam engine by the ingenious Mr. Watt, of Birmingham. He has contrived to preserve an uniform heat in the cylinder of his engines, by suffering no cold water to touch it, and by protecting it from the air, or other cold bodies, by a surrounding case filled with steam, or with hot air or water, and by coating it over with substances that transmit heat slowly. He makes his vacuum to approach nearly to that of the barometer, by condensing the steam in a separate vessel, called the condenser, which may be cooled at pleasure without cooling the cylinder, either by an injection of cold water, or by surrounding the condenser with it, and generally by both. He extracts the injection water and detached air from the cylinder or condenser by pumps, which are wrought by the engine itself, or blows them out by the steam. As the entrance of air into the cylinder would stop the operation of the engines, and as it is hardly to be expected that such enormous pistons as those of steam engines can move up and down, and yet be absolutely tight in the common engines, a stream of
water

water is kept always running upon the piston, which prevents the entry of the air; but this mode of securing the piston, though not injurious in the common ones, would be highly prejudicial to the new engines. Their piston is therefore made more accurately; and the outer cylinder, having a lid, covers it, the steam is introduced above the piston; and when a vacuum is produced under it, acts upon it by its elasticity, as the atmosphere does upon common engines by its gravity. This way of working effectually excludes the air from the inner cylinder, and gives the advantage of adding to the power, by increasing the elasticity of the steam.

In Mr. Watt's engines, the cylinder, the great beams, the pumps, &c. stand in their usual positions. The cylinder is smaller than usual, in proportion to the load, and is very accurately bored.

In the most complete engines it is surrounded, at a small distance, with another cylinder, furnished with a bottom and a lid. The interstice between the cylinders communicates with the boilers by a large pipe, open at both ends, so that it is always filled with steam, and thereby maintains the inner cylinder always of the same heat with the steam, and prevents any condensation within it, which would be more detrimental than an equal condensation in the outer one. The inner cylinder has a bottom and piston as usual; and as it does not reach up quite to the lid of the outer cylinder, the steam in the interstice has always free access to the upper side of the piston. The lid of the outer cylinder has a hole in its middle; and the piston rod, which is truly cylindrical, moves up and down through that hole, which is kept steam-tight by a collar of oakum screwed down upon it. At the bottom of the inner cylinder, there are two regulating valves,

valves, one of which admits the steam to pass from the interstice into the inner cylinder below the piston, or shuts it out at pleasure; the other opens or shuts the end of a pipe, which leads to the condenser. The condenser consists of one or more pumps furnished with clacks and buckets (nearly the same as in common pumps) which are wrought by chains fastened to the great working beam of the engine. The pipe, which comes from the cylinder, is joined to the bottom of these pumps, and the whole condenser stands immersed in a cistern of cold water supplied by the engine. The place of this cistern is either within the house or under the floor, between the cylinder and the lever wall; or without the house between that wall and the engine shaft, as conveniency may require. The condenser being exhausted of air by blowing, and both the cylinders being filled with steam, the regulating valve which admits the steam into the inner cylinder is shut, and the other regulator which communicates with the condenser is opened, and the steam rushes into the vacuum of the condenser with violence; but there it comes into contact with the cold sides of the pumps and pipes, and meets a jet of cold water, which was opened at the same time with the exhaustion regulator; these instantly deprive it of its heat, and reduce it to water; and the vacuum remaining perfect, more steam continues to rush in, and be condensed until the inner cylinder is exhausted. Then the steam which is above the piston, ceasing to be counteracted by that which was below it, acts upon the piston with its whole elasticity, and forces it to descend to the bottom of the cylinder, and so raises the buckets of the pumps which are hung to the other end of the beam. The exhaustion regulator is now shut, and the steam one opened again, which, by letting in the steam, allows

the

the piston to be pulled up by the superior weight of the pump rods; and so the engine is ready for another stroke.

But the nature of Mr. Watt's improvement will be perhaps better understood from the following description of it, as referred to a figure.—The cylinder or steam vessel A, of this engine (fig. 2.) is shut at bottom and opened at top as usual, and is included in an outer cylinder or case BB, of wood or metal, covered with materials which transmit heat slowly. This case is at a small distance from the cylinder, and close at both ends. The cover C has a hole in it, through which the piston rod E slides; and near the bottom is another hole F, by which the steam from the boiler has always free entrance into this case or outer cylinder, and by the interstice GG between the two cylinders has access to the upper side of the piston HH. To the bottom of the inner cylinder A is joined a pipe I, with a cock or valve K, which is opened and shut when necessary, and forms a passage to another vessel L called a *condenser*, made of thin metal. This vessel is immersed in a cistern M full of cold water, and it is contrived so as to expose a very great surface externally to the water, and internally to the steam. It is also made air-tight, and has pumps N wrought by the engine, which keep it always exhausted of air and water.

Both the cylinders A and BB being filled with steam, the passage K is opened from the inner one to the condenser L, into which the steam violently rushes by its elasticity, because that vessel is exhausted; but as soon as it enters it, coming into contact with the cold matter of the condenser, it is reduced to water, and the vacuum still remaining, the steam continues to rush in till the inner cylinder A below the piston

is left empty. The steam which is above the piston, ceasing to be counteracted by that which is below it, acts upon the piston HH, and forces it to descend to the bottom of the cylinder, and so raises the bucket of the pump by means of the lever. The passage K between the inner cylinder and the condenser is then shut, and another passage O is opened, which permits the steam to pass from the outer cylinder, or from the boiler into the inner cylinder under the piston; and then the superior weight of the bucket and pump rods pulls down the outer end of the lever or great beam, and raises the piston, which is suspended to the inner end of the same beam.

When water is exposed to a cold atmosphere, it first loses its free caloric, and is reduced in temperature, but no part of it begins to freeze till the mass is reduced somewhat below the thirty-second degree of Fahrenheit's thermometer; a small quantity of the water then becomes solid, which, by changing its state, sets at liberty a quantity of its combined heat, which restores the water in contact with it to the temperature of 32 degrees, or rather above it. The congelation is therefore at a stand till this sensible heat is abstracted by the atmosphere, and the mass again reduced somewhat below the thirty-second degree. Another portion of water then congeals, and the process is again stopped by the emission of heat. In this manner congelation pervades the whole mass, and is performed at intervals, which are very observable when the phenomenon of freezing is accurately attended to.

The same law operates in the passage of other bodies from the state of fluids to that of solids, and the contrary. Dr. Irvine has shewn, that when spermaceti and wax are melted, they contain the matter of heat in a combined

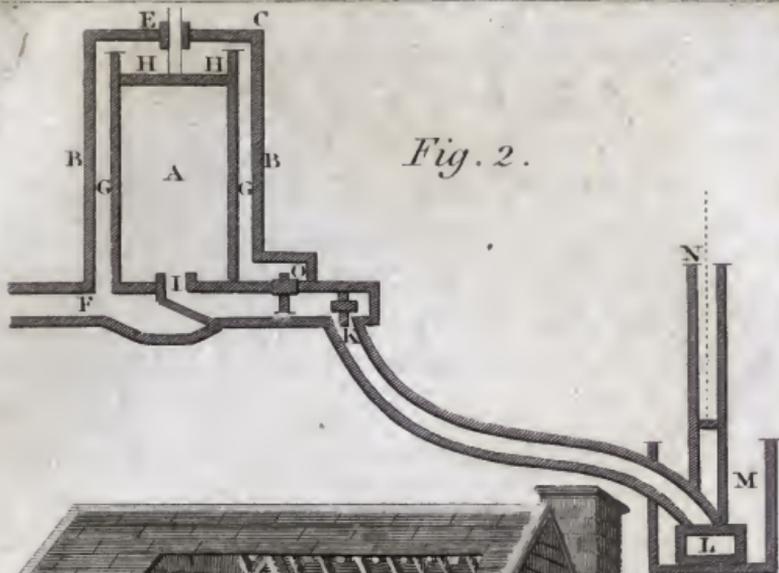


Fig. 2.

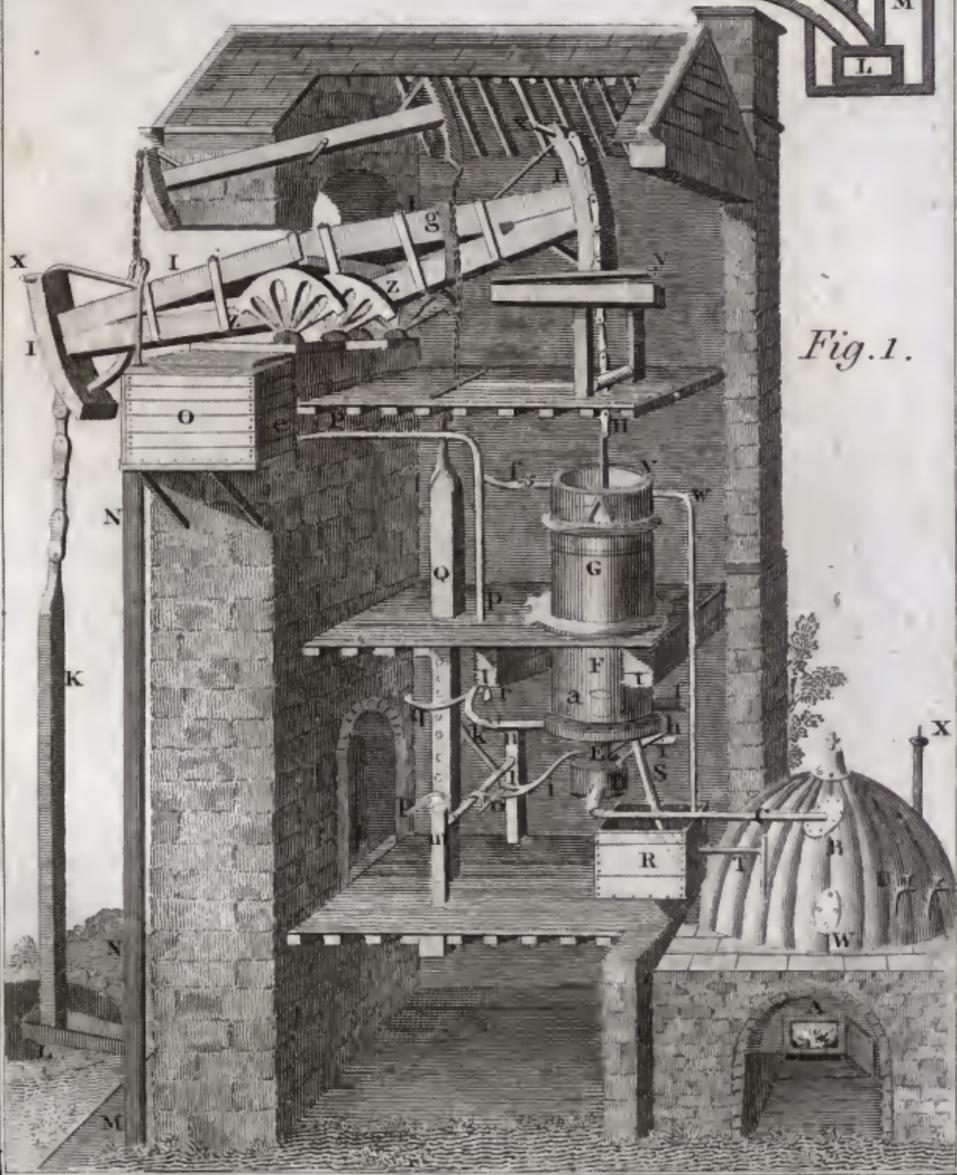


Fig. 1.



or latent state. By heating them much above their point of fluidity, he found that they lost their heat very soon, till some parts became solid; after this they continued of exactly the same temperature till the whole became solid, though exposed all the while to cold air; but when all became solid they cooled as they did at first. In the same manner water mixed with ice, whatever may be the temperature of the surrounding medium, and whether the quantity of ice is increasing or diminishing, always nearly preserves the temperature of 32 degrees.

The freezing of water was formerly attributed to the entrance of frigorific particles into that fluid; but the above doctrine, founded on the great discoveries of Dr. Black, is almost universally deemed so satisfactory as to have left the other, which is a mere hypothesis, scarcely a single advocate. The augmentation of the bulk of water in freezing seems to be the only fact which can with reason be alleged in support of the doctrine of frigorific particles; but this increase of bulk is not attended with any increase of weight, and may be much better explained, than by attributing it to the addition of frigorific particles, which were never proved to have any existence.

The increase which water acquires in becoming solid is about one-ninth or one-tenth of its whole bulk. Boyle took a brass tube, three inches in diameter, and put some water into it; he then brought down into the tube a plug with a weight placed at the head of it of seventy-four pounds. On exposing the tube to the cold, the water freezing and expanding itself, raised the seventy-four pounds. The expansive power of water, in the process of freezing, was proved by a remarkable experiment made in Canada. An iron shell, after having its mouth well plugged up, was filled

filled up with water and exposed to a severe frost which prevailed in that country. The expansion of the ice forced out the plug, and the water, which immediately followed, was frozen into an irregular mass or column of ice. The instances, however, already mentioned, are far less striking than one described by Muschenbroëck, in which a ball of iron, an inch thick, was burst asunder in the course of twelve hours by the expansive power of frost. That philosopher having calculated the force exerted by the freezing of water in a similar case, found it equal to a force capable of raising a weight of twenty-seven thousand seven hundred and twenty pounds. That the expansive power of freezing water, however, has certain limits, appears from the following experiment, made by the Florentine academicians. A brass globe filled with water, and closed at its orifice by a well-fitted screw, was immersed in freezing water, but did not burst; they then pared off such a quantity of the metal as left the sides of the globe unable to resist the expansion of the water; the force which was required to burst the globe in this state was computed at twenty-seven thousand pounds. When such is the expansive power exerted by water in passing to the state of ice, we cannot be surprized that vessels, which are left filled with water in frosty weather, should be burst by its freezing, and that the same thing should happen to water-pipes exposed to the action of frost. The pavement is sometimes loosened from the same cause, and in countries where very severe colds prevail, the sap of trees congeals, and their trunks are burst asunder with a noise like that of cannon. Frost fertilizes the ground, by loosening the cohesion of the particles of earth.

As ice is never perfectly clear or transparent, and as we find small cavities in it, some have thought that the

air insinuates itself; but this has been refuted by water being frozen under an exhausted receiver, and the same cavities being found in the ice. The ice, in fact, instead of being heavier, was found to be lighter. The expansion of ice, indeed, is evidently owing to the crystallization of the water, and the particles assuming a different arrangement, and not being in close contact. If this is admitted, as I apprehend it must, we cannot say, with propriety, that the solid particles of water expand. The spiculæ, of which ice consists, cut each other at angles of sixty or one hundred and twenty degrees.

When it snows at Moscow, and the air is not too dry, it is observed to be loaded with beautiful crystallizations, regularly flattened, and as thin as a leaf of paper. They consist of an union of fibres, which shoot from the center to form six principal rays, which are themselves divided into extremely small blades.

It appears, however, that the air previously contained in water is set at liberty on the congelation of that fluid, and may thus partly contribute to the swelling of ice, and occasion some of the cavities observable in it.

When water freezes slowly, its surface preserves its transparency to some depth, owing to the air which is separated passing downwards as the freezing proceeds. The air bubbles, however, soon begin to collect, and produce considerable inequalities, which increase as they approach the center. When, on the contrary, water is frozen with great rapidity, the bubbles of air disperse themselves pretty equally through the mass, which, in consequence, becomes opaque through its whole substance.

Reaumur observes that cast iron melted, in passing from
from

from a fluid to its solid state, expands. This effect is more sensible in this than in any other of the metals, on account of its platy texture. He found that cast iron, thrown among some of the same metal melted, swims upon the top. In the case of immediate expansion upon congealing, the iron seems to agree with water: they differ in this; the iron never expands by cold afterwards, whereas the ice, being exposed to greater degrees of cold, becomes more bulky; the solid parts not being so closely connected from a particular arrangement, which renders the whole mass lighter than before. Quicksilver contracts in becoming solid; and both cast iron and ice contain several interstices, which, if allowed for, make it appear that these bodies in reality occupy less space when solid, than in a fluid state.

C H A P. II.

H Y D R O S T A T I C S.

Discoveries of Archimedes in this Branch of Science.—Of the Moderns, —How Fluids are acted upon by the general Laws of Gravitation.—Particles of Fluids act independently of each other.—Experiment ascertaining this Principle.—Fluids press equally in all Directions.—Cautions necessary in constructing Aqueducts, &c. to guard against the lateral Pressure of Fluids.—All Parts of the same Fluid in Equilibrium with each other.—Surfaces of Fluids always in a Plane parallel with the Horizon.—Pressure of Fluids in proportion to their Height.—Hydrostatic Paradox.—Effects of Gravity on Fluids of different Densities.—Action of Air on the Surfaces of Fluids.—Use of a Vent Peg.—The Valenois.—The Siphon.—Action of Fluids on solid Bodies immersed in them.—Why certain Bodies sink and others swim in certain Fluids.—Bodies that swim displace a Bulk of Water equal to themselves in Weight but not in Magnitude.—The same Body will sink in one Fluid, which will swim in another.—The Hydrometer.—Fabrenheit's Hydrometer.—Recapitulation of the Doctrines respecting specific Gravity.—How to make a Globe of Iron swim on the Surface of Water.—Boats made of Copper.

WATER, as a fluid, has certain properties, which, though common to all unelastic or incompressible fluids, are usually considered under this topic; and indeed the sciences of hydrostatics and hydraulics, which regard these properties, immediately derive their names from that fluid*, on which the experiments, illustrative of them, are usually made.

Hydrostatics have for their object the weight and pressure of fluids; and in this branch of science the

* ὕδωρ (Hydor) water, and στατική (statiké) the science of weight. Hydraulics from ὑδωρ and αὐλός (aulos) a tube or pipe.

art of determining the specific gravities of bodies is usually included, but this I have already been under a necessity of anticipating * in some degree. *Archimedes*, among the ancients, accomplished the most remarkable discoveries in this science. He is honoured even at this day, as the inventor of the ingenious hydrostatic process, by which the purity or baseness of a crown of gold was ascertained. Among the moderns we are indebted to Gallileo, Torricelli, Descartes, Pascal, Guglielmini, and Mariotte, for the best information on this subject; and by their experiments (which are as curious as they are decisive) we are instructed in what we may expect or fear from the power of fluids violently acted upon by the principle of gravity, and in what manner and upon what principles we may employ, for the use of man, the hydraulic machines.

It has been observed in another place, that the propensity which bodies have of approaching towards the earth, or perhaps towards its center, is the only cause of what we term weight or gravity, and that it is by the continual efforts which they make to obey that law, that they press upon every obstacle which impedes their progress. As fluids, like solid bodies, are impelled by their gravity, so in this case they press upon every object which opposes their fall; but from their nature they press in a different manner from solid bodies; hence arise the peculiar phenomena into which we are now to inquire.

Fluids are matters, the component parts of which

* See Book I. Chap. III. It was necessary to explain the nature of specific gravity in that part of the work, both because it relates rather to bodies in general than to fluid substances; and because the frequent allusions to it in the progress of the work would not have been otherwise understood.

are moveable among themselves, having scarcely any cohesion one with another, and moving independently of each other. Some philosophers* have included in this definition what they term the grosser fluids, as, for example, a heap of corn, a heap of shot, of sand, &c. as well as the rarer and more elastic fluids, as common air, and all other aeriform substances. The proper objects, however, of the hydrostatic science, are those fluids which, in common language, are termed liquids, or those which always present to us a plane surface, level or parallel to the horizon.

All liquids are not equally fluid; hence it follows, that the laws of hydrostatics apply with less exactness in proportion as those substances depart from perfect fluidity. Water and oil both flow when the vessels, which contain them, are either overturned or broken; but the effusion of oil is slower than that of water, because the particles of oil have more cohesion among themselves. The most singular effects in hydrostatics principally depend upon the extreme minuteness of the particles of fluids, and upon their great mobility.

To preserve a lucid order in the consideration of this subject, it will be necessary to divide the objects of our inquiry into three branches. In the first place, therefore, I shall consider in what manner the principle of gravity acts on the particles of fluids, and the phenomena which it produces in the fluids themselves; as well as their action against the sides, the bottoms, and tops of the vessels in which they are contained. Secondly, I shall consider in what manner fluids of different densities act upon each other; and thirdly, the action of fluids on bodies immersed in them.

* See Briffon, Vol. I. p. 233.

I. In pursuing the first object of this inquiry, it may be established as an axiom :

1st, That the parts of the same fluid act with respect to their weight or pressure, independently of each other.

This property arises from their having scarcely any cohesion among themselves. It is otherwise with solid bodies; their several parts adhering together, they press in one common mass; hence the falling of solid bodies is productive of a different effect from that of liquids. We dread the falling of a pound of ice upon our heads, while we are much more indifferent concerning that of a pound of water. The latter, in its descent, is divided by the resistance of the air, by which some of its parts are retarded more than others; and the swiftness of the whole mass is still more retarded by this division than it otherwise would be; for by being thus divided it acquires a larger surface, which abates its effect. On the contrary, a solid body falls upon a small space, which receives its whole force. Hence it follows, that angular bodies falling upon any part of the human frame are more dangerous than flat or plane ones of the same weight, and descending from the same height.

It follows from this principle, that if an aperture is made at the bottom of a vessel full of any fluid, in order to prevent the flowing out of the liquor, it is only necessary to counteract the weight of that column of fluid which has the aperture for its base, and that to counteract that weight it is the same whether the vessel is full of liquor or whether it contains only a column, the base of which shall be equal to the aperture at the bottom.

Let the cylindrical vessel of glass A B (plate V. fig. 1.) have a hole in the bottom at C, furnished
with

with a cylindrical ferule of copper of an inch diameter D, which is to be stopped with a piston G, or the sucker of a pump well fitted to the ferule, and oiled, that it may yield to a moderate pressure. Let the piston be supported by a small rod G H, fastened at H to the silk which unites with the portion of the pulley M, with which the extremity of the lever M N is furnished, and which has for its center of motion the point L. The other portion of the pulley N, which terminates the other extremity of the lever, is also furnished with lines of silk, which support the small basin or scale I. Upon the copper ferule D then fit a cylindrical tube of glass F E, the interior diameter of which is equal to that of the ferule, and its height equal to that of the vessel A B. When the apparatus is disposed in this manner, fill the tube E F with water, and continue to put small weights into the basin or scale I, until the piston begins to rise. Afterwards take away the glass tube E F, and place the piston G in the copper ferule D, and pour water into the large vessel A B, and it will appear that the same weights as before in the basin I, will raise up the piston when the larger vessel A B is entirely full. Hence it follows that there is the same power to be counteracted, whether there rests upon the piston only a column of water of its own size, or whether the vessel A B is entirely full. Such a column, therefore, presses upon its base independently of the rest of the water contained in the vessel.

To account for this, let us suppose all the water in a vessel to be divided into several columns, 1, 2, 3, 4, 5, (plate V. fig. 2.) each composed of an equal number of parts. If the bottom of the vessel, which serves for the base and support of all the columns, is opened in a, the column 3, being no longer supported,

will descend through the aperture, sliding between the two columns 2 and 4, which are supported by the parts of the bottom of the vessel *b* and *c*, all the moveable parts of which become (if I may use the expression) small rollers, which retard the fall only in a very slight degree. This effect is the result of the small degree of cohesion between the parts of the fluid. If the columns 1 and 2 on the one part, and 4 and 5 on the other, were composed of parts adhering together, they would retard each other in their descent during their whole length, in the same manner as a wax candle would do; and by the fall of the column 3, a void would be made between them. But as all the particles are extremely minute, moving easily upon each other, they descend when the summit of the column 3 begins to descend, having no longer any support from that side; and the superficies of the whole mass descends in the same manner, though only one of the columns caused the flow from its fall. When the parts have a degree of viscosity, as those of oily fluids, or when the mass of the flowing liquor has much more of breadth than of height, the void which the descending column leaves above it is easily perceived, for then the surface, instead of being plane and even, is hollow in the middle, and assumes a funnel-like form, because the adjacent parts do not arrive with sufficient swiftness to replace those which descend through the aperture; besides the pressure of the air above the aperture is stronger than its resistance below.

From what has been now stated, it is easy to perceive how fluids differ from solids in the phenomena of gravitation. If the vessel *A B* (plate V. fig. 1.) being full of water, and the tube *E F* being removed, it was required to raise up the piston *G*; all that is necessary

necessary in this case is, to support the weight of the column of water directly above the piston, because this column can move independently of the remainder; but if the whole mass of water was converted into ice, then the mass ceasing to be a liquid, and all its parts adhering together, to raise up the piston it would be necessary to support the weight of the whole mass.

2dly, Fluids prefs equally in all directions.

In other words, they not only prefs from the top to the bottom like other bodies, but they also prefs, according to their weight, upon all bodies that oppose them in a lateral direction, and even from the bottom to the top. Hence, if a cask is filled with liquid oil, the oil will run out if an aperture is made in the side, but when it is congealed it will not run out on account of its having become a solid body, for solid bodies prefs only from their vertex to their base, and not laterally.

To understand properly this lateral pressure of fluids, and also that which they exert from their base towards their vertex, it is necessary to consider them as a mass of small globules deposited in a vessel; and to remember that these minute globules are not arranged regularly as upon a cord, but that very frequently one column exercises its pressure between two others, and has a propensity to displace them, as may be seen in plate V. (fig. 3.) where the perpendicular pressure which is made opposite to the point *d*, is directed by the lateral columns towards the sides, *ef*, of the vessel, in such a manner, that if the vessel was open in those places the liquid would flow out, on account of the great mobility of its parts. It is by the same mode of reasoning that the pressure of fluids, from their base towards their vertex, is accounted for: for example, when the column *df* (fig. 3.) has

a tendency to displace the two particles $g b$, the particle g cannot move any farther because it is impeded by the side and bottom of the vessel; but the particle b may be raised from the base towards the top, unless a column equal to the column $i k$, or something equivalent, presses upon it to prevent it.

It is upon this principle that the water, elevated by the New River water-works, after having descended from a basin in a vertical pipe, and then after having flowed horizontally in a succession of pipes under the pavement, is raised up again, through another pipe, as high as the fountain at the Temple Garden. It is also upon this principle that a vessel may be filled either at the mouth or at the bottom indifferently, provided that it is done through a pipe, the top of which is as high as the top of the vessel to be filled. Hence it follows, that when piers, aqueducts, reservoirs, or other hydraulic works for the retention of water are to be constructed, it becomes necessary to proportion their strength to the lateral pressure which they are likely to sustain, which becomes greater as the height of the water is more considerable. Nearly the same precautions are necessary to be taken with respect to what some philosophers call the grosser fluids, which also have a propensity to expand, as well on account of the smallness of their parts as from the small degree of cohesion which exists between them. Walls designed to support terrasses ought to be sufficiently strong to resist the lateral pressure of the earth and rubbish which they are to sustain, since this pressure will be greater as the particles of earth, and of the other materials of which the terrasses are composed, are less bound together, and in proportion as the terrasses are more elevated.

3dly, All the parts of the same fluid are in equilibrium

brium with each other, whether they are contained in one vessel or many, provided they communicate with each other; and their surfaces also are always in a plane parallel to the horizon.

This is a consequence of the principle which has been before established: for, since the particle *b* (fig. 3.) would be raised from the base towards the top, unless a column equal to the column *ik*, pressed upon it to retain it in its place; it follows that to be in equilibrium, the upper extremities of the two columns should be in the same horizontal plane, or in points equally distant from the center of the earth; which points, however, cannot be found by a right line; for in the distance of a thousand fathoms there is about one foot difference in the perpendicular height. From this property of fluids it follows, that water conducted by pipes placed in the earth, will remount as high as the place whence it flowed, whatever the depth under ground through which it may have been conducted by the pipes. It is customary to allow half an inch of inclination in the length of six feet, to counteract the resistance produced by friction; but it is clear from what has been said, that this is not absolutely necessary, for however long the passage might be, the water would still ascend as high as the place whence it came, but it would require a little longer time to accomplish the ascent. We are enabled, upon this principle, to account for the springs which are sometimes found on the tops of mountains. Such waters flow from mountains still more elevated (whether they are far or near) by subterraneous canals. It follows from this principle, that if there are many reservoirs which communicate together, it is necessary only to see one of them to know the height of the water in the others; for

for it must necessarily be of the same height there as in all the rest.

From what has been observed, viz. that when all the parts of the same fluid are in equilibrium, their surfaces will also be in a plane parallel to the horizon, or, in other words, every part of the surface at an equal distance from the center of the earth, it follows, that when the surface of water is very large, it becomes necessarily and sensibly convex. This is easily perceived at sea, where the masts of ships are observed at a distance before any other part of the ship can be distinguished.

4thly, Fluids press as well perpendicularly as laterally, not, however, in proportion to their quantity, but in proportion to their height above the plane of the horizon,

For example, if several vessels of the same height and base are filled with water, all their bottoms will bear the same degree of pressure, whatever may be the form and size of the vessels in other respects. Suppose three vessels to be filled with water, A B C D (fig. 4.) E F G H (fig. 5.) L M N O P Q (fig. 6.) whose heights A B, I F, L T are equal, and also supported by equal bases B C, F G, N O; it will be found, by experiment, that all the bottoms of these vessels will be equally pressed, though the quantities of water which they contain may be very different. In the vessel (fig. 4.) the bottom B C is pressed by the whole mass of water A B C D, because the fluid, in this case, presses in the same manner as a solid body; let us suppose the weight of the water to be six pounds: in the vessel (fig. 5.) it is easy to conceive, from what has been said before, that the bottom F G is also only pressed by six pounds, though
the

the vessel is evidently much larger than the first; because the bottom $F G$ supports only the column $I F G K$, equal to that of the vessel (fig. 4.) and this column exercises its pressure independently of the residue of the water in the vessel, which is supported by the sides $E F, H G$, of the vessel (fig. 5.) But the principal difficulty consists in comprehending how the bottom of the vessel $N O$ is still pressed by a weight of six pounds, although one pound of water would be sufficient to fill the vessel. It is accounted for in this manner: it is certain that upon the portion $T V$ of the bottom $N O$, there is a pressure equal to that of a column of water of which $T V$ is the base, and $L T$ the height. If, upon every other similar portion of the same bottom, there is a pressure equal to that of the column $L T V Q$, the bottom is equally pressed upon all its parts. For instance, there is a pressure upon the portion $V X$ equal to that of a column of water $Q V X R$, which is itself equal to the column $L T V Q$; for the small column of water $P V X S$, which rests above, has a propensity to be elevated by the pressure of the adjacent column $L T V Q$, and with a force equal to the excess $L M P Q$ of this great column over the small one; therefore the upper part, $P S$, is pressed by the same power; but the re-action is equal to the pressure. The part $P S$ re-acts with a force equal to the excess $L M P Q$ of the great column over the small one. There is, therefore, a pressure upon the portion $V X$ of the bottom $N O$, from the small column of water $P V X S$, and from the re-action of the part $P S$, equal to the pressure of a column of water, $Q P S R$, both of which added together are equal to the pressure of the column $L T V Q$. What has been said of the portion $V X$ may be said of all the rest. Hence

it follows that the bottom of the vessel (fig. 6.) is every where equally pressed.

There is a maxim deduced from what has been stated, which is termed by philosophers the hydrostatic paradox; it is nevertheless founded upon the surest basis of truth, and has a considerable influence in almost all hydraulic engines, viz. "that a given quantity of water may exert a force two or three hundred times less or greater, according to the manner in which it is employed." If, for instance, the same quantity of water as the vessel (fig. 5.) will contain, is poured into a vessel resembling that of (fig. 6.) but high enough to contain it, the pressure upon the bottom NO will be considerably greater than that upon the bottom FG.

One of the most useful machines to shew that a small quantity of water is capable of great pressure, is the hydrostatic bellows. This machine (Plate VI. fig. 1.) consists of two thick oval boards, each about three feet broad, and four feet long, united to each other by leather, like a pair of common bellows, or a barber's puff. Into the lower board a pipe B, several feet high is fixed at *e*. Now, in shewing experiments with this simple machine, which even the reader himself might easily make, let water be poured into the pipe at its top C, which will run into the bellows, and separate the boards a little: then to shew how much a little water will be able to effect by pressure, let three weights, each of an hundred pounds, be laid upon the upper board. Now if we pour more water into the pipe, it will as before run into the bellows, and raise up the board with all the weights upon it. And though the water in the tube should weigh in all but a single pound, yet the pressure of this small
force

Fig. 1.

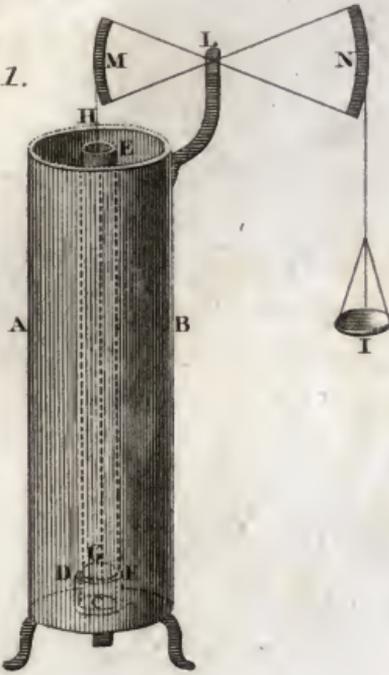


Fig. 2.

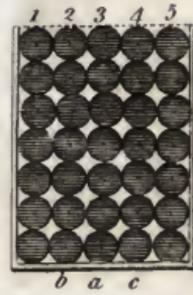


Fig. 3.

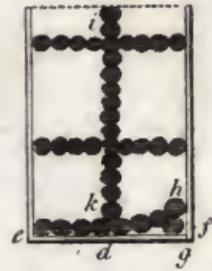


Fig. 4.

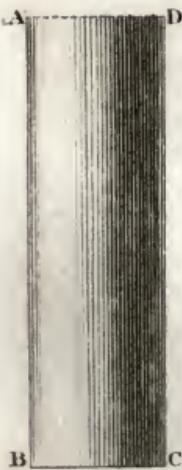


Fig. 5.

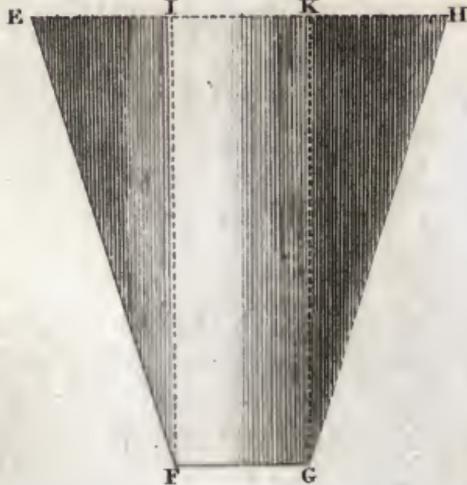
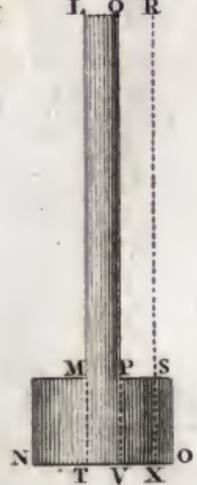


Fig. 6.





force upon the water below in the bellows, shall support the weights, which are three hundred pounds; nor will they have weight enough to make them descend, and conquer the weight of the water, by forcing it out of the mouth of the pipe.

It is clear from these principles, that the tun T O (fig. 2.) filled with water, may be burst by pressing it with some pounds additional weight of the fluid, through the tube A B, which may be supposed to be from twenty-five to thirty feet in height. From what has been said of the vessel (fig. 6.) it indeed necessarily follows, that the small quantity of water which the tube A B contains, presses upon the bottom of the tun as much as if a column of water had been added as wide as the tun itself, and as long as the tube, which would evidently be an enormous weight.

II. The effects of gravity on fluids of different densities will, from what has preceded, not be very difficult to comprehend.

It has been observed, that fluids are masses of small particles moveable with great facility among themselves independently of each other, pressing separately and in proportion to their masses.

It is proved also by chemical analysis, that even these minute particles are composed of particles still smaller. Now whether it results from the interposition of caloric (or the matter of fire) in greater or less quantities, which we know is the cause of all fluidity, and also of the difference that exists between the incompressible and elastic fluids; or whether it may depend upon the shape or size of the particles, which, as in solid bodies, may increase or diminish the porosity, it is certain, that there is a considerable difference with respect to density in different fluids.

From this difference in point of density, a separation
may

may be observed generally to take place, soon after mixing two heterogeneous fluids together, unless this effect is counteracted by some more powerful cause. It has been observed, that the particles, according to their weight, press independently of each other. Those therefore which have the most density, having more power to gain possession of the lower part of the vessel which contains them, oblige the others to yield and resign their situation; and hence a separation is effected. When oil and water, for instance, have been well shaken together, and afterwards the whole left in a state of rest, the water, having more density than the oil, takes the lower position and the oil rises to the surface. If this effect does not take place, it is owing to the intervention of one of the following causes. First, a kind of elective attraction, which may exist between the particles of different fluids, as when water and wine are mixed together, the water, though heavier than the wine, does not separate itself. Secondly, the viscosity of one of the substances, as when the whites of eggs are beaten together, and by that means a considerable quantity of air mixes with them; the air, though much lighter, has not power to disengage itself from the matter in which it is enveloped, in order to effect its escape.

If two fluids of different densities are placed in a state of equipoise with each other, and have the same base, their perpendicular heights above the horizon will be in a reciprocal ratio to their densities or specific gravities.

If, for example, mercury is put into an inverted siphon, and water is poured into one of the branches, in order to elevate the mercury in the other branch one inch above its level, it is necessary that the water should be about thirteen inches and an half high. The height

height of the water then will be thirteen times and a half of that of the mercury; because the specific gravity of mercury is about thirteen times and a half as great as that of water.

This observation will also apply to the reciprocal action of air and water, or air and mercury upon each other, as was evinced in a former book, when treating of the Torricellian experiment and the barometer*. Many of the phenomena, indeed, of hydrostatics and hydraulics are to be referred to the pressure of the atmosphere, and for this reason, the present subject has been in part anticipated, when it was necessary to treat of air as a fluid.

It is, however, proper on the present occasion, to recal to the reader's attention some of the properties of this fluid, and he will easily remember, that as a fluid, air is possessed of gravity, and consequently presses upon all bodies which oppose it; and it is necessary to add, that like water, it presses in all directions. Its perpendicular pressure has been already sufficiently proved; and its lateral pressure may also be easily demonstrated. If a small hole is made with a gimblet, either in the side or bottom of a cask or vessel which is quite full of liquor, it will not run out, because the external air which presses against the hole, sustains the liquor, which has not a sufficient height to overcome its pressure. Hence the necessity of a vent peg, to enable liquor to be drawn out of a full cask. The elasticity of the small quantity of air which is introduced at the vent presses the fluid, and overcomes the pressure of the air at the cock. There is an instrument in common use, called a Valencia, for extracting small quantities of liquor out of the

* See Book v. Chap. 9.

bung-holes of casks. It is a tube with a small aperture at the bottom and the top. When full, if the hole at the top is stopped with the thumb or finger, so as to prevent the pressure of the air at the top, the liquor will not run out of the hole at the bottom, being kept in by the force of the external air.

It is proper to observe, that all the effects which depend upon the pressure of air, take place in a room where the column of air is terminated by the ceiling, as well as without doors where the column of air has the whole height of the atmosphere; and the reason is, because the air in the room has a communication with that on the outside, supposing it to be only by means of the key-hole. Thus a barometer placed in a hall, will have its mercury as high as if it was placed in an open field.

The curious effects produced by siphons, all depend upon the pressure of the air.

A siphon is a bent tube *A B C* (fig. 3), made of glass, of metal, or of wood. One branch of which *A B*, is shorter than the other *B C*. In order to make use of this instrument, place the extremity of the short branch *A B* in the vessel *E E*, (fig. 4.) which may be supposed to contain any fluid matter, as water for instance. If the air then is drawn by suction* out of the siphon at the extremity *C* of the long branch *BC*, the liquor will begin to flow, and will not cease while the short branch *A B* remains immersed in the fluid. It is easy to see that the pressure of the air upon the surface of the fluid in the vessel, is the cause

* Suction is here evidently used in the popular sense of the word, to imply that action of the mouth which extracts the air from a given space: for in strict philosophical language there is no such thing.

of its discharge through the siphon. For suppose GF the confines of the atmosphere, all the points of the surface A of the liquor will be equally pressed by the column of air AF ; if, therefore, at some point of this surface, the pressure is suspended, the liquor must flow at that point, because it finds less resistance there than in any other part; this is therefore the obvious reason why the siphon becomes full immediately after the air is drawn out at the extremity C .

If the two branches of the siphon were of equal lengths, as BA , BD , the flow through the bent tube would not take place; because the column of air DG which would resist in D , being of an equal height with that which presses at A , would also be in equilibrium with it, in the same manner as the two columns of the fluid BA , BD . But since BC , one of the legs, is longer than the other, though the column of air GC , which answers to it, is really longer than that which presses in A ; yet it is not capable of preventing the passage of the fluid. To understand this more perfectly, let us consider the column of air GC to be divided into two parts, one of which GD , would form an equipoise with the column of air FA , and would be capable of stopping the flow from the tube if the branch BC ended in D . The portion of fluid which fills the part DC of the siphon, will find no other resistance in C than one column of air DC of the same length with it, which is evidently very inferior to it in weight. This portion of fluid then flows out, because it greatly exceeds in weight the column of air which is opposed to it. But while it continues to flow, nothing sustains that which is above it, which flows necessarily, while the pressure of the air at A furnishes a new supply of fluid to replace that which runs out. It is by these means, that the water in the

proportion to the height of the fluid; the pressure, therefore, which the body undergoes, is greater in proportion to the depth into which it is plunged. Lastly, it has been proved, that when two fluids are placed in equipoise, their respective heights are in proportion to their densities; and therefore bodies plunged to an equal depth, are compressed according to the density of the respective fluid.

If a body is heavier than the fluid in which it is immersed, it is evident that it will sink to the bottom by its specific gravity. If a body is lighter than the same bulk of the fluid into which it is plunged, a part of it will swim, and the remaining part which is immersed displaces a quantity of fluid which weighs exactly as much as the whole of the solid body*.

If,

* From what I have already explained, you must necessarily have discovered the rationale of *sinking* and *swimming*. You saw that when a body was bulk for bulk heavier than the fluid, by being immersed it loses only the weight of an equal bulk of the fluid, and consequently the *residual* or remaining gravity of the solid must carry it down to the bottom, or make it *sink*.

On the other hand, if the solid has less weight in the same bulk than the fluid, then it cannot by its weight displace or raise upwards its whole bulk of the fluid, but only so much of it as is equal to its own weight, and from this deficiency in weight it will be only partly immersed, and will therefore *swim* upon the upper part of the fluid.

Of all the animals, however, thrown into the water, man is the most helpless; the brute creation receive the art of swimming from nature, while man can only acquire it by practice; the one escapes without danger, the other sinks to the bottom. Some have asserted, that this arises from the different sensibilities each have of the danger; the brute, unterrified at his situation, struggles, while his very fears sink the lord of the creation.

But much better reasons may be assigned for this impotence of man in water, when compared to other animals; and one is, that he has actually more specific gravity, or contains more matter within the same surface than any other animal. The trunk of the

If, for instance, water is poured into a glass vessel (fig. 5.) furnished with a small cock near the bottom; if the height of the water in the vessel is marked with a small bandage of thread or paper; and, lastly, if a ball of wood is thrown into it, it will appear that part of the wood will be immersed, and part of it remain above the water, and that the immersed part will raise the water in the vessel just as much as if a volume of water had been added equal to the solid contents of the part under water.

If a quantity of water is then let out of the vessel by means of the small cock, until the surface is reduced as low as the mark which pointed out its height at the beginning of the process, it is clear, that the water drawn out in this manner will be equal in its solid contents to those of the immersed part of the wooden ball; and also, if this volume of water is weighed, it will be found to be of exactly the same weight as the whole ball of wood.

Hence it follows, that a boat upon a river displaces a quantity of water exactly of the same weight with the boat and its lading; and if more weight is added, it will sink deeper in the water in the same proportion; and the immersed part is more or less in extent, ac-

body in other animals is large, and their extremities proportionably small; in man it is the reverse, his extremities are very large in proportion to his trunk. The specific weight of the extremities is proportionably greater than that of the trunk in all animals, and therefore man must have the greatest weight in water, since his extremities are the largest.

Besides this, other animals to swim have only to walk (as it were) forwards upon the water; the motion they give their limbs in swimming is exactly the same they use upon land; but it is different with man, who makes use of those limbs to help him forwards upon water, which he employs to a very different purpose upon land. ADAMS'S *Lectures*, Vol. iii. p. 408.

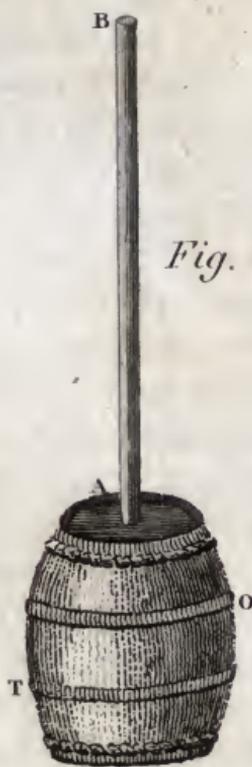


Fig. 3.

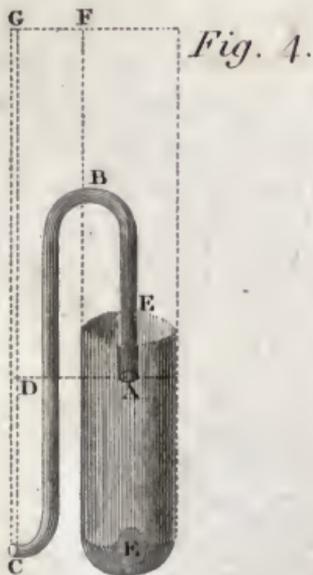


Fig. 4.

Fig. 5.





according to the density of the water. Hence, as water when impregnated with salt, is heavier and denser than pure water, as was formerly proved *; it follows, that the same boat and lading will *draw* less water (according to the seaman's phrase) in the ocean, than in a river of fresh water, and that if it is laden to the utmost extent in salt water, it will sink when it comes into fresh water.

Upon this principle depends the use of the hydrometer. For it will be found that bodies immersed in mercury, sustain a greater loss of weight, or require a greater power to sink them, than in salt water; in salt water than in fresh; and in pure water, they still sustain a greater loss of weight than in spirit of wine, which is a lighter and less dense fluid.

The hydrometer, then, is an instrument by which the specific gravity of different fluids is determined. The most simple, and that which is most in use, consists of a glass globe with a long narrow neck (plate VII. fig. 1.) A C, divided all the way up into equal parts. In order that this instrument may sustain itself in the middle of liquors in a vertical position, it is made in such a manner that the center of gravity is in the lower part of it; it is for this purpose, that another small hollow ball S is placed under the larger ball, in which some mercury is usually lodged, but in such a quantity only as that the whole hydrometer shall weigh about as much as an equal bulk of that fluid which is appointed to be proved.

When the hydrometer is constructed in this manner, if it is plunged in the liquors which are to be compared, it will not entirely sink, because it is supposed

* Book vi. chap. 7.

to be a specific gravity, about or nearly equal with that of the fluid.

If, therefore, the weight of the hydrometer is such, that it will sink in water as far as E, it will sink still deeper in lighter fluids; it will sink for instance in wine as far as F; in spirit of wine as far as G, &c. But if it is plunged into liquors heavier than water, it will not sink so far as E; for example, in beer it will only sink to D, and always as much less as the liquor into which it is plunged is denser and consequently heavier.

By this process it will be easily discovered, whether one kind of fluid is lighter than another with which it is compared; but the proportion cannot be accurately determined; for in order to that, it would be necessary to know exactly the proportion between the tube AC and the balls B and S; which is impossible according to the above mode of constructing the instrument; and it would also be further necessary that the tube AC should be perfectly cylindrical, which never is the case. The most certain mode of acquiring this exact knowledge is, to operate always with equal volumes of fluids: and for this purpose, it is necessary to make use of Fahrenheit's hydrometer.

This instrument (fig. 2.) is composed of a small oval glass bulb or bottle B; the neck of which AC is very small, and terminates with a basin DE, designed to receive small weights.

The instrument is ballasted by means of a small ball of glass S fixed underneath it, in which there is deposited some quicksilver. A small grain of smalt (*a*) is fixed upon the neck, and the instrument is then complete.

In order to make use of this hydrometer, it is necessary to begin by knowing its exact weight, which should

should be marked upon it, to prevent its being forgotten. The instrument is then plunged into distilled water; and by putting weights into the basin D E, it is made to sink as far as the grain of smalt (*a*). The weights which were made use of to produce this immersion, added to the weight of the hydrometer, gives exactly the weight of the volume of water measured by the instrument. By repeating the same operation upon any other fluid, the weight of the volume of that fluid measured by the hydrometer, may be known with equal exactness. Hence it follows, that the quantity of these two volumes are equal, because they are measured by the same instrument: the difference of their weight then will give the difference of their specific gravity, or the relation between their densities. To determine this relation exactly, the following proportion must be observed: The specific gravity of the proved liquor, is to that of distilled water as the weight of a volume of that fluid measured by the hydrometer, is to the weight of the volume of water also measured by it. If the specific gravity of the one is known exactly, the specific gravity of the other may be determined by it, and also that of all other fluids which are proved in the same manner.

The whole of what has been advanced in this chapter, and in that of the first book upon specific gravity, may be briefly summed up in the following propositions: First, when two bodies are equal in their magnitude, bulk, or volume, their specific gravities are to each other as their densities. So that one body has twice the specific gravity of another, when it has twice the density of that other body comprized in the same space or magnitude.

Secondly, when two bodies lose an equal weight in the same fluid, they have the same magnitude or solid

contents, whatever form they may assume, since they each lose a weight equal to the bulk or volume of fluid which they displace.

Thirdly, the specific gravity of bodies is inversely as their bulk when their weights are equal. As one body has twice the specific gravity of another, when with the same weight it has only half the magnitude of that other body.

Fourthly, the specific gravities of two bodies are in a direct proportion to their densities, and in an inverse proportion to their magnitudes. This proposition is a necessary consequence of two preceding, viz. of the first and third.

Fifthly, the same body will lose a greater quantity of its weight in a fluid specifically heavier than in a lighter one; because it will always lose a portion of its weight equal to the weight of that bulk of fluid which it displaces. It requires then a greater force to sustain it in a lighter than in a heavier fluid: it will require more force to sustain it in air than in water.

Sixthly, the specific gravities of bodies of an equal weight (when weighed in a common balance) are proportionate to the weight which they lose in the same fluid. So that of two bodies of equal weight, if the one loses one-fifth and the other two-fifths of its weight in the same fluid, the specific gravity of the first is to that of the second as two to one.

Seventhly, if a body is of the same specific gravity as a fluid, when immersed in that fluid it will be in equilibrium with it, and remain at any depth at which it is placed.

Eighthly, if a body specifically lighter than a fluid is plunged entirely into it, and then left to itself, it will remount with a force equal to the excess of weight which a volume of that fluid possesses above an equal bulk of the body immersed.

Ninthly,

Ninthly, the specific gravity of a solid is to that of a fluid heavier than itself, and upon which it will swim, as the bulk of the immersed part is to the bulk of the whole body. So that if the magnitude or bulk of the immersed part is to the magnitude of the whole body as two or three, the specific gravity of the solid is to that of the fluid as two is to three.

Tenthly, the weight and the magnitude of a body, and also the weight of a fluid specifically heavier than the body, being given, suppose it is required to find the force requisite to keep that body entirely immersed in the fluid. As this force is equal to the specific weight of the fluid, find, by means of the given bulk of the solid, and the known weight of a cubic foot of the fluid, by the rule of three, the weight of a bulk of the fluid equal to the bulk of the solid. Subtract from this weight, the weight of the solid, and the remainder will be the force required. For example, suppose it was required to find the force necessary to retain under water a solid of eight cubic feet in contents, and of four hundred pounds weight. Since a cubic foot of water weighs about seventy pounds, the weight of eight cubic feet of water is five hundred and sixty pounds; then if four hundred pounds are subtracted, the one hundred and sixty remainder, is the force necessary to keep the solid immersed in the water, and to prevent it from rising to the surface.

Eleventhly, the weight of a body specifically heavier than a fluid, and the weight of that fluid specifically lighter, being given, suppose it is required to determine the cavity which that body should have, in order that it may swim upon the fluid.

The weight of a cubic foot of the fluid being given, the bulk of the portion of the fluid equal in weight to that of the body, is found by the rule of three. If then

the cavity of the body is made so, that the bulk may be a little larger than the magnitude already found, the body will have less weight under the same magnitude than the fluid. For example, suppose that it is required to make a ball of iron of thirty pounds, and of such a magnitude as that it will swim upon water. Since the weight of a cubic foot of water is seventy pounds, a volume of water weighing thirty pounds will be three-sevenths of a cubic foot: hence it will be easy to find what the diameter of a sphere must be, the solid contents of which shall be three-sevenths of a cubic foot. Therefore, the ball of iron must be made hollow within, and in such a manner that its diameter may be greater than the diameter of a sphere, the solid contents of which is three-sevenths of a cubic foot: if this ball is made eleven inches three lines in diameter, it will swim. Hence we see that it is not necessary for a body to swim, that it should be composed of matter specifically lighter than water; it suffices that its bulk or volume should be great and its gravity small; for though copper is about eight times as heavy as water, yet military men have occasionally employed boats of copper in constructing bridges for the passage of troops.

A copious table of specific gravities is given in the appendix to this volume.

C H A P. III.

H Y D R A U L I C S *.

Of the Discharge of Fluids through small Apertures.—The Discharge of Fluids through successive Pipes.—Artificial Fountains.—Pumps.—The Raising Pump.—The Forcing Pump.—The Sucking Pump.—The Compound Pump.—The Fire Engine.—Motion of Water in Conduit Pipes.—Oscillatory Motion of Water in a Siphon.—Oscillatory Motion of Waves.—Motion of Wheels acted upon by Water; and Construction of Water Mills.

THE science which has for its object the motion of fluids is called hydraulics; and its immediate application is to furnish us with the means of conducting water from one situation to another, by canals or aqueducts, and to elevate it by pumps, jets-deaux, and other hydraulic engines, either for the purposes of ornament or use.

In treating of this subject I shall commence with the simplest principles, and shall first speak of the discharge of fluids through small apertures.

When water flows from a vessel which has a hole or aperture in the bottom, small in comparison to the width of the vessel, the water descends vertically, and the surface appears smooth, but at three or four inches from the bottom the particles turn from this direction, and proceed on all sides with a motion more or less oblique towards the aperture. The same effect takes place when water flows through an aperture late-

* Almost the whole of this chapter, and great part of the preceding, are translated from the first volume of Brisson's "Traite Elementaire de Physique," Chap. VIII.

rally. The tendency of the particles towards the aperture is a necessary consequence of their perfect mobility; for they will certainly be directed towards the point where there is the least resistance, and that point is the aperture.

It is also to be observed, that in this case, at a small distance from the bottom, a kind of funnel is formed in the water, the point of which corresponds to the center of the aperture; when, however, the water flows through a lateral orifice or aperture, there is formed only a kind of half funnel, which does not appear to commence till the surface is near touching the upper side of the hole. It is probable that the funnel begins to form itself from the first moment of the flow; but it does not become perceptible till the surface is only at a small distance from the bottom.

It appears also, that the funnel commences higher or lower, according to the width of the bottom; and that the formation of it is less prompt or less perceptible, according to the proportion of the aperture to the extent of the bottom. The funnel is also augmented by any roughness which may exist at the sides or bottom of the vessel.

Water flows out of a small hole in the bottom of a vessel with a velocity equal to that which a ponderous body acquires in falling from a height equal to the vertical height of the surface of the fluid above the aperture.

The same law takes place in a lateral orifice; for the pressure of the fluid is equal (at the same depth) in all directions, and consequently produces the same degree of velocity.

A fluid, in running out of an aperture, acquires a velocity sufficient to make it remount to a vertical height

height equal to that of the surface of the fluid above the aperture, in the same manner as a falling body acquires a velocity capable of making it ascend to the height from which it descended.

It is evident, from the theory of falling bodies, that if the velocity of the fluid in running through the aperture was uniformly continued, the fluid would move through a space double the height of the fluid above the aperture, in the same time that a falling body would employ in descending from that height.

The height being the same, the velocity of the fluid in running out of the orifice will always be the same, whatever the species of the fluid may be, and whatever its density. It is true, that when the fluid has more density it presses more forcibly, but then the mass is more considerable, and it is evident, that when the moving powers are proportioned to the masses which they put in motion, the velocities are equal.

The quantities of a fluid discharged in the same space of time through different orifices, supposing the vessels equally full during the whole of the experiment, are to each other as the products of the areas of the apertures by the square roots of the heights. For instance, it has been proved by experiment, that a circular orifice of an inch diameter, made in a thin vessel or partition, and under a surface of fluid four feet in height, will furnish, in one minute of time, five thousand four hundred and thirty-six cubic inches French.

If, therefore, it was an object to ascertain how much a circular orifice of two inches diameter, under nine feet of height from the surface of the water, would furnish in the same time, the following proportion must be employed (it must be observed, that the orifice of two inches is four times as great as an orifice

of.

of one inch, because the areas of circles are as the squares of their diameters):

$$1 \times \sqrt{4} : 4 \times \sqrt{9} :: 5436 : *$$

Or at length

$$2 : 12 :: 5436 : 32616$$

12

$$\underline{\underline{2)653232}}$$

Therefore 32616 cubic inches of water will flow from an aperture of two inches in diameter in one minute, the orifice being made nine inches from the surface, which is supposed to be kept at that height the whole time.

If a vessel of a prismatic form is filled with water, and permitted to empty itself entirely through an orifice at the bottom, and the time that it consumes in emptying itself is observed; and if afterwards, having replenished the vessel, the water is made to flow through the same aperture, the vessel being kept full the whole time, there will run out in this second instance, during the same time that the vessel took to empty itself at first, a quantity of water double that which runs out in the first case, for the abstraction of the water produces a kind of funnel, which in this last case does not take place.

We often perceive water flow through lateral apertures, which, though small in comparison to the width of the reservoirs, cannot be regarded as having all their points at an equal distance from the surface of the fluid; such, for example, as the apertures through which water sometimes flows in mills. The common method of determining the quantity discharged is as follows: suppose, in the first place, the aperture to be stopped up by a plate of metal, which is perforated with

with a number of holes; if each of these holes is regarded as particular and insulated, the rapidity of the flow through each will be according to the correspondent height of the fluid; then if the number of holes are multiplied *ad infinitum*, or, which will amount to the same thing, if the plate is supposed to be entirely taken away, the velocity at each point of the supposed orifice will be according to the correspondent height of the fluid; and in estimating the quantity of water discharged, some attention must be paid to the inequality of the motion; yet it must not be asserted that this reasoning is entirely conclusive. In proportion as the sum of the small holes made in the plate is small in comparison with the size of the reservoir, the portions of water which flow through each hole are forced out by the absolute weight of the column above; but the moment that the number of apertures augment *ad infinitum*, and the streams of water which run through them become contiguous; it cannot be clearly said that the liquid flows in the same manner as through small insulated holes; yet as this hypothesis gives a result sufficiently conformable to experiments, it may be useful to preserve it, and the more so, as it leads to very simple calculations, and in all common questions this simplicity may be preferable to the minuteness of fractional operations.

The quantity of water which issues from these apertures in a given time is not so great as their size might at first suggest, because the stream is contracted by running out of each orifice, and that contraction extends to a distance nearly equal to half the diameter of the aperture; and the diameter of the contracted stream is to the diameter of the aperture a little more than as three to four, or as three and one-sixth to four, or nineteen to twenty-four; so that its area is to that

of the aperture as ten to sixteen. It is nearly the same when water flows through lateral apertures. The contraction of the stream is a proof of what has been before stated, viz. that within a vessel, the lateral particles direct themselves towards the orifice with a motion more or less oblique; and this oblique motion may be decomposed into two forces, the one parallel to the plane of the orifice, and which contracts the stream; the other perpendicular to the same plane, and the only one which produces the efflux.

This contraction occurs also when water is made to flow through pipes, and that at the entrance of the water into the pipe, and not at its exit, where the stream preserves a cylindrical form. I shall prove that this contraction diminishes, in a sensible manner, the quantity of water which would naturally flow.

In order to ascertain these facts by experiments, many have been made. In all the following instances the orifices, through which the water flowed, were pierced perpendicularly through plates of copper of about one-twenty-fourth of an inch thick, and the time of each experiment is reduced to one minute.

The constant height of the water above the center of each orifice was 11 feet 8 inches 10 lines. No. of cubic inches, furnished in 1 minute.

- | | |
|---|--------|
| Exp ^t . 1. Through an horizontal circular orifice of $\frac{1}{2}$ inch (6 lines) diameter | 2,311 |
| 2. Through ditto of 1 inch diameter | 9,281 |
| 3. Through ditto of 2 inches diameter | 37,203 |
| 4. Through an horizontal rectangular orifice of 1 inch long and $\frac{3}{12}$ inch wide | 2,933 |
| 5. Through an horizontal square orifice of 1 inch the side | 11,817 |
| 6. Through ditto of 2 inches each side of the orifice | 47,361 |

Constant height = 9 feet.

- | | |
|--|-------|
| 7. Through a lateral circular orifice of $\frac{1}{2}$ inch diameter | 2,018 |
| 8. Through ditto of 1 inch diameter | 8,135 |

Constant height = 4 feet.

- | | |
|--|-------|
| 9. Through a lateral circular orifice of $\frac{1}{2}$ inch diameter | 1,353 |
| 10. Through ditto, of 1 inch diameter | 5,436 |

Constant height = $\frac{7}{12}$ inch.

- | | |
|---|-----|
| 11. Through a lateral circular orifice of 1 inch diameter | 628 |
|---|-----|

It follows from the preceding table,

1. That the quantities of water discharged in the same time, by different apertures, under the same height of surface in the reservoir, are to each other nearly as the areas of the apertures. Compare together the results of the second and third experiments, of which the areas of the orifices are in the proportion of one to four, and it will be found that the quantities of water afforded, viz. nine thousand two hundred and eighty-one cubic inches, and thirty-seven thousand two hundred and three inches, are very nearly in the same proportion.

2. That the quantities of water discharged in the same time through the same aperture, under different heights of surface in the reservoirs, are to each other nearly as the square roots of the corresponding heights of the water in the reservoir above the center of the aperture. - Compare together the results of the eighth and tenth experiments, where the heights of the reservoirs are nine and four feet, the square roots of which are three and two, and it will be found that the two quantities of water, eight thousand one hundred and thirty-five cubic inches, and five thousand four hundred and thirty-six cubic inches, which run through the same orifice of one inch diameter under the different heights of nine feet and four feet, are to each other nearly in the proportion of three to two.

3. That in general the quantities of water discharged in the same time through different apertures, under different heights of surface in the reservoirs, are to each other as the areas of the apertures are to the square roots of the heights of water in the reservoirs.

4. That in consequence of the friction, the small apertures furnish a less quantity of water in proportion than

than the great ones, under the same height of water in the reservoir; because, comparatively to the extent of the area of each orifice, there are more points of friction against the sides of the orifice in the small than there are in the great ones; for the circumferences do not diminish so much as the areas.

5. That of many apertures of equal areas, that of which the circumference is the least will, on account of the friction, furnish more water than the others, under the same height of the reservoir; circular apertures are, for this reason, the most advantageous of all; for the circumference of a circle is the shortest line that can be made use of to inclose a given space; therefore there is less surface of friction relatively to the size of the area.

It is easy to perceive, that the quantity of water discharged in the table of experiments is not near so great as might be expected from the extent of the areas and the heights of the reservoirs. The quantity is in fact diminished by the friction, and still more by the contraction of the stream; for the velocity which is in proportion to the entire altitude of the fluid is not sensibly changed. Supposing, first, that the area of the stream is the same as that of the orifice; and supposing, secondly, that the stream is contracted, then the difference of the quantities afforded is as sixteen to ten; that is, supposing the area of the aperture to be diminished in the proportion of sixteen to ten, the discharge of the fluid out of vessels kept equally full may be determined with sufficient exactness. By the expression, *an inch of water*, is understood the quantity which flows out of a circular and lateral orifice of one inch diameter, the surface of the water being constantly kept seven-twelfths of an inch above the center of the orifice. This is the case with the eleventh

experiment in the preceding table, where it appears that the quantity of water furnished is six hundred and twenty-eight cubic inches. M. Mariotte, who made the same experiment, found the quantity to be a little more; but it is probable that he might commit a small error, because the experiment I have just cited was made, M. Briffon informs us, with the utmost care and attention. A (French) pint of water, he adds, instead of weighing two pounds, as is commonly believed, is proved to fall short of that weight considerably, as will be evident by strictly examining that experiment.

These facts being premised, I shall request the attention of the reader, secondly, to the discharge of fluids through additional pipes.

When, instead of causing water to pass through an aperture made in a thin substance, it is made to flow through an additional vertical pipe of the same diameter with the orifice, the quantity of water discharged is more considerable, because the contraction of the stream is greater in the first case than in the second.

In the following experiments, the constant height of the water in the reservoir above the upper base of the additional vertical pipe is 11 feet $8\frac{1}{2}$ inches (French), and the diameter of the pipe one inch.

The variable heights of the tube expressed in lines.		Number of cubic inches of water discharged in one minute.
<i>Lines.</i>		
Exper. 1. - - 48	{ The water running through a full pipe.	- - 12,274
2. - - 24		- - 12,188
3. - - 18		- - 12,168
4. - - 18	{ The water not filling the pipe.	- - 9,282

It appears from this table of experiments, that the longer the vertical pipe is, the greater will be the quantity of water discharged, because the contraction of the stream is less, as may be seen by comparing the three first experiments. There is always, however, some contraction, though the water appears to flow out of a full pipe.

In comparing the quantities of water discharged in the third and fourth experiments, it will appear, that the two quantities, 12,168 cubic inches and 9,282 cubic inches, are to each other nearly in the relation of thirteen to ten; but it has been observed before, that the quantity of water discharged through an aperture made in a thin substance, if the stream was not contracted, would be to the quantity of water discharged through the same orifice, if the stream was contracted, nearly as sixteen to ten. Hence then it may be concluded, that the height of the water in the reservoir and the different apertures being the same, the quantity of water discharged through an orifice made in a thin substance, in which there was no contraction of the stream, the quantity of water discharged through

an additional pipe, and the quantity which would flow through an orifice made in a thin partition, in which there was a contraction of the stream, are to each other nearly as the three numbers, sixteen, thirteen, ten, and these proportions are found sufficiently accurate for common purposes.

Hence also it may be inferred, that additional pipes counteract only in part the contraction of the stream. The most sensible of all contractions of this nature is that which takes place when water flows from a large reservoir through a small aperture made in a thin substance.

If the additional pipe, instead of being vertical, or placed in the bottom of the vessel or reservoir, is horizontal, or placed in the side, it will afford the same quantity of water, provided that it is of the same length, and that the exterior aperture is placed at the same distance below the surface of the water in the reservoir.

If the additional pipe, instead of being cylindrical, is conical, having its largest base attached to the side of the reservoir, it will produce a much greater quantity of water. The most advantageous form, indeed, for procuring the greatest quantity of water in a given time through a certain aperture, is that which the stream itself naturally assumes in coming out of an aperture in a thin substance; that is, the form given to the pipe should be that of a truncated cone, the diameter of the smaller base of which should be the same as that of the aperture through which the water is to flow.

It is necessary also, that the area of the smaller base should be to the area of the greater as ten to sixteen; and the distance between the two bases should be nearly equal to half the diameter of the greater base. The
remainder

remainder of the length of the pipe may be either cylindrical or prismatic. The discharge will then be equally abundant with that which would take place through an aperture equal to the smaller base made in a thin partition, and in which the stream suffered no contraction. This form may be applied to practice whenever it is required to draw a certain quantity of water from a river by an aqueduct, &c. through a canal or lateral pipe.

If we compare the different quantities of water discharged through additional pipes of different diameters with different altitudes of the water in the reservoirs, we shall have the results stated in the following table, the additional pipes being supposed to be two inches long, and vertical, or placed in the bottom of the reservoir.

The constant height of the water above the aperture,	The diameter of the additional pipes in twelfths of an inch (lines.)	No. of cubic inches discharged in one minute.
Ex. 1. } 2. } 3. } 4. }	552 lines. }	6 } The water running through a full pipe. { 1,689.
		10 } { 4,703.
		6 } The water not following the sides. { 1,293.
		10 } { 3,598.
5. } 6. } 7. } 8. }	228 lines. }	6 } The water running through a full pipe. { 1,222.
		10 } { 3,402.
		6 } The water not filling the tube. { 935.
		10 } { 2,603.

The first inference from these experiments is, that the quantity of water discharged by different additional pipes, under the same height of water in the reservoir,

is proportional to the areas of the apertures, or to the squares of their diameters.

Secondly, it appears that the quantities of water discharged through additional pipes of the same diameter, under different altitudes of water in the reservoir, are proportional to the square root of the altitude.

Thirdly, that in general the quantities of water discharged in the same space of time through different additional pipes, under different heights of water in the reservoir, are to each other nearly as the product of the square of the diameters of the pipes by the square root of the altitude of the reservoirs.

The efflux of water, therefore, through additional pipes, follows the same laws as water when discharged through apertures made in thin substances. On these experiments the following table was formed, of the quantities of water discharged through a given aperture made in a thin substance, supposing the stream to suffer no contraction, or through the same aperture with a contraction of the stream, or through the same aperture with an additional pipe.

Constant height of the water in the reservoir above the aperture, expressed in (French) feet.	Cubic inches of water discharged in one minute through an aperture of one inch diameter without any contraction of the stream.	Cubic inches of water discharged in one minute through an additional pipe of one inch diameter and two inches long.	Cubic inches of water discharged in one minute through an aperture of one inch diameter with a contracted stream.
1	4381	3539	2722
2	6169	5002	3846
3	7589	6126	4710
4	8763	7070	5436
5	9797	7900	6075
6	10732	8654	6654
7	11592	9340	7183
8	12392	9975	7672
9	13144	10579	8135
10	13855	11151	8574
11	14530	11693	8990
12	15180	12205	9384
13	15797	12699	9764
14	16393	13197	10130
15	16968	13620	10472

III. There is no application of the doctrines of hydraulics more surprising, or more gratifying to the eye, than that which is seen in the variety of artificial fountains, or jets d'eau, which the ingenuity of man has been able to construct for ornament in general, and for use in some instances, particularly in warm climates. The principles on which these are constructed it will not be difficult, after what has been stated, fully to comprehend.

Whatever may be the direction of the jet or fountain, the quantity of water expended will be the same, provided

provided that the ajutage *, and the height of the reservoir above the ajutage, is the same. This is a necessary consequence of the equal pressure of fluids in all directions.

Water, when discharged through an ajutage, however small it may be, has a velocity sufficient to raise it to the height of the surface of the water contained in the reservoir; so that a vertical jet d'eau throws up the water as high as the reservoir whence it proceeds, if nothing obstructs it.

There are, however, many causes which contribute to diminish the elevation of water by jets d'eau. First, the friction in the pipes from the reservoir to the ajutage; secondly, the friction against the circumference of the aperture; thirdly, the resistance of the air to the motion of the column; fourthly, the gravity of the particles of water themselves, which, in rising, lose some of their velocity, and recoil upon those which succeed them. Thus by inclining the pipe a little, we find that the water will rise higher than when it is exactly vertical; but in this case, the effect is not so agreeable to the eye of the spectator, as when the water which rises above the pipe into the air falls perpendicularly, in a manner, back upon itself.

When the ajutage is placed in an oblique direction to the horizon, the force of the projection and the gravity of the water cause the stream which ascends into the air to form a parabola, the amplitude of which is in proportion to the height of the reservoir.

When the ajutage is placed horizontally, the water forms a semi-parabola.

Fountains elevate the water in proportion as the aperture of their ajutages is large; because, first, of

* A tube which is fitted to the mouth of the vessel through which the fountain is played.

two jets d'eaux proceeding from the same reservoir, and flowing from their ajutages with an equal degree of velocity, the greater will, in the first place, experience less friction; and secondly, it has a greater mass, and consequently more power to overcome the obstacles which may oppose it.

But, though large jets d'eau elevate water higher than small ones, they do not expend a greater quantity in proportion; for the quantity of water discharged is as the product of the aperture of the ajutage by the degree of velocity at the time of the discharge; and this velocity is the same in both, no allowance being made for the friction.

In order to make large fountains elevate water higher than small ones, it is evidently necessary that the conducting pipes should be sufficiently large to furnish water in abundance; for if they are small, experience proves that the small fountains in that case will elevate water higher than larger ones; it follows, then, that the diameter of the pipe, which conveys the water, should be in proportion to that of the ajutage, in order to elevate the water to the greatest possible height.

If we compare two different jets d'eau, and are desirous that each should elevate water to the greatest possible height, it is necessary that the square of the diameters of the conduit pipes should be in proportion to each other in the compound ratio of the diameters of the ajutages and the square root of the altitudes of the reservoirs. Thus, if it is known by experiment what the diameter of a conduit pipe should be, to supply an ajutage of given dimensions, it may be easily determined what the diameter of another pipe should be to furnish another ajutage of a determinate size, the height of the reservoir being also given.

It has been proved by experiments, that when the diameter of the ajutage is half an inch, and the height of the reservoir fifty-two feet, the diameter of the pipe which conducts the water ought to be three inches and a quarter; and that for an ajutage of half an inch diameter, the height of the reservoir being sixteen feet, the diameter of the pipe ought to be about two inches and one-third. There is no inconvenience in making the conduit pipe of a greater diameter than is required by this rule; but on the contrary, there would be an inconvenience in making it of a smaller diameter.

Sometimes the ajutage is made in the form of a cone, and sometimes in that of a cylinder; but those who conceive that it is indifferent in which of those forms it is made are mistaken, for the cylindrical form is by far the most disadvantageous.

By comparing many experiments made upon artificial fountains, it has been determined, that the differences between the altitudes of vertical jets and the height of their reservoirs, are to each other as the square of the altitudes of the former. If then it is known what quantity of water a jet elevates at a certain height of the reservoir, the quantity which any other jet of a given height will elevate, compared with the height of its reservoir, may be easily found by the rule of single proportion.

When it is necessary to bend the conducting pipes, the utmost care should be taken to avoid bending them at right angles, for the striking of the current against these angles very considerably diminishes the velocity.

The following table will greatly facilitate the application of these principles.

The heights of jets, and the correspondent heights of reservoirs, are found in the two first columns. The
third

third column contains in (Paris) pints, of which thirty-six make a cubic foot, the quantities of water discharged in one minute through an ajutage of half an inch diameter, relatively to the heights in the second column. The quantity discharged through an ajutage of half an inch diameter being known, the quantity which will be discharged by any other ajutage, under the same height of the reservoir, may be found by single proportion; for it has already been proved, that the quantities of water discharged are to each other as the areas of the ajutages, or as the squares of their diameters. In the fourth column are found the diameters for the conducting pipes of an ajutage of half an inch diameter, according to the heights in the second column. The diameters of pipes for other ajutages, and other heights of the reservoir, are found by following the preceding rule.

Fractions are not observed in the calculations for the two last columns.

The heights of jets, expressed in feet.	The heights of reservoirs, in feet and inches.	Quantities of water discharged in one minute through an aperture of half an inch diameter, in pints.	Diameters of the pipes, according to the 2d and 3d columns, in lines.
Feet.	Feet. Inches.	Pints.	Lines.
5	5 1	32	21
10	10 4	45	26
15	15 9	56	28
20	21 4	65	31
25	27 1	73	33
30	33 0	81	34
35	39 1	88	36
40	45 4	95	37
45	51 9	101	38
50	58 4	108	39
55	65 1	114	40
60	72 0	120	41
65	79 1	125	42
70	86 4	131	43
75	93 9	136	44
80	101 4	142	45
85	109 1	147	46
90	117 0	152	47
95	125 1	158	48
100	133 4	163	49

IV. From objects of mere pleasure and ornament, our attention is next solicited to an invention of eminent utility, and of ancient date, though the modern improvements are very considerable even in this branch of mechanics.

Pumps are hydraulic engines, designed for the purpose of elevating water; they are composed of hollow cylinders A B (Plate VII. fig. 3.) or E F (Plate VIII. fig. 1.) of an equal diameter throughout their whole length, which is called *the body of the pump*, and in which

which a kind of stopple I, called the *piston*, is made to slide, or move up and down. The piston is put in motion by means of a rod of metal X x , at the extremity of which X the handle is placed, and elevated by the lever X Y, or by some other contrivance; to this is annexed a pipe A T (Plate VII. fig. 3.) to conduct the water to the height required; and, lastly, the suckers S s.

There are several kinds of pumps; some are called sucking pumps and others forcing pumps, and there are others which are at the same time both sucking and forcing pumps.

The *raising pump* is composed of the body of the pump A B, (Plate VII. fig. 3.) to the lower part of which is affixed the end of a pipe B N, open at the bottom, or (which is still better) pierced with holes its whole length, in such a manner that large pieces of dirt and rubbish may be prevented from entering the body of the pump. At the union of this end of the pipe with the body of the pump is placed a valve or sucker s, which, when raised up by the pressure of the water beneath, permits the fluid to ascend into the body of the pump, but which, by being pressed down again by the action of the pump, prevents effectually the efflux of the water by the same aperture. In the body of the pump there is a box or piston I, pierced quite through, furnished at the upper end with a sucker S, and joined at x , by the assistance of a head somewhat in the form of that of a pair of compasses, to the rod x X, which enables it to act by the aid of a lever X Z Y. At the upper part A of the body of the pump is placed the raising pipe A T, which has its spout at T. This pump ought to be placed in a well or bason, in such a manner that the body of the pump

pump A B should be entirely under the surface of the water A A.

Now if the piston I is raised by lowering the extremity Y of the lever Y Z X, so that the lever may assume the position *y* Z *u*, the piston will rise in the body of the pump, where it will create an imperfect vacuum equal to the distance X *u*, and consequently the water beneath will raise the sucker *s*, and will pass out of the basin into the pump. When the piston is lowered again, this pressure causes the sucker *s* to close, and the sucker S to rise up; hence the water which was below the piston is then above it. By a second exertion of the piston, this quantity of water is elevated, and by the same mechanism a fresh quantity is permitted to pass into the pump, and afterwards to rise above the piston, in the same manner as the first portion was raised; so that by a certain number of exertions of the piston, the raising pipe A T is filled. When this is accomplished, at every exertion or stroke of the piston there is ejected at the spout or discharging pipe T a mass of water equal to a cylinder, the base of which is equal to the width of the piston, and of a height equal to the space through which the piston passes in the body of the pump. This space is commonly called the play of the piston.

It is not difficult to estimate the weight of the column of water with which the piston is charged, when the raising pipe is full, and consequently the force which is necessary to be exerted at Y in order to work the pump. It has been observed before, that fluids press in proportion to their perpendicular height, and the width of the base which opposes their descent. In a pump, this base is the piston, and the perpendicular

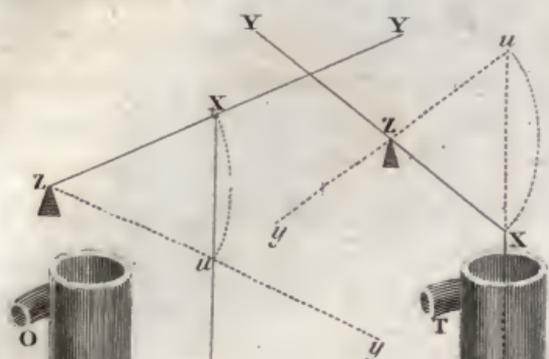


Fig. 3.

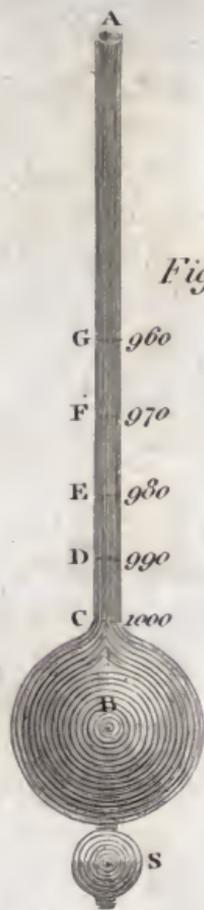


Fig. 1.



Fig. 2.

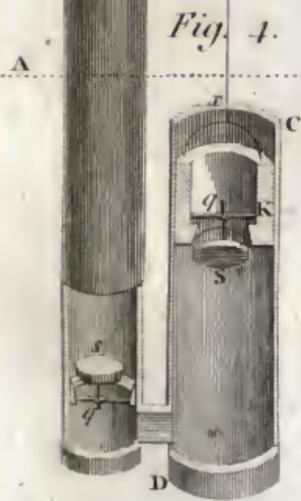


Fig. 4.





cular height is that of the raising pipe above the surface of the water; so that when the raising pipe is full, the charge upon the piston is equal to the weight of a cylinder of water, the diameter of which is equal to that of the piston, and the height equal to that of the raising pipe above the surface of the water, whatever may be the diameter of the mounting pipe; and this charge or weight upon the piston is easily calculated, when it is known that a cylinder of water of one foot diameter and one foot high weighs about fifty-five (French) pounds.

It follows, therefore, that the weight of a column of water is not diminished by diminishing the diameter of the raising pipe; but that, on the contrary, the resistance which ought to be overcome is even augmented on account of the increase of the friction, which is more considerable in small pipes than in large ones, because the relative surfaces augment as the diameters diminish. Thus, only for the expence, it would be wrong to make, as is commonly done, the raising pipe smaller than the body of the pump; on the contrary, it would be better to construct it of a diameter greater than that of the body of the pump, as the friction would be proportionably diminished.

The *forcing pump* is composed of the body of the pump C D, (Plate VII Fig. 4.) stopped close at the bottom, but entirely open above, and in which is a piston K, which only differs from that of the pump already described in this, that its sucker S is placed at the bottom instead of the top. This piston, like that of the pump just mentioned, is put in action by means of the lever Y X Z, which has its point of support in Z. The raising pipe A O is placed at the side of the body of the pump, with which it communicates, and is furnished with a sucker s in its lower

part, and with a spout O at its upper extremity. This pump, as well as the preceding, ought to be immersed in a well or basin in such a manner that the body of the pump C D should be entirely under the surface of the water A A.

The water fills the body of the pump by falling through the aperture C, and by passing over the piston K, the sucker of it S, considering its position, will naturally open. If the piston K is lowered, by placing the lever Y X Z in the position *y a Z*, the resistance of the water against the sucker S will close it immediately. This water then, being incapable of repassing above the piston, is forced up the pipe A O, by raising up the sucker *s*. As soon as the piston is raised again, the sucker *s* is closed by the pressure of the water which is above, and the sucker S is opened by its own weight. A new mass of water then passes below the piston, which by a second depression of the piston, is forced to pass, like the first, into the pipe A O; so that by a certain number of strokes of the piston, that pipe becomes full of water, which is then discharged at the spout O as in the pump already described. If the pistons in both of them are of the same diameter, and the raising pipes of the same perpendicular height, the weight of the two columns of water will be equal, and the two pumps will require the same power to work them; for in that case it requires the same power to elevate the piston charged with a column of water as it does to force the column of water by means of the piston.

The sucking * pump (Plate VIII. Fig. 1.) is composed of the body of the pump E F, open above, and

* So called, because it was originally supposed, but erroneously, to act by suction.

with a pipe of aspiration or sucking pipe *F P* adapted to the lower part. At the union of this pipe with the body of the pump is a sucker *s*, designed to permit the water, while the piston is raised, to enter through the pipe of aspiration *P F* into the body of the pump *F E*, and to prevent it, while the piston is lowering, from being discharged the same way. In the body of the pump is a piston *L*, made like that at *I* in Plate VII. Fig. 3. and which it put in action in the same manner by the assistance of the lever *X Z Y*. This pump should be placed in such manner as to have only the lower extremity of the aspiration pipe *F P* plunged into the water.

While the pump remains inactive, the two suckers *S* and *s* are naturally closed from their own weight. If the piston *L* is raised up by means of putting the lever *X Z Y* in the situation *u Z y*, the column of air which rests above is elevated, and the air which is closed up in the aspiration pipe, from the surface of the water *a* to the piston, having then more space to occupy, becomes more rarified than the external air. This last then presses more forcibly upon the surface of the water *a*, and causes it to rise in the aspiration pipe, till the interior air has regained its former density by occupying less space. Thus, after several strokes of the piston, the water reaches the body of the pump, and passes over the piston, by raising up the suckers *s* and *S*, one after another, and the piston, by its subsequent elevation, forces the water to escape at the spout *E*.

As it is the pressure of the air which causes the water to rise in this pump, and as this pressure can sustain only a column of water of about thirty-two feet, it is clear that the aspiration or sucking pipe

should not exceed that length. In common practice it is indeed seldom made so long as thirty-two feet. In order that the pressure of the atmosphere may be such as to sustain a column of water of that height, it is necessary, first, that the sucking pump should be made with the greatest exactness, and that it should continue in a perfect state; secondly, that it should be placed upon the level of the sea, or very near it, because it is there that the pressure of the atmosphere is most forcible; thirdly, that the pressure of the air should not vary; but in general all these circumstances are not required. Mechanics are satisfied, in general, with making the aspiration pipe twenty-three or twenty-four feet long. If it is necessary to elevate water to a greater height, the forcing pump is more commodious for that purpose. The latter, it is true, is subject to several inconveniences. It is necessary to place the body of the pump either in wells or in a basin; and when it is required to repair it, which often happens, one of two things is necessary, either to empty the well or the basin, or to draw up the body of the pump, which is extremely troublesome and expensive. To remedy these inconveniencies, the best and most usual mode is, when water is to be elevated from a great depth, to make the pump at once both a forcing and sucking pump, in the manner which I shall presently explain.

In the year 1766 it was reported, through the channel of the public papers, that at Seville, in Spain, a simple sucking pump had been constructed, which elevated water to the height of sixty feet, and it was consequently concluded, that the world had till then been notoriously imposed upon by the current maxim, that the pressure of the air could raise a column of water
only

only to the height of thirty-two feet. M. Briffon has carefully examined into the fact, and his explanation is curious and interesting.

An ignorant tinman, at Seville, had made a sucking pump sixty feet long, because he had occasion to elevate the water to that height. When the pump was fixed in its place, and put in action, he was unable to make the water rise into the body of the pump. Enraged at this disappointment, he gave it a blow with his hammer, which produced a small aperture in the aspiration pipe at about ten feet above the surface of the water in the basin. Immediately a small portion of water arrived at the body of the pump. After this process it was reported, that a sucking pump had been constructed, which elevated water to the height of sixty feet; but the reader will be enabled to judge of the truth of this assertion from the following observations:

Let us suppose that the aspiration pipe, P F (Plate VIII. Fig. 1.) had from *a*, the surface of the water of the basin, to F, a distance of sixty feet, and that after a certain number of strokes of the piston, the water rises to *c*, thirty-two feet high; if then a small hole is made at *b*, ten feet above the surface of the water, the air which enters at this hole, and presses in all directions, will cause the column of water of ten feet, which is below *b*, to fall into the basin, and the pressure of the air upwards at *b* has only a column of water of twenty-two feet to support.

But that pressure is capable not only of raising that column to the height of sixty feet, but even to the height of eight thousand feet; for air, near the surface of the earth, is eight hundred times less dense than water, and supposing (which is not the case) it was not diminished in elevating, then the ten feet of water,

cut off by the pressure of the air at b , downwards, would be more than equivalent to eight thousand feet of air. The column of air, therefore, which presses at b , will be too strong for more than eight thousand feet; thus the twenty-two feet of water remaining above will not be in equilibrium with the column of air till after it has risen higher than eight thousand feet.

In order to have a second portion of water with a pump of this construction, it is in the first place necessary to stop the aperture which was made at b , then to give several strokes with the piston to elevate the water as high as c ; and lastly, to open again the orifice at b . Observe the simplicity of this process for raising so small a quantity of water! for it is necessary that the aspiration pipe should be of a very small diameter, otherwise the column of water would break, and the air would pass through, and not one drop of water could be raised into the body of the pump. This fact (adds M. Brisson) may serve to convince those who are fond of novelty, that before an opinion generally received is pronounced to be false, it is necessary to think twice at the least. A short time after the constructing [of this pump at Seville, M. Bellangé, a goldsmith in Paris, made one in imitation of it, to which he gave the additional property of throwing water fifty-five feet high, by means of a continued *jet* or ejecting pipe, though the machine was only a simple sucking pump.

To a small bodied pump of two inches and one-twelfth in the interior diameter, the piston of which had eight inches play, he adapted an aspiration pipe of ten-twelfths of an inch diameter, and fifty-six feet long; this pipe was furnished with a sucker at its junction with the body of the pump, and with another at

its lower extremity. This extremity was plunged into a tun full of water. M. Bellangé had made a small perforation in this pipe of about one twenty-fourth of an inch diameter, at twelve or fifteen inches above the surface of the water in the tun. The apparatus being disposed of in this manner, he moved the piston gently, but the water did not rise; the small hole furnished a sufficient quantity of air to fill the aspiration pipe. He then moved the piston with great velocity; the small hole could not, in so short a space of time, furnish a sufficient quantity of air to fill the pipe; a little water rose and mixed itself with the air, so that the column became composed of small cylinders, alternately of air and water, and though it was fifty-five feet high, it was much short of the weight of a column of water thirty-two feet high. If we calculate, therefore, according to the diameter of the body of the pump, and the extent in which the piston played, what quantity of water this pump would have furnished if the air had not entered, and then compare this quantity with that which it really furnished, we shall find that the latter is greatly inferior; for in six minutes five hundred and thirty strokes of the piston may be given, which would furnish only thirty-six pints of water; this pump, therefore, would not furnish the eighth part of the water which it ought to do upon the common principles of the sucking pump; so that though the construction might appear to be more ingenious, it was not in reality to be preferred to that of Seville.

The *compound forcing pump* is composed of the body of the pump G H, (Plate VIII. Fig. 2.) open above, and the aspiration pipe H V adapted to the lower end. At the union of this pipe with the body of the pump

is a sucker S, designed for the same use as in the simple sucking pump. In the body of the pump is a piston M, not pierced as the preceding, but solid, and put in action by the aid of the rod \times X, and of the lever Y X Z, which has its point of support, or fulcrum, at Z. At the side of the pump, and towards the bottom of its body, is adapted a raising pipe H R, furnished with a sucker s near its base, and with a spout R near its superior extremity. This pump ought to be placed in such a manner that the lower extremity only of the aspiration pipe H V should be immersed under water.

It is easy to perceive that the first action of this pump will be the same as that of the sucking pump, which has been described; for if the piston M is raised by putting the lever Y X Z in the situation $y u Z$, the column of air which rests above will be elevated; the air which is in the aspiration-pipe will become, by that means, rarer than the exterior air. The latter then presses more forcibly upon the surface of the water A A, and carries it, after some strokes of the piston, into the body of the pump; when it is arrived there, if the piston M is lowered, the sucker S will close, and the water is forced along the raising-pipe H R, by the rising of the sucker s, which, as soon as the pressure ceases, falls again from its own weight and that of the water above it.

This pump is very convenient, on account of its body being placed out of water, which affords an opportunity of making the necessary repairs with facility, and also on account of its being capable of carrying water to any height which may be required: in order to effect this, all that is necessary is, to lengthen the raising-pipe, and to augment the power which puts
the

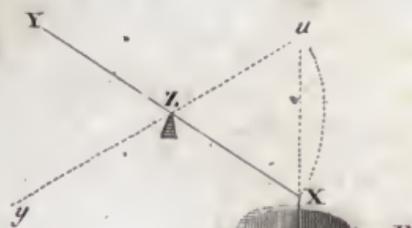
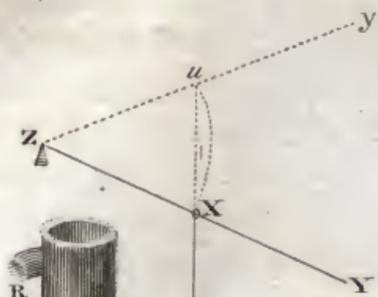
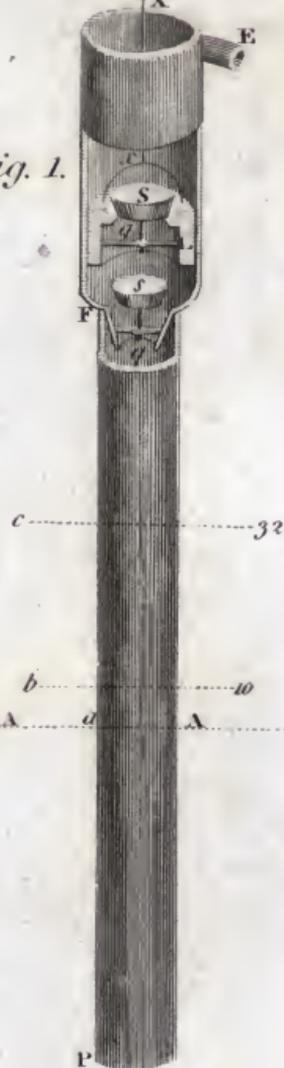
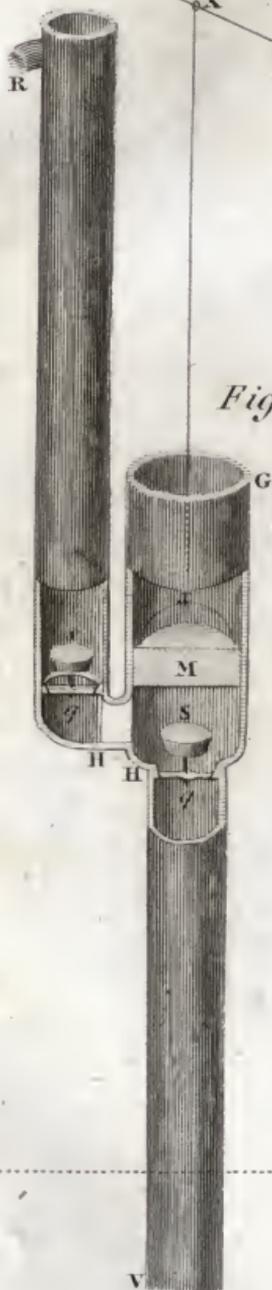


Fig. 1.

Fig. 2.





the pump in action. I believe this is at present the most usual form of what are called forcing pumps in this country.

The fire engine is an hydraulic engine, which may be classed with the pump that I have now described. It is at once a sucking and forcing pump, but has a continued *jet*, or ejecting pipe, though it has only one body. The essential parts of this pump are composed, like the compound pump, (Plate VIII. Fig. 2.) with this difference, that its aspiration pipe is much shorter, and that instead of a solid raising pipe it has a leathern tube of a convenient length. This pump (Plate IX. Fig. 1.) is then composed of the body of the pump A H, open above, and to the lower part is adapted the aspiration pipe H T. At the union of this pipe with the body of the pump is placed a sucker S, designed to prevent the water, which has once passed into the body of the pump, from returning into the basin. In the body of the pump is a piston M, not pierced but solid, and which is put in motion by the aid of a metal rod x X, and of a lever Y X Z, which has its fulcrum or point of support at Z. Towards the bottom of the pump, in the side, is an aperture C, which is covered again by means of a valve c l, of which the tail l is a spring, and which is fixed on with a small screw. This valve is designed to prevent the water, which is expelled from the body of the pump, from entering again when the piston M is raised. The body of the pump is surrounded with a pipe A B D E, about two or three inches more in diameter than the body of the pump, and the intermediate space between them is filled with air. To the lower part of this pipe, and upon the side, is adapted another small crooked pipe E R, furnished at the end R with a sucker s , and with
a screw

a screw ferule, intended to receive a nut, by means of which the leathern pipe is joined to this end of the engine, and which serves instead of the raising pipe in the common forcing pump. All this apparatus is placed (as may be seen in Plate IX. Fig. 2.) upon a box or case *NO* lined with lead, which contains the water. The cross bar *Q* supports the upper end *F* (Fig. 1.) of the body of the pump, which, for that purpose, is of a smaller diameter than the rest; and the lid *L* (Fig. 2.) of the box has an aperture in the middle, to admit the aspiration pipe *HT* to pass through it.

From this explanation it will be evident, that if the piston *M* is raised up by putting the lever *Y X Z* in the situation *y u Z*, the sucker *s* and the valve *c*, placed at *C*, will be closed by the pressure of the exterior air. This same pressure, exercising its force upon the surface of the water *V V*, obliges it to pass into the body of the pump by raising up the sucker *S*. It then acts as a sucking pump; but when the piston *M* is lowered, its pressure closes the sucker *S*, and opens the valve which is at *C*; the water then passes, not only into the leathern pipe *abcd*, (Fig. 2.) by raising up the sucker *s* (Fig. 1.) but also into the space between the body of the pump and the pipe which incloses it, by rising towards *I K*, and compresses the air which is confined there. Immediately after the piston *M* is raised again, that air, being no longer compressed, unfolds itself by its elasticity, acts upon the water which is between the body of the pump and the pipe which inclosed it, and forces it also into the leathern pipe, so that when the piston is lowered, the water is forced by the piston itself, and when it is raised, the water is forced by the elasticity of the air, which furnishes a continued stream, though the pump has only one body or principal tube,

It is evident that these fire engines should be able to furnish a continued stream, and this can only be effected by employing the elasticity of the air, while the piston is rising; but in order to effect this, a double force is required to put the pump in motion; in other words, a force capable of expelling the column of water, and an equal force to compress the air. But this is not an inconvenience, for, in case of fire, it very seldom happens that hands are wanting to assist; on the contrary, it frequently happens that the assemblage of people is rather too numerous.

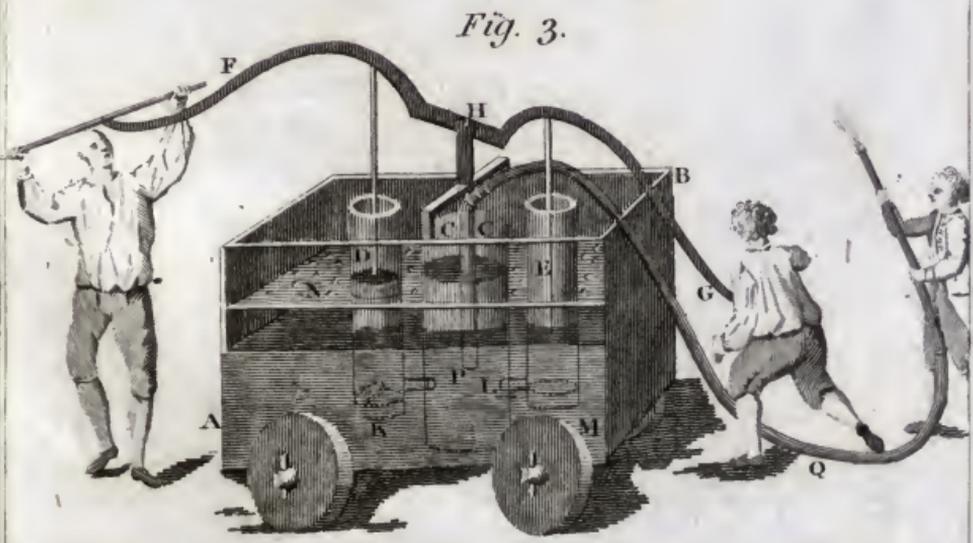
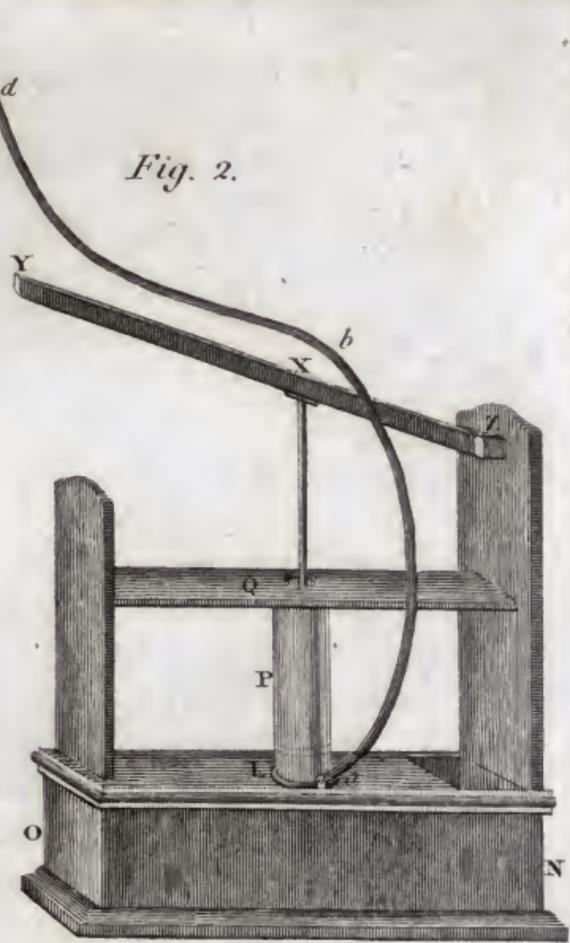
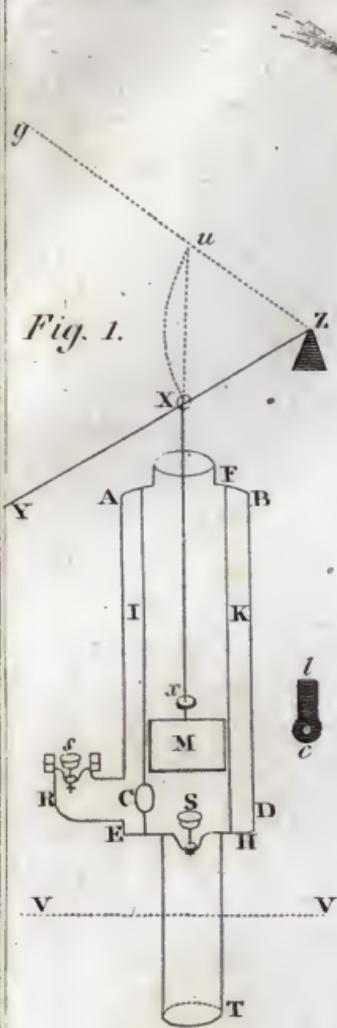
Such is the engine which M. Briffon has described, and it is, I presume, that which is in common use in France. Its simplicity is admirable; yet I apprehend that our English fire engines are more powerful, and furnish a more uninterrupted stream or current of water through the leathern pipe. In Fig. 3. is a representation of our improved fire engine. This, the reader will see, is wrought by two forcing pumps, which act alternately; and the stream is made continual from the spring of air confined in a strong metal vessel C C, in the fire engine A B, fixed between the two forcing pumps D and E, wrought with a common double lever F G moving on the center H. The pistons in D and E both suck and force alternately, and are here represented in their different actions, as are also the respective valves at I K and L M.

The water to supply this engine, if there is no opportunity of putting the end of a sucking pipe, occasionally to be screwed on, into a moat or canal (which would spare much hurry and labour in case of fire) is poured into the vessel A B; and being strained through the wire grate N is, by the pressure of the atmosphere, raised through the valves K and M into

the

the barrels of D or E, when either of their forcers ascend; whence again, upon their descent, it will be powerfully propelled into the air-vessel C C, through the valves I and L by turns: the common air then between the water and the top of the air-vessel C C will from time to time be forcibly crowded into less room, and much compressed; and the air being in that condensed state possessed of a strong and lively spring, and always endeavouring to dilate itself every way equally in such a circumstance, bears strongly both against the sides of the vessel wherein it is confined, and the surface of the water thus injected; and thus produces a constant regular stream, which rises through the metal pipe P into the leather one Q, and this latter being perfectly flexible, may be led about into rooms and entries, as the case may require.

Should the air contained in this vessel be compressed into half the space it took up in its natural state, the spring of it will be nearly doubled; and as before it equalled and was able to sustain the pressure of the atmosphere, since it has now a double force, by the power of that spring alone it will throw water into air of the common degree of density about thirty feet high. And should this compressure be still augmented, and the quantity of air, which at first filled the whole vessel, be reduced into one-third of that space, its spring will be then able to resist, and consequently to raise the weight of a treble atmosphere; in which case it will throw up a jet of water sixty feet high. And should so much water again be forced into the vessel as to fill three parts of the capacity, it will be able to throw it up about ninety feet high: and wherever the service shall require a still greater rise of water, more water must be forced into this vessel; the air therein being thus driven by force into a still narrower





rower compass, at each explosion, its gradual restitution to its first dimensions is what regularly carries on the stream between the strokes, and renders it continual during the operation of the machine.

Various agents are employed to put pumps in action, such as men, horses, streams of water, vapour, wind, &c. Small pumps, such as those in common wells, or fire engines, are generally wrought by men. When a considerable quantity of water is required to be raised, the moving power must be increased; and in order that a regular effort may be employed, or very nearly so, several additions are occasionally made to the mechanism of pumps, so that when one set of pistons descend another set may be made to rise by the same force. The great engine at Marli is wrought by an apparatus of this kind.

The action of these engines depends upon the regularity of the alternate motion of the suckers or valves. It follows then, that these should be so constructed and disposed as perfectly to retain the water when they are closed, and to open easily when the action of the machine is directed to that object.

V. Of the motion of water in conduit pipes.

When it is required to conduct water from one place to another, it is very clear that the conducting pipes must be longer than the space through which it is to be conveyed.

In treating of the discharge of water through additional pipes, I have taken but a cursory notice of the resistance by friction, because there it is scarcely perceptible; but it is not the same with respect to pipes of considerable extent; the friction of the water against their sides lessens considerably the velocity of the flowing

ing water, as has been proved by experiments. I shall first speak of rectilinear pipes.

In the following experiments two pipes were employed, one of an inch and a quarter diameter, and the other of two inches. The two pipes were successively lengthened from thirty feet to one hundred and eighty; and the constant height of the water in the reservoir, above the pipes, was sometimes one foot, and sometimes two.

The following table shews the results of these experiments:

The constant height of the water in the reservoir above the pipe, in inches.	The distance to which the water was conveyed, expressed in feet.	The number of cubic inches of water furnished in one minute, by a pipe of an inch and a quarter diameter.	The number of cubic inches of water furnished in one minute by a pipe of two inches diameter.
1	30	2778	7680
1	60	1957	5564
1	90	1587	4534
1	120	1351	3944
1	150	1178	3486
1	180	1052	3119
2	30	4066	11219
2	60	2888	8190
2	90	2352	6812
2	120	2011	5885
2	150	1762	5232
2	180	1583	4710

If, by the aid of the table of additional pipes, which has been before inserted, we should wish to find the quantity of water discharged by two additional pipes of one inch and one-third and two inches diameter, under the same height of the reservoir, and without having any regard to friction, but only to the areas of the

the orifices of the pipes, it will be found, that during one minute,

1. The height of the reservoir being one foot, the pipe of one inch and one-third diameter, in this case there will be discharged six thousand two hundred and ninety-two cubic inches of water.

2. The height of the reservoir being two feet, the same pipe will furnish eight thousand eight hundred and ninety-three cubic inches of water.

3. The height of the reservoir being one foot, and the pipe two inches in diameter, there will be discharged fourteen thousand one hundred and fifty six cubic inches of water.

4. The height of the reservoir being two feet, the same pipe will furnish twenty thousand and eight cubic inches of water.

It is easy to perceive, that these quantities of water are much greater than the corresponding quantities in the above table; and that the quantity furnished by each pipe diminishes, in fact, in proportion to its length, because there is then a greater surface of friction. But it must be remarked, that the diminution of the quantity of water discharged is not exactly in proportion to the length of the pipe. The discharge is indeed diminished as the pipe is made longer; but this diminution decreases (if I may use the expression) in the progress of the current; for the first thirty feet the discharge is diminished much more than in the second thirty feet; and the third augmentation of thirty feet to the length diminishes the discharge still less than the second; and so of the rest. The result of all this is, that in common practice, where great precision is not required, it may be laid down as a rule, that the quantities of water discharged in equal times, through the same horizontal pipe, under the same height of the reservoir,

reservoir, and at different distances from the source or reservoir, are to each other nearly in an inverse proportion of the square roots of these distances.

It may be observed from the preceding table, that a pipe of one inch and one-third diameter furnishes less water in proportion than one of two inches diameter, under the same height of the reservoir, and of the same length. The reason of this is, because there is, relatively to the quantities of water which these pipes will contain, more surface of friction in the small pipe than in the larger one.

If the same pipe was curvilinear instead of being strait, the discharge would still be diminished from this circumstance, though not in any considerable degree; but the diminution would be still greater if the curvilinear pipe was placed in a vertical instead of a horizontal position. The diminution (small as it is) is produced by the resistance which the water meets in running against the angles of the pipe, which deprive it of a part of its velocity.

But if the pipe, instead of being curvilinear, was angular in several points, the diminution would be greater, and the more so in proportion as those angles should be more acute, because then the resistance to the water would be more direct. When the pipes are curved, and their curvature vertical, as in Plate X. Fig. 1. there are then declivities and ascents in which the air will lodge, and resist or even impede the course of the water. For example, let A B C D E F G be a pipe, the upper extremity of which A answers to a reservoir which supplies it with water, and the extremity G goes to furnish a fountain. The pipe being filled with nothing but air, and water being made to run from A, this water will drive the air before it, and fill the portion of the pipe A B more than the portion

B C;

BC; the water having arrived at the bending C, will flow down the lower part of this bending, and will proceed to fill the bending D, leaving behind it the column of air CD, which cannot escape. The water, continuing to run, will rise from D to E, and having arrived there, it will still flow down the lower part of this declivity to fill the bent F, leaving behind it a second column of air EF, which will remain confined there, notwithstanding the pressure of the column AB; for the column of air CD cannot counterbalance the pressure of the column of water DE, any more than the column of air EF is capable of counterbalancing the column of water FI; so that though the water in the pipe AB is considerably above the level G, the water can only rise towards I, and there ceases to flow. The only remedy is, to let out the two columns of air CD and EF, by placing at the elbow of the bendings two small pipes C and E, through which the air may escape, and when the course of the water is well arranged the apertures may be closed with bungs.

VI. Of the oscillatory motion of water in a siphon.

It is well known that the duration of the oscillations of two pendulums of unequal lengths are to each other as the square roots of those lengths. The oscillatory motion of water in a siphon is of the same nature.

Suppose a siphon (Fig. 2.) composed of three branches, two vertical ln, mo , and one horizontal no ; suppose that the interior diameter of the siphon is equal through its whole extent; that in this siphon, the fluid, in a state of rest, occupies the space $anod$; then the two surfaces ab, cd , are upon a level. Suppose then, that, by some cause, the liquid is forced to descend to gb , in the branch mo , and consequently to elevate itself to

ef, in the branch *ln*; as soon as this cause ceases to act, the fluid will be operated upon merely by the common laws of gravitation and motion. The excess of the length of the column *en*, above that of the column *bo*, will force the fluid to descend, and that even below the level of the other, on account of the acceleration of its descent, which will cause the fluid in the other branch *mo* to rise; the fluid will then descend and ascend alternately, or in oscillations similar to those of a pendulum; and the deviation of each of these oscillations will be precisely the same as that of the oscillations of a pendulum half as long as the length *pqr* of the column of the fluid.

Since the oscillations of water follow the same law as those of a pendulum, it follows, that if the length of the column of water is augmented or diminished, the duration of each oscillation will be augmented or diminished.

VII. The oscillatory motion of water in waves has been compared by Sir Isaac Newton * to the oscillatory motion of water in a siphon.

Let *ABCDEF* (Fig. 3.) be supposed a sheet of water, the surface of which rises and falls in successive waves; let *ACE* be the tops of these waves, and *BDF* the intermediate hollows or concavities, which separate them. As the waves are formed by the successive ascent and descent of the water in such a manner that the higher parts become the lower, and so alternately and successively, and as the weight of the elevated water is the moving power which causes the lowest parts to ascend and the highest to descend, these alternate risings and fallings are considered as ana-

* Principia, lib. 2. prop. 46.

logous to the oscillatory motion of water in a siphon, and they observe the same laws relative to their duration.

If there is then a pendulum, the length of which is equal to half the transversal distance that exists between the top or apex of a wave A (for example) and the cavity B, that is equal to half $A b$, the highest parts will become the lowest in the same space of time in which this pendulum vibrates, and in the space of another oscillation they will again become the highest. Each of these waves then will roll its whole course during the time which the pendulum takes in performing two oscillations; and as a pendulum four times the length of the preceding, that is, the length of which is equal to the width of the wave $A C$, will make only one oscillation, while the first makes two, it follows, that the waves perform their oscillations in the same space of time as a pendulum equal in length to the width of the same waves would perform its oscillations. What is meant by the width of waves, is the transversal space $A C$, which is between their greatest elevations, or the space $B D$, which is between their greatest concavities.

It follows from these premises, that waves, which are about three feet and three quarters of an inch wide, roll their whole width during a second of time, and consequently they roll one hundred and eighty-three feet six inches and five-sixths in a minute, and in an hour eleven thousand and fourteen feet two inches; waves four times as wide will roll this space in twice the time; it follows then, that the wider or more expanded the waves are, the greater will be the space which they roll over in a given time.

But what has now been stated respecting the motion

of waves, is founded upon this hypothesis, that all the parts of the water rise and fall in right lines; yet it must be observed, that both their rise and fall are more frequently made in curved lines than in strait ones; so that the determination given above respecting the space which waves roll over in a given time may be regarded only as an approximation to the truth.

VIII. The motion of wheels acted upon by the fall or force of water, though strictly a branch of mechanics, is yet intimately connected with the science of hydraulics.

The wheels of some water-mills are furnished with wings, float-boards, or shelves, at their circumference, with very little or no concavity; others are furnished with a kind of ladles or boxes, which will contain a considerable quantity of water. In the first case, the water acts upon the wheels principally by its shock or fall; in the second, by its weight. I shall first speak of wheels moved by the shock of the water.

It has been proved by experience, that the more numerous the wings or float-boards are in proportion to the diameter of the wheel, the faster it moves. To wheels of twenty feet diameter, there are commonly placed about forty float-boards; but a greater number, as for example forty-eight, would be still more advantageous. To the wheels of those mills which are raised upon boats or rafts in rivers, there are usually only eight or ten floats; but these wheels would have more effect if they had fifteen or sixteen.

When a wheel with wings or float-boards turns in a kind of frame or case, so as to prevent the water from falling immediately into the general current, the impulse which it receives from the water is about

one-fifth greater in proportion to the velocity of the fluid, than it would receive in an unconfined stream, because in the latter case the water which abounds is turned behind the float, and resists it; on the contrary, when the wheel moves in a frame, there is only a small quantity of water, which moves with as much velocity, or with rather more, than the float-board.

It has been proved by experience, that when this case or frame is but just wide and deep enough to admit the wheel to move freely, and the water has an opportunity of running out after having given its shock or impulse, the direct and perpendicular force against the floats of the wheel is about twice the force which the float would receive if it was plunged to the same depth in an unconfined current.

When a wheel furnished with forty-eight floats turns in a case or frame, and it is not plunged very deep in the water, its circumference will have about two-fifths of the velocity of the current, in which case the machine will produce the greatest effect.

It appears that float-boards are the most advantageous when they are placed in a direct line towards the center of the wheel; because but few of them would be required, since they would then be struck perpendicularly by the water, which produces the most powerful effect. When they incline, the shock is oblique, which diminishes the effort; yet a certain degree of inclination causes the water to rise the length of the float, and to remain there a certain time; it then acts by its gravity after having acted by its shock or fall, and the effect which results from this arrangement more than compensates for the diminution which the shock suffered from the obliquity with which the force was applied in the first instance. In general, the wheels placed in frames which have a cer-

tain declivity should have their floats or buckets inclined so much towards the radius as to cause them to be struck in a more perpendicular direction, that they may receive an augmentation of force from the weight of the water. The most advantageous inclination of the floats towards the radius appears by experience to be between twenty and thirty degrees.

A wheel placed near a reservoir turns swifter than in any other place, because then the whole force of the descending fluid is effectually applied; but if there is a necessity for placing it at the end of the water-course, at a certain distance from the reservoir, the channel of the water-course or frame should incline about the tenth part of its length, so that the sloping may give to the water that degree of velocity which would otherwise be destroyed by friction; the wheel will then receive the same impulse as if it was placed close to the reservoir.

Water acting by its weight produces a much greater effect than when it acts by its shock in falling. M. Parent, in the year 1704, and M. Pitot, in 1725, indeed demonstrated, that a wheel (supposed to be without friction) moved by a current of water, and designed to elevate a portion of that water to the height of that which puts it in motion, is incapable of elevating it higher than $\frac{4}{27}$ or $\frac{1}{7}$ nearly; whereas the water acting upon the wheel by its own weight would be capable of elevating to the height from which it descended half of the water which descended.

When, therefore, we have only a small quantity of water, and are obliged to husband it well (which often happens, because there are more small streams than large rivers) we should contrive to make this water act by its weight rather than by its shock or impulse; for this purpose, instead of having wheels with plain

float-boards, they should be furnished with concave or hollow ones resembling buckets, whenever we can have a fall of more than four feet, and especially where there is not the necessary quantity of water to turn a mill with wheels, furnished with plain float-boards.

M. Deparcieux, in the *Memoirs of the French Academy of Sciences**, has proved, that the flower wheels with buckets move, the more will be their effect with an equal expence of water. He made a small wheel of twenty inches diameter, the circumference of which was furnished with forty-eight buckets. Upon the axis of this wheel were placed four cylinders of different sizes; the least was one inch in diameter, the next two inches, the third three inches, and the fourth was four inches in diameter. These cylinders were different axes, about which a cord, which elevated a weight by means of a returning pully placed above the machine, wrapped itself. The axis of the wheel was supported at each end by two rollers easily put in motion; this was to diminish the friction. To the fore part of the wheel, and a little higher than its axis, was attached a small shelf, upon which was placed a vessel with a hole pierced in it on that side towards the wheel, which was filled with water. Above this vessel was placed a large bottle full of water inverted, and the neck of it was plunged a few lines in the water of the vessel, in order that the bottle should only empty itself in proportion as the water in the vessel ran through the aperture. The water in flowing fell into a channel which carried it into the buckets of the wheel. By this means he made sure of employing, at each experiment, always the same quantity of water.

* For the year 1754, page 603 and 671.

The following table contains the results of the experiments made by M. Deparcieux. He sometimes elevated weights of twelve ounces, and sometimes of twenty-four ounces: the heaviest, resisting the most, compelled the wheel to turn slower. He wrapped the cords which supported the weights successively round the different cylinders, and found that the same weight resisted more in proportion as its cord was wrapped round a larger cylinder.

Diameter of the cylinders.	Elevation of a weight of 12 ounces.	Elevation of a weight of 24 ounces.
1 Inches.	69 $\frac{1}{2}$ Inches.	40
2	80 $\frac{1}{2}$	43 $\frac{1}{2}$
3	85 $\frac{1}{2}$	44 $\frac{1}{2}$
4	87 $\frac{3}{4}$	45 $\frac{1}{4}$

When the cord was wrapped round a larger cylinder, or the elevated weight was more considerable, the wheel turned slower. It appears from these results, that the same weight was carried so much higher according as its cord was wrapped round a larger cylinder. It appears also, that double the weight, which retarded the rotation still more, was carried to more than half of the height to which the single weight was carried; in that case, therefore, the effect was greater.

It may be laid down as a principle, that water acts by its weight much more forcibly from the same height or fall, than by its impulse; and that the slower wheels with buckets move, the greater, with the same expence of water, will be their effect. This augmentation of effect is caused by the same quantity of water acting longer, while the wheel moves with less velocity.

C H A P. IV.
OF THE OCEAN.

Saltnefs of the Ocean.—Different Opinions as to the Cause.—Probable Reasons why the Sea has been always falt.—Temperature of the Sea at different Depths.—Modes of rendering Sea-water fresh.

THE greatest quantities of water with which we are acquainted are by no means pure, but united with saline matter. The ocean is falt in all parts of the world; but the degree of saltnefs differs much in different climates, and is almost universally found to be greater in proportion as the water is taken up nearer the equator, where the heat of the sun is greatest, and the evaporation of the watery particles consequently more considerable. When treating of sea falt, the result of various observations relating to this subject were detailed.

The cause of the saltnefs of the ocean has been a subject of investigation among philosophers in almost all ages, but it still remains in great obscurity. There can be little doubt, that a large quantity of saline matter existed in this globe from the creation; and, at this day, we find immense beds of sal gem, or common falt, buried in the earth, particularly near Cracow; but whether these collections have been derived from the ocean, and deposited in consequence of the evaporation of its waters in certain circumstances, or whether the ocean was itself originally fresh, and received its salt from collections of saline matter situated at its bottom, or from that brought by the influx of rivers, cannot now be ascertained. No accurate observations

on the degree of saltness of the ocean in particular latitudes were made till the present century, and it is not possible, therefore, to ascertain what was the *state* of the sea at any considerable distance of time, nor, consequently, whether its degree of saltness increases, decreases, or is stationary. From differences among aquatic animals, however, some of which seem adapted to salt water, and some to fresh, it is probable, that both these states of water existed from the creation of the world. We know it is true, that some kinds of fish, as salmon, are capable of existing both in fresh and in salt water, and that habit has a powerful influence over all animals; but this is not sufficient to refute the main fact, that some kinds of fish thrive only in salt water, others in fresh; some in standing pools, and others in rapid currents.

That excellent philosopher and chemist, to whose labours I am indebted for some of the most valuable parts of these volumes, the bishop of Landaff, has recommended a most simple and easy mode of ascertaining the saltness of the sea in any latitude; and as the language, in point of perspicuity and correctness, cannot be improved, I shall take the liberty of inserting it in his own words.

‘As it is not every person who can make himself expert in the use of the common means of estimating the quantity of salt contained in sea water, I will mention a method of doing it, which is so easy and simple, that every common sailor may understand and practise it, and which at the same time, from the trials I have made of it, seems to be as exact a method as any that has yet been thought of.—Take a clean towel or any other piece of cloth, dry it well in the sun or before the fire, then weigh it accurately, and note down its weight; dip it in the sea water, and, when taken out,

wring

wring it a little till it will not drip, when hung up to dry; weigh it in this wet state, then dry it either in the sun or at the fire, and, when it is perfectly dry, weigh it again. The excess of the weight of the wetted cloth above its original weight, is the weight of the sea water imbibed by the cloth; and the excess of the weight of the cloth, after being dried, above its original weight, is the weight of the salt retained by the cloth; and by comparing this weight with the weight of the sea water imbibed by the cloth, we obtain the proportion of salt contained in that species of sea water.

‘Whoever undertakes to ascertain the quantity of salt, contained in sea water, either by this or any other method, would do well to observe the state of the weather preceding the time when the sea water is taken out of the sea, for the quantity of salt contained in the water near the surface may be influenced both by the antecedent moisture and the antecedent heat of the atmosphere*.’

Whether the sea is saltier or not at different depths has not yet been ascertained; but that its temperature varies considerably in proportion to the depth we have decisive proof.

‘With respect to the temperature,’ says bishop Watson, ‘of the sea at different depths, it seems reasonable enough to suppose, that in summer time it will be hotter at the surface than at any considerable depth below it, and that in winter it will be colder. Suppose a cistern, twelve feet in depth, to be filled with spring water of 48 degrees warmth, to the height of eleven feet; then, if we fill up the cistern to its top, by gently pouring water heated to 100 degrees upon the surface

* Watson’s Chemical Essays, vol. ii. p. 116.

of the spring water, it may readily be understood, that the heat of this water will not be instantaneously communicated through the whole mass of water in the cistern, but that the water will decrease in heat from the surface to the bottom of the cistern. On the other hand, if on the 11 feet of spring water heated to 48 degrees, we pour a foot of water heated only to 33 degrees, it may be expected, that the spring water, which is nearest to the cold water, will be sooner cooled by it than that which is at a greater distance; and on this account the water at the bottom of the cistern will be warmer than that in the middle or at the top. It must be observed, however, that cold water being, bulk for bulk, heavier than hot water, the water which has only 33 degrees of heat will descend, by its superior weight, into the mass of water contained in the cistern, and thus the water in the cistern will be cooled, not only by the bare communication of cold from the upper water, but by the actual mixture of that water with the rest, so that the difference between the heat of the water at the bottom and top will not be so great as it would have been if the cold water had not mixed itself with the rest. These suppositions of hot and cold water incumbent on the spring water in the cistern, are analogous to the action of the summer and winter atmospheres incumbent on the surface of the sea. No person, who has bathed in deep standing water in summer time, can have failed to observe, that the water grew colder and colder, according to the depth to which he descended. I have frequently observed, that the surface of a pool of water of two feet in depth, has in a sunny day, even in winter, been five degrees hotter than the water at its bottom.

Mr. Wales describes the instrument he made use of for trying the temperature of the sea at different depths,

depths, in the following terms: "The apparatus for trying the heat of the sea water at different depths consisted of a square wooden tube of about 18 inches long and three inches square externally. It was fitted with a valve at the bottom, and another at the top, and had a contrivance for suspending the thermometer exactly in the middle of it. When it was used it was fastened to the deep sea line, just above the lead, so that all the way as it descended the water had a free passage through it, by means of the valves which were then both open; but the instant it began to be drawn up, both the valves closed by the pressure of the water, and of course the thermometer was brought up in a body of water of the same temperature with that it was let down to*." With this instrument, which is much the same with one formerly described by Mr. Boyle, in his observations about the saltness of the sea, water was fetched up from different depths, and its temperature accurately noticed, in different seasons and latitudes.

' August 27, 1772, south latitude $24^{\circ}. 40'$. The heat of the air was $72\frac{1}{2}$,—of the water at the surface 70,—of water from the depth of 80 fathoms 68 †.

' December 27, 1772, south latitude $58^{\circ}. 21'$. The heat of the air was 31,—of the water at the surface 32,—of water from the depth of 160 fathoms $33\frac{1}{2}$ ‡.

' In the voyage to the high northern latitudes before mentioned, they made use of a bottle to bring up water from the bottom, which is thus described.

* See *Astronomical Observations made in a Voyage towards the South Pole, &c. in 1772, 1773, &c. by W. Wales. Introduction, p. 53.*

† *Wales's Obser. p. 206.*

‡ *Ibid. p. 208.*

“ The bottle had a coating of wool, three inches thick, which was wrapped up in an oiled skin, and let into a leather purse, and the whole inclosed in a well-pitched canvas bag, firmly tied to the mouth of the bottle, so that not a drop of water could penetrate to its surface. A bit of lead shaped like a cone, with its base downwards, and a cord fixed to its small end, was put into the bottle; and a piece of valve leather, with half a dozen slips of thin bladder, were strung on the cord, which, when pulled, effectually corked the bottle on the inside.” I have here put down two of the experiments which were made during that voyage.

‘ August 4, 1773, north latitude $80^{\circ}.30'$. The heat of the air was 32,—of the water at the surface 36,—of water fetched up from the depth of 60 fathoms under the ice 39*.

‘ September 4, 1773, north latitude 65° . The heat of the air was $66\frac{1}{2}$,—of the water at the surface 55,—of water from the depth of 683 fathoms 40.

‘ It appears from all these experiments that, when the atmosphere was hotter than the surface of the sea, the superficial water was hotter than that at a great depth; and when the atmosphere was colder than the surface of the sea, it is evident that the superficial water was somewhat colder than that at a considerable distance below it: and I doubt not that this will generally be the case, though sudden changes in the temperature of the atmosphere, which cannot be instantly communicated to the sea, may occasion particular exceptions.

‘ In the year 1779, several experiments were made, with great accuracy, in order to investigate the tem-

* Voyage towards the North Pole, p. 143.

perature of the lake of Geneva, and of other lakes in Switzerland, at different depths; we learn from them, that in winter time there is very little difference between the heat of the water at the surface, and at a great depth below it; but that in summer, the superficial water is considerably warmer than that which is at a great distance from the surface. The experiments were made with a thermometer graduated after Reaumur's scale; some of them, reduced to Fahrenheit's scale, are expressed below.

‘ Temperature of the lake of Geneva at different depths, in the beginning of February 1779, after a month's uninterrupted frost.

‘ Heat of the open air variable from 37 to 40 degrees.

‘ Water at the surface of the lake	-	-	42 $\frac{1}{8}$
Depth 100 feet	-	-	42 $\frac{1}{8}$
Depth 250 feet	-	-	42 $\frac{1}{8}$
Depth 950 feet, bottom	-	-	41 $\frac{2}{8}$ $\frac{1}{10}$

‘ In another part of the lake, open air from 37 to 40.

Surface	-	-	-	42 $\frac{1}{8}$
Depth 350 feet	-	-	-	42 $\frac{2}{8}$
Depth 620 feet, bottom	-	-	-	41 $\frac{2}{8}$ $\frac{7}{10}$

‘ Temperature of the lake of Neuchâtel, July 17, 1779.

Air	-	-	-	75 $\frac{1}{5}$
Surface	-	-	-	73 $\frac{5}{8}$
Depth 225 feet, bottom	-	-	-	41*.

Sea water may be rendered fresh by freezing, which excludes or precipitates the saline particles, or by distillation, which leaves the salt in a mass at the bottom

* Watson's Chemical Essays, vol. ii. p. 129.

of the vessel. Upon these principles, a mode of obtaining a supply of fresh water at sea was recommended some years ago to the Admiralty, by Dr. Irving. It consisted in only adapting a tin tube of suitable dimensions to the lid of the common ship's kettle, and condensing the steam in a hoghead which served as a receiver. By this mode a supply of twenty-five gallons of fresh water per hour might be obtained from the kettle of one of our ships of war. I have not understood, however, that the plan has been as yet introduced into general practice.

C H A P. V.

O F R A I N.

Recapitulation of Doctrines relative to spontaneous Evaporation.—Vapour by some supposed to consist of hollow Vesicles.—Rain.—Different Theories of Rain.—Snow.—Hail.—Rain which froze in coming in contact with the Earth.—Large Hail-stones.—Fogs.—Dew.—Hoar Frost.—Instances of partial freezing when the general Temperature is above the freezing Point.

IN a preceding volume, when treating of the effects of heat or fire, and particularly of vapour, it was necessary to introduce a few observations relative to spontaneous evaporation. It is proper, however, to repeat, in this place, that philosophers are by no means agreed with respect to the cause of this phenomenon. By some it has been attributed to a solution of water in air similar to that of saline substances in water; by others, to the action of the electric fluid. The first of these opinions had till lately obtained almost universal assent, but is now relinquished, since it is found that evaporation proceeds, as well in the exhausted receiver of the air pump, as when air is present. Electricity has been found to promote evaporation, and clouds are almost universally electrical; but evaporation is carried on continually where there is no reason to suppose the presence of the electric fluid, at least where its operation cannot be discovered by any known test. It is at present commonly supposed, that redundant heat is the general cause of the evaporation of water, and that it always proceeds in proportion to its

temperature, compared with that of the surrounding medium.

There is one circumstance very much in favour of the opinion, that the emission of heat is the chief cause of evaporation, which is, that every liquor cools when it evaporates, because the portion of the fluid which disappears carries away a quantity of caloric from the liquor, which becomes latent in the vapour.

A doubt has arisen among philosophers, whether water, as it exists in a transparent state in the atmosphere, is in particles of an uniform density, or assumes the form of hollow vesicles. When there is a tendency to rain or snow, it is known to exist in the state of minute drops and icicles; but the solution is then not perfect, its transparency is impaired, and clouds are produced.

The existence of hollow spheres is said to have been actually observed by several persons; but as a microscope of considerable magnifying power must be employed, this may have been a source of error, and may have produced delusive appearances. The simplest and most instructive manner of observing them is to expose a cup of some warm aqueous fluid, of a dark colour, as coffee, or water mixed with ink, to the rays of the sun in a fine day, when the air is very calm; a cloud will rise from the fluid to a certain height, and then disappear. An attentive eye will soon discover that this cloud consists of small round grains, of a whitish colour, and detached one from the other. To acquire a more distinct idea of their form, they may be observed, as they rise from the surface of the liquor, with a lens of about one inch and an half focus, being careful, however, to keep the lens out of the vapours, that they may not deprive it of transparency.

Spherical

Spherical balls of different sizes may in this manner be observed proceeding from the surface with more or less rapidity. The more delicate rise swiftly, and soon traverse the field of the lens; the larger fall back into the cup, and, without mixing with the fluid, roll upon its surface like a light powder, which obeys every impulse of the air. The lightness of these small spheres, their whiteness, &c. give them an appearance altogether different from solid globules; their perfect resemblance to the larger balls, that are seen floating on the surface of the liquid, can leave no doubt of their nature: it is sufficient to see them to be convinced that they are hollow bubbles, like those blown from water and soap. M. Kratzenstein endeavoured to estimate their size, by comparing them with a hair, and found that they were twelve times smaller than the hair, the diameter of which was the three hundredth part of an inch, and consequently one of these was only the three thousand six hundredth part of the same measure.

These bubbles may even be sometimes, it is said, observed in a fog, or in a cloud, when the observer is situated on a hill. To this end M. de Saussure used a lens of one and an half or two inches focus, which he held near his eye with one hand, in the other he held any smooth, flat, and polished surface, of a black colour, as the bottom of a tortoise shell box, bringing this towards the lens till it was very near the focal distance; he then waited till the agitation of the air brought some particles of the cloud into the focus of the lens; when the cloud was thick this soon happened, and he perceived round and white particles, some passing with the rapidity of lightning, others moving slowly; some rolling on the surface of the tortoise shell, others striking against it obliquely, and

rebouncing like a ball from a wall, and others fixing themselves to it. Small drops of water might also be seen to settle on the tortoise shell, but they were easily distinguished from the hollow spherules, by their transparency, their gravity, and their pace. Further, clouds do not form a rainbow; it is produced by solid drops; when a cloud is not in an actual state of resolution, it does not change the form of the stars which are seen through it; for infinitely thin meniscusses do not sensibly change the course of the rays of light; but as soon as the cloud begins to resolve itself into solid drops, or even without clouds, when solid drops begin to be formed in the air, the stars seen through them are all defined, surrounded with a diffuse light, circles, and halos; hence, these meteors are the forerunners of rain, for rain is nothing more than these drops augmented, or united. When the vesicular vapours are condensed by cold, the water which formed the bubble crystallizes, sometimes into hoar frost, sometimes into snow; when it does not freeze, they unite in dew, or descend in rain. Many other curious properties concerning the vesicular and concrete vapours are related in M. de Saussure's *Essai sur l'Hygrometrie* *.

The precipitation of water from the atmosphere in rain has given rise to as much speculation as evaporation; and it must be confessed, that the cause of neither has yet been very clearly ascertained. By some it is supposed, that the capacity of the air for suspending aqueous vapour is in proportion to its heat, and therefore that any circumstance which cools the atmosphere will produce rain. If, therefore, according to this theory, a stratum of cold air meets with a warmer stra-

* See Adams's *Lectures on Natural Philosophy*.

tum, a fall of rain is occasioned, because the warmer stratum is cooled. To this it has been replied, that by this mixture the colder stratum must be as much warmed as the warmer is cooled, and, therefore, that no precipitation ought to take place. In order to obviate this difficulty, Dr. Hutton supposes that heat enables the atmosphere to suspend water in an increasing ratio, according to the quantity of it. Thus, if two degrees of heat enable a certain quantity of air to suspend two given measures of water, three degrees of heat will enable the same quantity of air to suspend more than three such measures. Upon this supposition, if two strata of air, each of which is charged with as much water as its temperature enables it to suspend, meet together, and are reduced to a mean temperature, they will not be able to suspend as much water as in their separate state, and a precipitation of part of the water will consequently be produced*.

Others consider rain as an electrical phenomenon †, and it is very generally allowed, that electricity at least concurs with other causes in producing it. Bodies charged with the same electricity, whether it is negative or positive, always repel each other, and the aqueous particles which compose clouds, being acted on in this way, will be prevented from uniting into drops sufficiently large to fall to the earth. The rapidity with which rain falls after a discharge of lightning from a cloud, tends much to confirm this opinion. Rain also falls heaviest from the center of a

* That heat has a considerable influence in suspending aqueous vapour, appears from the phenomenon of dew; which, the reader will remember, is part of the water taken up by the air during the day time, but which is again deposited during the coolness of the night.

† See Book IV. chap. 6.

cloud, where the electric matter has been found by experiment to be generally in equilibrium; while very little is discharged from the edges, which are usually found to be electrified either positively or negatively.

The wind has been supposed to have an effect in producing rain, by driving the aqueous particles into contact, and thus causing them to unite into drops. But, by experience, wind seems to have the direct contrary influence, and frequently prevents rain.

Besides rain, many other phenomena are produced by the capacity which air has in different circumstances of taking up, suspending, and depositing water; the chief of these are snow, hail, fogs, clouds, dew, and hoar frost.

The cold of the higher regions of the atmosphere is sometimes so great, as to freeze the aqueous particles which form clouds. If the particles become frozen before they have had time to unite into drops, many of the small icicles which are produced, uniting together, and being connected only at a few points, form flocculent masses, which are called snow. The order and arrangement of the icicles is not always the same; they vary greatly, and this produces the variety which is observed in snow. It is remarkable, that though snow varies at different times, yet what falls together is always the same; that is, the snow which falls at a particular time, consists of flakes, which vary only in size, but are all formed of particles disposed in a similar manner. We are not sufficiently acquainted with the laws by which the concretion or crystallization of bodies are regulated, to explain the cause of these phenomena. On account of the small quantity of matter contained in snow, in proportion to the surfaces exposed, it meets with great resistance in passing through the atmosphere, and consequently falls
* very

very slowly. Its great surface also renders it very susceptible of evaporation, which considerably diminishes its weight even in the coldest weather.

If the cold is so moderate, as to allow the particles of water to unite into drops before congelation takes place, particles of ice are produced, which are called hail. The same thing may be supposed to happen when the lower regions of the atmosphere are colder than the upper, which, though contrary to the general course of things, sometimes happens. In such a case, the aqueous particles, after having united above into rain, are congealed in their descent, and are converted into hail. In the year 1775 or 1776, rain fell at Liverpool, which became solid as soon as it reached the surface of the earth, in such a manner as to give a covering of ice to whatever was wet with it, and even to form icicles on the dress of persons exposed to it. This phenomenon I have also witnessed elsewhere.

Hail, when first formed, must be perfectly round, because formed from a fluid; and all fluids, when placed in such situations as to receive an equal pressure in every direction from the medium which surrounds them, naturally assume a spherical form. Hail, however, when it arrives at the earth is often angular; this must be explained, either by supposing that the particles have begun to dissolve, or that they were sufficiently cold to congeal and attach to their surface, the aqueous particles with which they came into contact in their fall. Hail, when first formed, is never larger than the drops of water which fall in rain; but from the cause just mentioned, hail-stones have sometimes been known to fall as large as nuts, or even as hens' eggs. In order to convince ourselves, that such hail-stones owe their extraordinary size to the

additions which they receive in falling, it is only necessary to examine them: they will almost uniformly be found to be angular, and never to have an uniform density from the circumference to the center, which clearly proves, that they are composed of different particles of ice connected together. In confirmation of the same opinion, it is observed, that the hail which falls on mountains, is smaller than that which descends in the neighbouring vallies. The same observation has been repeatedly made with respect to rain, by persons in the habit of ascending mountains, for the purpose of philosophical experiment.

It sometimes happens from the state of the atmosphere, or a concurrence of circumstances not easily to be ascertained, that a great quantity of aqueous particles are raised in the atmosphere, where, being incompletely dissolved, they form a thick vapour, which extends itself in the lower part of the atmosphere; these particles, destroying the transparency of the atmosphere, form fogs. Fogs are more frequent in low, wet, and marshy situations, near rivers and ponds, than in such parts of a country as are elevated and dry. It sometimes happens, that certain exhalations are mixed with fogs, which are perceived by their unpleasant smell, and by an acute sensation which is felt by the throat and eyes.

Fogs are much more frequent in cold seasons, and in cold climates, than in such as are warm, because in the former, the aqueous particles being condensed almost as soon as they proceed from the surface of the earth, are incapable of rising into the higher parts of the atmosphere. If the cold is augmented, the fog freezes and attaches itself in small icicles to the branches of trees, to the hair and clothes of persons exposed to it, to the blades of grass, &c.

When

When fogs rise to a considerable height in the atmosphere, and are collected in a dense state, whether this happens from any action of the air or from other causes, they form clouds, which float in different regions of the atmosphere according to their specific gravity; since they necessarily rise or fall, till they arrive at that part of the atmosphere which is in equilibrium with themselves. As the atmosphere is heaviest below, dense and thick clouds, which are at the point of uniting into rain, float near the surface of the earth, while the fleecy and thin clouds soar aloft. We often observe both kinds at different heights in the atmosphere at the same time. As clouds are formed of water, they are most copiously produced where the air has most opportunity of acting on that fluid. Consequently winds which blow from the west and south west, from the Atlantic ocean, bring more clouds to this country than easterly winds, which only pass over a narrow channel of the sea.

During the day time the sun heats the earth, water, air, and every thing which is exposed to its rays. The heat communicated to all these bodies is diminished after sun set, but the air is more suddenly cooled than the more solid bodies. Heat, therefore, which has always a disposition to distribute itself equally, passes from the surface of water and earth into the air, and carries with it some aqueous particles, which are suspended near the surface. When the cold increases during the night, these vapours are condensed, and occasion that dampness which is felt on the clothes of persons exposed to the night air, and form that dew which is so refreshing to vegetables scorched during the day time by the summer's sun.

In cold weather the dew becomes frozen into hoar frost, for the formation of which it is not necessary
that

that the earth, or even the air, should be so far cooled as to occasion the congelation of water into ice. This fact can only be explained, by considering that these small drops of water expose a large surface to the action of the air; and by this means evaporation, which powerfully produces cold, is promoted. For the same reason clothes hung out to dry, are frequently frozen stiff, when no ice is formed in water exposed to the same degree of cold, but in circumstances less favourable to evaporation.

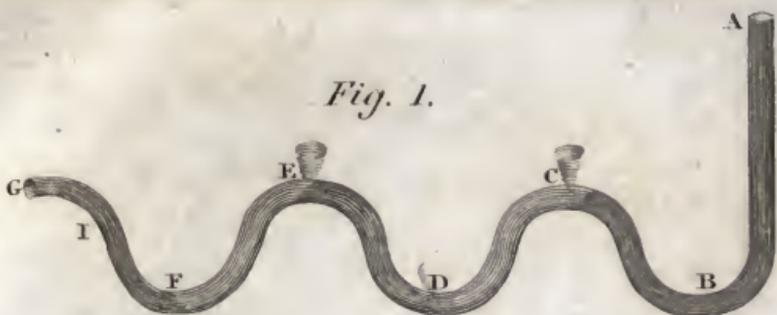


Fig. 1.

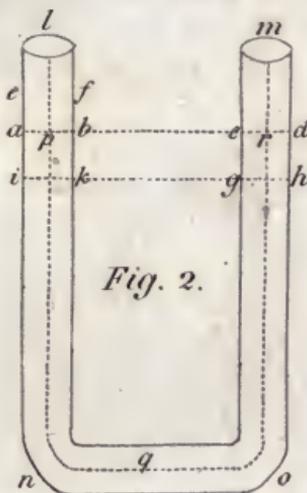


Fig. 2.

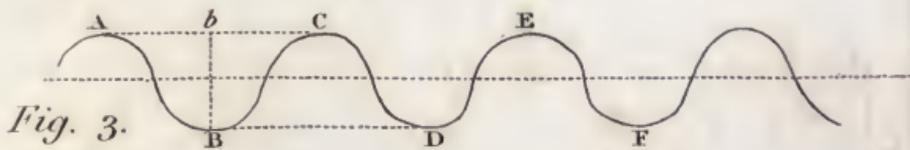


Fig. 3.

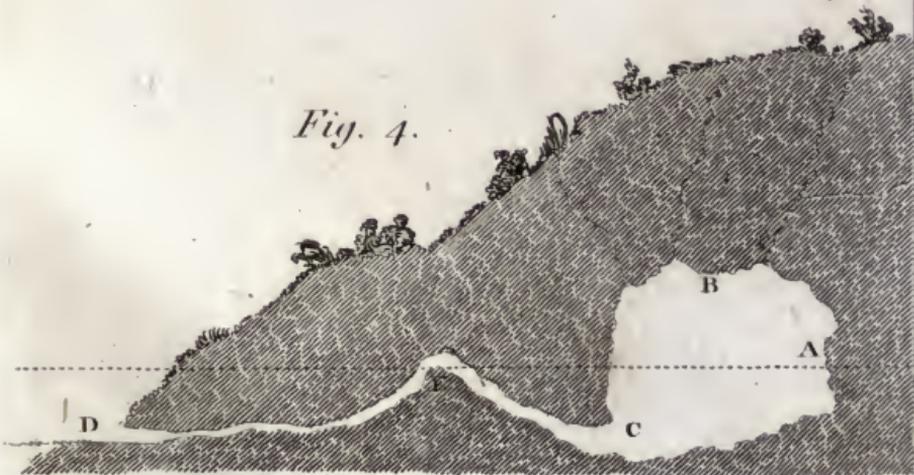


Fig. 4.



C H A P. VI.

OF SPRINGS AND RIVERS.

Origin of Springs.—Digging of Wells.—Nature of Springs.—Marshes.—Cheap and easy Mode of draining them.—Intermitting Springs.—Rivers.—Their Source, &c.

THE water which falls on the surface of the earth, in rain, snow, &c. penetrates its substance till it meets with a stratum of clay, stone, or some other matter which stops its descent; it then glides laterally on the stratum which sustains it, and in the direction to which it leans, till meeting with an aperture, it appears on the surface of the earth in the form of a spring. As water always has a tendency to descend, springs are always lower than the source from which they are supplied; springs are most common on the sides and at the bottom of mountains; they are seldom found quite at the summit of a mountain, and are rare where a country is every where level to a considerable distance, because there the strata are parallel, and do not conduct the water to any particular point. In order to obtain water, therefore, in flat countries, it is in general necessary to dig into the earth, when it is found to flow copiously from the sides of the opening, at no great distance from the surface. When wells are dug in elevated situations, water is seldom met with till we have dug to a considerable depth, and got below the general level of the country.

A curious circumstance occurs in the making of wells at Modena and Stiria in Italy. The workmen begin by digging through several strata or soils, till they

they come to a very hard kind of earth much resembling chalk; here they begin their mason-work, and build a well, which they carry on at their leisure till they have finished, without being interrupted with one drop of water, and without any apprehension of not finding it when they come to make the experiment. The well being finished, they bore through the hard bed of chalk, upon which the well is built, with a long auger, but take care to get out of the well before they draw it out again; which when they have done, the water springs up into the well, and in a little time rises to the brim, nay sometimes overflows the neighbouring grounds. Now there can be little doubt, that these waters flow from reservoirs which are collected within the Appennine mountains, not far from Modena, and taking their course through subterraneous passages, endeavour to force their ascent to the same height from which they descend, wherever they can find a vent.

As all the water which falls in rain has undergone a natural distillation, it is much more pure when it first falls, than after it has passed through different strata of the earth and rises in springs. Spring water is always found to contain some foreign admixture; if this should be only an earthy salt, the water is called hard; if it contains other substances, it then receives the denomination of mineral water; but these will require to be treated of in a distinct chapter.

The water which lies upon marshes and swampy grounds, has generally its source in some spring, which is placed above the level of the marsh. The soil, therefore, in those places, being generally of a spongy texture imbibes the water, and permits it to disperse through its whole mass, rather than force its way through a certain aperture; and as marsh lands are commonly

commonly level, the water will be more easily diffused through the soil, than it can be upon the declivity of a hill. The great art, therefore, in the draining of marshes is to discover the source, which may be looked for on the brow of some eminence which overhangs them; and it may generally be found by observing where the boggy part grows narrow and angular, and points as to an apex, which is the spring whence all the mischief proceeds. When the source is once discovered, the water may be easily drawn off by drains, aqueducts, or pipes, according to the circumstances of the case. The common mode of draining land by cutting deep trenches, or drains, through the marsh itself, to serve as reservoirs for the water, is much more laborious, and expensive, and indeed seldom answers the end proposed; for as soon as the trenches fill, the ground is rendered as swampy as ever; and even where drains are made on the principle of an inclined plane to draw off the water, they are frequently stopped by the mud of the marsh, and the least stoppage exposes the land again to at least a partial overflow.

There are some springs which exhibit a very curious phenomenon, a kind of tide or intermission, by which the water at certain periods appears to rise to a considerable height, and gradually to subside. These are called intermitting springs. It was long imagined, that these fountains were replenished by some connection with the sea; that the water was freshened by its progress through sand and earth, and that their rising and falling depended on the tide. It was, however, found, that the periods of the water rising and falling in these springs, did not correspond in point of time with the tides of the adjacent seas, and that the periods were different in different springs, contrary to the regular

gular rising and falling of tides in the ocean. The phenomenon has since been very satisfactorily explained, and upon a very simple and obvious principle. It has been already shewn, that when a siphon is inserted in a vessel containing water, if the air is drawn out of the siphon, or by any means the water is made to flow over the bent of the tube, which lies above the brim of the vessel, the water will continue to flow over the brim through the siphon till the whole is exhausted.

To account, therefore, for the intermitting spring, we have only to suppose, that a cavity or receptacle is formed in the bowels of the hill or mountain, where the spring is situated, which gradually fills with water like other reservoirs; by the interposition of some stratum of stone or rock, the tube or cavity which conveys the water from this receptacle to the spring or mouth where it issues, is bent in the form of a siphon, the bent of which is considerably higher than the bottom of the reservoir. Whenever, therefore, the reservoir or receptacle is filled as high as the bent of the tube, the water will rise in it to its level, and begin to flow into the spring, which will continue till the receptacle is exhausted. While this process is going on the water in the spring will rise; and as soon as the receptacle is exhausted, the water, being drawn off by a stream or rivulet, will appear to fall in the well of the spring, and will continue to fall till the receptacle is again supplied to the height of the siphon or tube, when the process of filling will be again renewed.

To render the matter perfectly plain, let A B C (Plate X. fig. 4.) represent the cavity or receptacle, from the bottom of which C proceeds the tube or siphon D E. When the water rises in the receptacle to the level of E in the tube, it will begin to flow into the

the

the spring at D, on the principle explained in the preceding paragraph, and the whole phenomenon will be easily accounted for.

With any person who has carefully observed the course of rivers, and traced them to their sources, there can be little doubt that they are formed by the confluence of springs, or of the little streams or rivulets that issue from them; with perhaps the exception of those rivers which proceed from lakes, where the reservoir is ready formed, and generally by the same means.

In the beginning of the present century, the philosophical world was agitated by a debate concerning the origin of those waters which are necessary for the supply of rivers, &c. one party contended strongly for the existence of a large mass of water within the bowels of the earth, which supplied not only the rivers but the ocean itself; at the head of these we may place the ingenious but fanciful Burnet. The French philosophers, on the contrary, asserted, that the waters of the ocean were conveyed back by some subterraneous passages to the land, and being filtrated in their passage, returned again to the sea in the course of the rivers; but this opinion appears contrary to all the known principle of hydrostatics.

In opposition to these hypotheses, our illustrious countryman Halley contended that the process of evaporation, and the immense deposition of water in consequence of it, was fully adequate to the whole supply. If, indeed, we consider the immense quantity of water which is continually carried up into the atmosphere by evaporation, as stated in a former chapter, and consider that this is a process which is continually going on, not only from the ocean but from the rivers themselves, and from the whole surface of the earth, we shall

shall see but little reason to doubt of Dr. Halley's hypothesis, but may reasonably conclude, that this kind of circulation is carried on through all nature, and that the sea receives back again through the channel of the rivers, that water which it parts with to the atmosphere.

• All rivers have their source either in mountains, or elevated lakes; and it is in their descent from these, that they acquire that velocity which maintains their future current. At first their course is generally rapid and headlong; but it is retarded in its journey by the continual friction against its banks, by the many obstacles it meets to divert its stream, and by the plains generally becoming more level as it approaches towards the sea.

• Rivers, as every body has seen, are always broadest at the mouth; and grow narrower towards their source. But what is less known, and probably more deserving curiosity, is, that they run in a more direct channel as they immediately leave their sources; and that their sinuosities and turnings become more numerous as they proceed. It is a certain sign among the savages of North America, that they are near the sea, when they find the rivers winding, and every now and then changing their direction. And this is even now become an indication to the Europeans themselves, in their journies through those trackless forests. As those sinuosities, therefore, increase as the river approaches the sea, it is not to be wondered at, that they sometimes divide, and thus disembogue by different channels. The Danube disembogues into the Euxine by seven mouths; the Nile, by the same number; and the Wolga, by seventy.

• The largest rivers of Europe are, first, the Wolga, which is about six hundred and fifty leagues in length, extending

extending from Reschow to Astrachan. It is remarkable of this river, that it abounds with water during the summer months of May and June; but all the rest of the year is so shallow as scarcely to cover its bottom, or allow a passage for loaded vessels that trade up its stream. The next in order is the Danube. The course of this is about four hundred and fifty leagues, from the mountains of Switzerland to the Black Sea. The Don, or Tanais, which is four hundred leagues from the source of that branch of it called the Softna, to its mouth in the Euxine Sea. In one part of its course it approaches near the Wolga; and Peter the Great had actually begun a canal, by which he intended joining those two rivers; but this he did not live to finish. The Nieper, or Borysthenes, rises in the middle of Muscovy, and runs the course of three hundred and fifty leagues, to empty itself into the Black Sea. The Old Cossacks inhabit the banks and islands of this river; and frequently cross the Black Sea, to plunder the maritime places on the coasts of Turkey. The Dwina takes its rise in a province of the same name in Russia, runs a course of three hundred leagues, and disembogues into the White Sea, a little below Archangel.

The largest rivers of Asia are, the Hohanho, in China, which is eight hundred and fifty leagues in length, computed from its source at Raja Ribron, to its mouth in the Gulph of Changi. The Jenisca of Tartary, about eight hundred leagues in length, from the Lake Selinga to the Icy Sea. This river is, by some, supposed to supply most of that great quantity of drift wood which is seen floating in the seas, near the Arctic circle. The Oby, of five hundred leagues, running from the lake of Kila into the Northern Sea.

The Amour, in Eastern Tartary, whose course is about five hundred and seventy-five leagues, from its source to its entrance into the sea of Kamtschatka. The Kiam, in China, five hundred and fifty leagues in length. The Ganges, one of the most noted rivers in the world, is about as long as the former. It rises in the mountains which separate India from Tartary; and running through the dominions of the Great Mogul, discharges itself by several mouths into the bay of Bengal. It is not only esteemed by the Indians for the depth, and pureness of its stream, but for a supposed sanctity which they believe to be in its waters. It is visited annually by several hundred thousand pilgrims, who pay their devotions to the river as to a god; for savage simplicity is always known to mistake the blessings of the deity for the deity himself. They carry their dying friends, from distant countries, to expire on its banks; and to be buried in its stream. The water is lowest in April or May; but the rains beginning to fall soon after, the flat country is overflowed for several miles, till about the end of September; the waters then begin to retire, leaving a prolific sediment behind, that enriches the soil, and, in a few days time, gives a luxuriance to vegetation, beyond what can be conceived by an European. Next to this may be reckoned the still more celebrated river Euphrates. This rises from two sources, northward of the city Erzerum, in Turcumania; and unites about three days journey below it, whence, after performing a course of five hundred leagues, it falls into the Gulph of Persia, fifty miles below the city of Bassora in Arabia. The river Indus is extended, from its source to its discharge into the Arabian sea, four hundred leagues.

The largest rivers of Africa are, the Senegal, which

runs

runs a course of not less than eleven hundred leagues, comprehending the Niger, which some have supposed to fall into it. Later accounts, however, seem to affirm that the Niger is lost in the sands, about three hundred miles up from the western coasts of Africa. Be this as it may, the Senegal is well known to be navigable for more than three hundred leagues up the country; and how much higher it may reach is not yet discovered, as the dreadful fatality of the inland parts of Africa, not only deter curiosity, but even avarice, which is a much stronger passion. The celebrated river Nile is said to be nine hundred and seventy leagues, from its source among the mountains of the Moon, in Upper Æthiopia, to its opening into the Mediterranean Sea. Upon its arrival in the kingdom of Upper Ægypt, it runs through a rocky channel, which some late travellers have mistaken for its cataracts. In the beginning of its course, it receives many lesser rivers into it; and Pliny was mistaken, in saying that it received none. In the beginning also of its course, it has many windings; but, for above three hundred leagues from the sea, runs in a direct line. Its annual overflowings arise from a very obvious cause, which is almost universal with the great rivers that take their source near the line. The rainy season, which is periodical in those climates, floods the rivers; and as this always happens in our summer, so the Nile is at that time overflown. From these inundations, the inhabitants of Egypt derive happiness and plenty; and, when the river does not arrive to its accustomed heights, they prepare for an indifferent harvest. It begins to overflow about the 17th of June; it generally continues to augment for forty days, and decreases in about as many more. The time of increase and decrease, however, is much more

inconsiderable now than it was among the ancients. Herodotus informs us, that it was an hundred days rising, and as many falling; which shews that the inundation was much greater at that time than at present. M. Buffon * has ascribed the present diminution, as well to the lessening of the mountains of the Moon, by their substance having so long been washed down with the stream, as to the rising of the earth in Egypt, that has for so many ages received this extraneous supply. But we do not find, by the buildings that have remained since the times of the ancients, that the earth is much raised since then. Besides the Nile in Africa, we may reckon Zara, and the Coanza, from the greatness of whose openings into the sea, and the rapidity of whose streams, we form an estimate of the great distance whence they come. Their courses, however, are spent in watering deserts and savage countries, whose poverty or fierceness have kept strangers away.

But of all parts of the world, America, as it exhibits the most lofty mountains, so also it supplies the largest rivers. The principal of these is the great river Amazons, which, from its source in the lake of Lauricocha, to its discharge into the Western Ocean, performs a course of more than twelve hundred leagues †. The breadth and depth of this river is answerable to its vast length; and, where its width is most contracted, its depth is augmented in proportion. So great is the body of its waters, that other rivers, though before the objects of admiration, are lost in its bosom. It proceeds after their junction, with its usual appearance, without any visible change in its breadth.

* Buffon, vol. ii. p. 82.

† Ulloa, vol. i. p. 388.

or rapidity ; and, if we may so express it, remains great without ostentation. In some places it displays its whole magnificence, dividing into several large branches, and encompassing a multitude of islands ; and at length, discharging itself into the ocean, by a channel of an hundred and fifty miles broad. Another river, that may almost rival the former, is the St. Lawrence, in Canada, which rising in the lake Assiniboils, passes from one lake to another, from Christinaux to Alempigo ; and thence to lake Superior ; thence to the lake Hurons ; to lake Erie ; to lake Ontario ; and, at last, after a course of nine hundred leagues, pours their collected waters into the Atlantic ocean. The river Mississippi is more than seven hundred leagues in length, beginning at its source near the lake Assiniboils, and ending at its opening into the Gulph of Mexico. The river Plata runs a length of more than eight hundred leagues from its source in the river Parana, to its mouth. The river Orooncko is seven hundred and fifty leagues in length, from its source near Pasto, to its discharge into the Atlantic ocean.

Such is the amazing length of the greatest rivers ; and even in some of these, the most remote sources very probably yet continue unknown. In fact, if we consider the number of rivers which they receive, and the little acquaintance we have with the regions through which they run, it is not to be wondered at that geographers are divided concerning the sources of most of them. As among a number of roots by which nourishment is conveyed to a stately tree, it is difficult to determine precisely that by which the tree is chiefly supplied ; so among the many branches of a great river, it is equally difficult to tell which is the original. Hence it may easily happen, that a smaller branch is taken for the capital stream ; and its wind-

ings are pursued, and delineated, in prejudice of some other branch that better deserved the name and the description. In this manner*, in Europe, the Danube is known to receive thirty lesser rivers; the Wolga thirty-two or thirty-three. In Asia, the Hothanno receives thirty-five; the Jenisca above sixty; the Oby as many; the Amour about forty; the Nankin receives thirty rivers; the Ganges twenty; and the Euphrates about eleven. In Africa, the Senegal receives more than twenty rivers; the Nile receives not one for five hundred leagues upwards, and then only twelve or thirteen. In America, the river Amazons receives above sixty, and those very considerable; the river St. Lawrence about forty, counting those which fall into its lakes; the Mississippi receives forty; and the river Plata above fifty.

The inundations of the Ganges and the Nile have been already mentioned, and it might be added, that almost all great rivers have their periodical inundations from similar causes. The author already quoted observes, that, 'besides these annually periodical inundations, there are many rivers that overflow at much shorter intervals. Thus most of those in Peru and Chili have scarce any motion by night; but upon the appearance of the morning sun they resume their former rapidity: this proceeds from the mountain snows, which, melting with the heat, encrease the stream, and continue to drive on the current while the sun continues to dissolve them †.'

* There are some rivers which are said to lose themselves in chafms under the earth, and to flow for several miles in secret and undiscovered channels. On

* Buffon, vol. ii. p. 74.

† Goldsmith's Earth, p. 200.

X Alph " ... CAVERNS measureless. To man -- this

this circumstance is founded one of the most beautiful fables of antiquity, relative to the fountain of Arethusa, in Sicily. The same thing is affirmed of the Rhine, and even of the river Mole, in Surrey, which, from this circumstance, derives its name. With respect to the two latter rivers, however, some doubts are entertained of the fact, but these are rather a subject of inquiry to the geographer than to the natural historian.

C H A P. VII.

H O T S P R I N G S.

Probable Causes of these Phenomena.—Abound most in volcanic Regions.—Hot Springs in Iceland, near Mount Hecla.—At Geyser.—In the Island of Ischia.—At Viterbo.—Explanation of these Phenomena.—Burning Well in Lancashire.—Explained.

TH E R E are few objects in natural history, which present themselves to our consideration, accompanied with greater difficulties than those tepid springs, which exist in different parts of the world, of different degrees of temperature, and exhibiting a variety of the most curious phenomena. Many of these have existed as long as the earliest records, and for whole centuries have exhibited little variation in their temperature.

If any circumstance could serve to support the very dubious hypothesis of an immense reservoir of fire in the center of the earth, it would be these phenomena; yet there is but little reason to suppose that the origin of these tepid springs lies at any vast depth beneath the surface; and, indeed, if we admit the notion of a central fire, its effect ought to be more general than it is found to be. The most probable hypothesis is, therefore, that the same causes operate to produce these, which produce volcanoes; and the only inference to be drawn from their permanent temperature is, that the masses of matter, which produce volcanic eruptions, may exist for a long series of time, even in a state of inflammation, without bursting those bandages with which nature has confined them; and that heat may long be continued to a considerable degree

degree in the earth, without exhibiting to our affrighted senses the formidable phenomenon of a volcanic fire.

It is, however, in volcanic regions, that tepid waters are found in the greatest quantity; and it is in these that they display the most striking phenomena. At Laugervarm, a small lake, two days journey from Mount Hecla, in Iceland, there are hot spouting springs, one of which throws up a column of water to the height of twenty-four feet. A piece of mutton and some salmon trout were almost boiled to pieces, in six minutes, in one of these springs. At Geyser, in the same island, there are forty or fifty spouting springs within the compass of three miles; in some the water is impregnated with clay, and white in its appearance; in some, where it passes through a fine ochre, it is red as scarlet; in some it spouts forth in a continued stream; in others, at intervals, like an artificial jet d'eau. The largest which Von Troil observed had an aperture nineteen feet in diameter, through which the water spouted, at intervals, nine or ten times a day; round the top of it is a basin, which, together with the pipe, is in the form of a caldron; the margin of the basin is nine feet higher than the conduit, and its diameter fifty-six feet. The water was thrown up in an immense column, at different times, to the height of from thirty to sixty feet, and at one time to the height of ninety-two feet. Previous to this explosion the earth began to tremble in three different places, and a noise was heard like a battery of cannon*.

Another writer states, that at Geyser, in Iceland, there springs up a hot water, which upon cooling,

* Von Troil's Letters on Iceland.

deposits siliceous earth; and that of this very matter it has formed for itself a crater, in which columns of water, of a stupendous bulk, after they have been thrown to the height of ninety feet and upwards, fall, and are again received. The heat of the water during the explosion cannot be measured; but after it has risen and fallen through a stratum of air ninety feet thick, it raises the thermometer to 212° , which evinces that the heat in the bowels of the earth must be much more intense; and at this we shall cease to wonder when we consider, that in this case the subterraneous fire acts upon the water in caverns, closed up by very thick strata of stones, an apparatus far more effective than Papin's digester. The crater was at first undoubtedly formed, and is daily strengthened by siliceous earth, which quits the menstruum on its being cooled, falls down, and, being in somewhat like a soft state, concretes*.

About sixty yards from the shore of the island of Ischia, at a place called St. Angelo, a column of boiling water bubbles on the surface of the sea with great force, and communicates its heat to the water of the sea near it. It boils winter and summer, and is of great use to the inhabitants in bending their planks for ship-building, &c. The fishermen also frequently employ this curious caldron to boil their fish. Near the shore of this island Sir William Hamilton found, when bathing in the sea, many spots where the sand was so intensely hot under his feet as to oblige him hastily to retire.

There is also a boiling spring near Viterbo, in the Roman state, called the Bullicame. It is a circular pool of about sixty feet in diameter, and ex-

* Bergman's Dissert. 13.

ceedingly deep, the water of which is constantly boiling. It is situated in a plain surrounded by volcanic mountains. A stony concretion floats on the surface of the pool, which, being carried off by the superfluous water, is deposited, and is constantly forming a labes or tufa, of which the soil all around the pool is composed.

These fountains are best accounted for by supposing the pipe or conduit to communicate with a large reservoir of water, which, being subject to the heat of a volcanic fire, the steam generated in the reservoir by the boiling of the water acts forcibly on the water in the shaft or pipe, and ejects it by its elastic force in the form of a fountain, which will act with more or less vigour according to the degree of heat, and according to the resistance which the water encounters in its passage.

The most singular circumstance is the number of these springs which are found in almost every country; and even in those countries which have long ceased to be volcanic. England itself has its tepid springs, and those of Bath, Buxton, &c. are well known. Cambden mentions a well, near Wigan, in Lancashire, which was called the burning well. If a candle was applied to its surface, he says, a flame was excited like that of ardent spirits set on fire, and the heat and inflammation thus excited would continue sometimes for the space of a whole day, and was sufficient to boil eggs, and even meat. As I recollect, Cambden mentions the well as having lost its inflammable property in his time; but he notices two others of a similar description, one in the same neighbourhood, and another in Shropshire. I have never myself witnessed a similar phenomenon, nor do I know

know of any such that exists at present, at least in Britain.

Should, however, the fact be as it is related by Camden, the reader, after what has been stated in a preceding chapter, will not find it difficult to explain the cause. The country where the well is, or was situated, abounds in coals. The well is therefore impregnated with naphta, or some bituminous vapour; this, upon the application of an ignited body, is capable of inflammation, and can even communicate a considerable portion of heat to the water of the well itself. There is no proof, however, that the Bath or Buxton waters are impregnated with any bituminous matter, though coals are plentiful in the neighbourhood; and as these waters contain a small portion of iron, there is reason to suppose them connected with beds of pyrites, or possibly with a latent subterraneous fire. On the whole, we are not sufficiently acquainted with the internal parts of the earth to account satisfactorily for these and other phenomena of a similar kind, and whatever is advanced in the way of theory on these topics should be advanced with becoming diffidence, and rather with a view of exciting the attention and curiosity of others, than for the purpose of establishing a system un sanctioned by experiment, or building a reputation on the fallible basis of mere hypothesis.

C H A P. VIII.

MINERAL WATERS.

Capacity of Water as a Solvent.—Substances commonly found in Mineral Waters.—Fixed Air.—Mineral Acids.—Alkaline salts.—Neutral Salts.—Earthy Substances.—Sulphur.—Metals.—Mode of examining and analyzing Mineral Waters.—Chemical Tests.—Analysis of the most celebrated Mineral or Spa Waters.—Aix-la-Chapelle.—Bath.—Bristol.—Buxton.—Cheltenham.—Epsom.—Harrowgate.—Matlock.—Pymont.—Scarborough.—Spa.—Reflections on the Use of Mineral Water in general.

THE capacity which water has of holding a variety of substances in solution has been frequently mentioned in the course of these volumes, and indeed is a fact so well known and understood, that to insist much upon it would be useless and even impertinent.

It was also intimated, that the water of springs receives the name of mineral water from the foreign substances which are contained in it. These substances are various, and more than one is commonly found in mineral waters; but in general they may be referred to the following heads:

1. Fixed air, or carbonic acid gas. This ingredient occasions an appearance of briskness in water, similar to that of fermenting liquors, which is chiefly observable when the water is poured from one vessel into another. It is very volatile, and soon escapes on the water being exposed to the air. This ingredient frequently occasions giddiness in persons who are not accustomed to it. An artificial water of this kind may be prepared at any time by impregnating water with fixed air.

2. The

2. The vitriolic, nitrous, and muriatic acids. One or other of these acids exist in almost all mineral waters: they are usually combined with earthy or metallic bases, but sometimes, especially the vitriolic, exist in a separate state, so as to occasion a sensible acidity.

3. An alkaline salt is found in many waters in Hungary, Tripoli, and other countries. It is usually the fossil alkali which is combined with fixed air in the Seltzer waters, and with the mineral acids in a great variety of others. The vegetable and volatile alkalies rarely or never are ingredients in mineral waters.

4. Neutral salts are not uncommon in springs. Common salt, nitre, and vitriolated magnesia, are the most usual; the latter is very abundant in a spring at Epsom in Surrey, and has therefore obtained the name of Epsom salt. Sal ammoniac has also been found in some springs in the neighbourhood of volcanoes and burning coal mines.

5. Earthy substances. Of these the calcareous is sometimes found to abound so much, as to be deposited on such substances as it comes in contact with, and occasion petrification. In this case the suspension of the calcareous earth seems to depend on the presence of fixed air, which, making its escape when the water issues into the open air, suffers the calcareous earth to separate. The calcareous earth of waters is very commonly united with the vitriolic acid, and exists in the form of gypsum, which is only soluble in water in the proportion of one part in seven or eight hundred. Calcareous nitre and muriated calcareous earth are also occasionally found in springs.

6. Sulphur. Many waters seem by their offensive smell to contain sulphur, though very few of them,
upon

upon more accurate examination, are found to afford it. The waters generally called sulphureous or hepatic, are only impregnated with sulphureous or hepatic gas, which is a solution of sulphur in inflammable air. This is the same gas which rises from liver of sulphur, and liver of sulphur itself has been detected in a very minute quantity in mineral waters. Sometimes bitumens are met with in mineral waters, and commonly make their appearance on the surface.

7. Metals. Of these iron is most frequently found in water, sometimes copper, and more rarely zinc. Waters which contain iron are called chalybeates, and are very common.

It was formerly imagined that iron was suspended in mineral waters by means of the vitriolic acid; but M. Monnet has ascertained, that very few of them contain vitriolic acid, and that the carbonic acid, or fixed air, is almost the only medium by which the iron is suspended. The carbonic acid is sometimes in excess, so as to render the chalybeate water acidulous, in other instances it suspends the iron without being in excess. Chalybeates may, in general, be known by the yellow ochry sediment deposited in their course, and also by striking a purple colour with decoction of galls.

In examining any mineral waters, the first object of attention is, to have the water as fresh as possible, since, if it contains any volatile matters, they will soon fly off. A great number of trials are therefore to be made on the spot. The contents of the neighbouring strata, particularly of any high ground, from which the water seems to proceed, are also to be regarded, as they often serve to account for the properties of mineral waters.

One of the most obvious circumstances to be attended

tended to is the degree of the heat of the water, and for this purpose it is necessary to be provided with an accurate thermometer. There are many springs which have a temperature a little above the medium temperature of the atmosphere, though this may not be so remarkable as to have obtained them the name of hot springs. The middle temperature of these springs is found to be about forty-eight degrees, but on elevated situations it is less, in proportion to their height above the sea. It may also be proper to compare the temperature of these mineral springs with that of some common springs in the neighbourhood. The sensible qualities, as the colour, taste, and smell, are to be observed. In order to discover whether any elastic fluid escapes from it, and of what nature it is, let some of the water be put into a bottle, and a bladder tied about its neck. The air which escapes may be submitted to examination. In order to obtain it, it is only necessary to tie another string above the bottle, and then to cut between them, so as to separate the bladder, which may be plunged in water or mercury, and its contents received in the pneumatic apparatus. In order to separate all the air from water, it must be heated nearly to its boiling point, which may easily be done by immersing it in a vessel of boiling water, while it is contained in the bottle to which the bladder is annexed. The elastic fluids, which may be separated from mineral waters, are chiefly two, carbonic acid gas, and sulphureous gas. It is proper to observe the changes which are spontaneously produced on mineral waters by different degrees of heat. If any matter is deposited during the evaporation of the mineral water, it must be collected for further examination.

With respect to the addition of certain foreign substances

stances called re-agents, to discover the contents of mineral waters, it may in general be remarked, that this mode is less certain than evaporation; the latter method, however, is not free from objections, as the application of heat to any body not unfrequently deranges the previous state of combination among its component principles. The chemical tests best adapted to the discovery of the contents of mineral waters are the following: lime, volatile alkali, fixed alkalies, vitriolic acid, tincture of turnsole, muriated barytes, acid of sugar, arsenic, Prussian alkali, and the nitrous solutions of silver and mercury. When it is proposed to discover the contents of a mineral water, it is best to begin with such tests as are least capable of altering it, and afterwards, having observed their effects, to proceed to complete the analysis by tests which have a more extensive influence. Lime water seizes the carbonic acid, and forms a precipitate of chalk; it also precipitates salts with the basis of clay and magnesia, as well as the metallic salts. If after mixing an equal quantity of lime water with a mineral water, no precipitation takes place in twenty-four hours, it may be concluded, that it contains neither carbonic acid at liberty, nor a combination of that acid with fixed alkali, nor earthy salts with the basis of aluminous earth or magnesia, nor any metallic salt. But if a precipitation takes place on the addition of lime water, the next step is to examine the properties of the precipitated matter; if it has the properties of chalk, such as insipidity, the producing of an effervescence with vitriolic acid, and forming with it a compound nearly insoluble in water, that is gypsum, it must be concluded that the water contained carbonic acid, which, uniting with the lime of the lime water, produced chalk. If, on the con-

trary, the precipitated matter is small in quantity, and subsides very slowly; if it does not effervesce, and affords with the vitriolic acid a styptic salt, it may be concluded that it is alum, and that the mineral water contained clay: If a bitter and very soluble salt is formed on the addition of the vitriolic acid, it is the Epsom salt, and the water contained the earth of magnesia. If the addition of vitriolic acid to the precipitate produces sal martis, the water held iron in solution.

The addition of caustic volatile alkali will act like lime water, except that it will not produce a precipitation from the presence of uncombined carbonic acid in the water; the compound formed by volatile alkali with that acid not being insoluble, like the chalk formed by the union of carbonic acid with lime. But besides the aluminous, the magnesian, and the metallic salts, the caustic volatile alkali will decompose those which have lime for their basis, and thus we advance one step further in the analysis of the water. The Prussian alkali precipitates the combinations of carbonic and vitriolic acid with chalk. The nitrous solutions of silver and mercury decompose all the muriatic and vitriolic salts, which may be various both in quantity and in kind. In these cases the muriatic or vitriolic acid contained in the mineral water, seizes the silver or the mercury, and forming with it an insoluble compound, falls to the bottom in a thick cloud, while the nitrous acid unites with the basis which is deserted by one or both of the other acids. It is not necessary in this place to enter into a minute detail of the methods of distinguishing the difference of the precipitates, according as the muriatic or vitriolic acid was concerned in their production, but I shall refer

the reader for information on this point to what was stated when treating of the combinations of silver and mercury with the different mineral acids.

By tincture of turnsole the predominance either of an alkali or an acid is discovered: as vegetable blues are turned red by acids, and green by alkalies. Acid of sugar is a very sensible test of lime, when combined with the sparry or acetous acids. A solution of arsenic in the marine acid will precipitate sulphur from water, in which it is held dissolved by means of carbonic acid. It may be added, that white arsenic becomes yellow if immersed in water containing hepatic gas; and a piece of polished iron will receive a copper-colour from water in which copper is dissolved. If a mineral water is found to contain a fixed alkali, it may be determined whether it is the vegetable or mineral alkali by means of vinegar. With vegetable alkali vinegar yields a deliquescent salt; with the mineral, foliated crystals.

It may be proper briefly to notice the composition and obvious properties of some of the most celebrated mineral waters, and the disorders in which they are supposed to have most efficacy.

‘ AIX-LA-CHAPELLE.—This place has long been famous for its hot sulphureous waters and baths. They arise from several sources, which supply eight baths constructed in different parts of the town. These waters near the sources are clear and pellucid, and have a strong sulphureous smell resembling the washings of a fowl gun; but they lose this smell by exposure to air. Their taste is saline, bitter, and urinous. They do not contain iron. They are also neutral near the fountain, but afterwards are manifestly, and pretty strongly alkaline, infomuch that cloaths may be

washed with them without soap. The gallon contains about two scruples of sea salt, the same quantity of chalk, and a dram and half of fossil alkali. They are at first nauseous and harsh, but by habit become familiar and agreeable. At first drinking also they generally affect the head. Their general operation is cathartic and diuretic, without griping or diminution of strength; and they also promote perspiration. The quantity to be drunk as an alterative, is to be varied according to the constitution, and other circumstances of the patient. In general, it is best to begin with a quarter, or half a pint in the morning, and increase the dose afterwards to pints, as may be found convenient. The water is best drunk at the fountain. When it is required to purge, it should be drunk in large and often repeated draughts*.

The heat of the different baths of the Aix-la-Chapelle waters varies from one hundred and six of Fahrenheit's thermometer to one hundred and thirty. In bathing it is proper to begin with the most temperate.

'BATH has long been famous for its warm chalybeate waters.' There are several springs, but their waters are all of the same nature. There are six baths; but the principal are the *King's* bath, the *Queen's* bath, and the *Cross* bath. The others are only appendages to these. The two former raise the thermometer to 116°, the latter to 112°. The water when viewed in the baths has a greenish, or sea colour: but in a phial it appears quite transparent and colourless, and it sparkles in the glass. It has a very slight saline, bitterish, and chalybeate taste, which is not disagreeable, and sometimes somewhat of a sulphu-

* Elliot on Min. Waters, p. 119, &c.

reous smell; but this latter is not usually perceptible, except when the baths are filling. The gallon of Bath water contains twenty-three grains of chalk, the same quantity of muriat of magnesia, thirty-eight of sea salt, and 8.1 of aerated iron. As it rises from the pump, it contains fixed air, or other volatile acid, in a sufficient quantity to curdle milk and act upon iron. The Bath water operates powerfully as a diuretic, and promotes perspiration. If drunk quickly, in large draughts, it sometimes purges; but if taken slowly and in small quantity, it rather has the contrary effect. An heaviness of the head, and inclination to sleep, are often felt on first drinking it*.

This water when taken inwardly is said to give a stimulus and vigour to the whole constitution, it therefore proves useful in old rheumatic complaints, and in cases of gout connected with much debility. During the use of the Bath water, and some time previous to it, the patient should live on a light diet, easy of digestion. The course should be continued for a month or six weeks. In local complaints, as in stiff joints and chronic pains, the application of the water by pumping is more efficacious than bathing the whole body.

BRISTOL.—‘The springs are known by the name of the *Hot Wells*. The water at its origin is warm, clear, pellucid and sparkling; and if let stand in a glass, covers its inside with small air-bubbles. It has no smell, and is soft and agreeable to the taste. It raises the thermometer from about seventy to eighty degrees. It contains $12\frac{3}{4}$ grains of chalk, $5\frac{1}{4}$ of muriat of magnesia, and $6\frac{1}{2}$ of sea salt in the gallon †.

* Elliot on Min. Waters, p. 134, &c.

† Ibid. p. 145. &c.

The Bristol waters are particularly recommended in pulmonary complaints; the fame, however, of Bristol has probably been more owing to the mildness of the air in that part of England, than to the virtues of its waters.

BUXTON.—‘ This is a hot water, resembling that of *Bristol*. It raises the thermometer to 81° or 82° . It has a sweet and pleasant taste. It contains a little calcareous earth, together with a small quantity of sea salt, and an inconsiderable portion of a cathartic salt. Iron has been discovered in it, but in so extremely small a quantity as not to deserve notice: and even that perhaps owing to accident. This water taken inwardly is esteemed good in the diabetes; in bloody urine; in the bilious cholic; in loss of appetite, and coldness of the stomach; in inward bleedings; in atrophy; in contraction of the vessels and limbs, especially from age; in cramps and convulsions; in the dry asthma without a fever; and also in barrenness. Inwardly and outwardly it is said to be good in rheumatic and scorbutic complaints; in the gout; in inflammation of the liver and kidneys, and in consumptions of the lungs; also in old strains; in hard callous tumours; in withered and contracted limbs; in the itch, scabs, nodes, chalky swellings, ring-worms, and other similar complaints. Besides the hot water, there is also a cold *chalybeate* water, with a rough iron taste. It resembles the *Cawthorp* water*.’

‘ **CHELTEHAM**, in *Gloucestershire*, is one of the best and most noted cathartic chalybeate waters in England, though it is not so much frequented as formerly. The gallon contains eight drams of a cathartic salt, partly vitriolated natron, partly vitriolated magnesia; twenty-

* Elliot on Min. Waters, p. 151, &c.

five grains of magnesia, part of which is united with marine, part with aerial acid; and nearly five grains of iron combined with aerial acid. It also yielded thirty-two ounce measures of air, twenty-four of which were fixed air, the rest azotic with a portion of hepatic air. The dose is from one pint to three or four. It operates with great ease, and is never attended with gripings, tenesmus, &c. It is best taken a little warm. It also creates an appetite; is thought excellent in scorbutic complaints, and has been used with success in the gravel. As the spring has been calculated to yield only thirty-five pints of water an hour, without frugal management there would not be enough to supply the demands of the drinkers. The Walton water has lately been recommended as a substitute to obviate this inconvenience.

EPSOM, *in Surry*.—The water has a slight saline taste, is clear, and without smell. But if it is kept in covered vessels for some weeks in the summer it will stink, and acquire a nauseous and saltish bitter taste. This was the first water from which the salt thence called *Epsom salt* was obtained. But the salt usually sold by that name is different from that yielded by the Epsom water, though perhaps not inferior in virtue. It is made from the bittern left after the crystallization of common salt from sea water. The Epsom water is cathartic; for which purpose it must be drunk to the quantity of two or three pints. It is also diuretic.

HARROWGATE.—‘ There are four springs at this place, but the waters of all of them are nearly alike, except in the quantity of the saline matter they contain. Of the three old springs, the highest gave three ounces of solid matter; the lowest, an ounce and an half; and the middle one, only half an ounce. Of the

latter one hundred and forty grains were earth. The water as it springs up is clear and sparkling, and throws up a quantity of air-bubbles. It has a strong smell of sulphur, and is supposed to be the strongest sulphureous water in England. It has a salt taste, as it contains a considerable quantity of sea salt, together with a little marine salt of magnesia, and calcareous earth*.

~~X~~ Harrowgate water is cathartic when taken in doses of several pints. When used externally as a fomentation, it is said to be useful in some disorders of the skin; and by some physicians it is considered as efficacious in destroying worms.

MATLOCK.—‘At this place (which is perfectly romantic) are several springs of warm water, which appear to be of the nature of the *Bristol* water, except that it is very slightly impregnated with iron. Its heat is about 69°, and its virtues are similar to those of the *Bristol* and *Buxton* waters. The baths are recommended in rheumatic complaints, in cutaneous disorders, and in other cases where warm bathing is serviceable. There are great numbers of petrifications in the course of this water †.

.. PYRMONT, in *Westphalia*.—‘This is a very brisk chalybeate, abounding in fixed air; and when taken up from the fountain, sparkles like the briskest *Champaign* wine. It has a fine, pleasant, vinous taste, and a somewhat sulphureous smell. It is perfectly clear, and bears carriage better than the *Spa* water. A gallon of it contains 46 grains of chalk, 15.6 of magnesia, 30 of vitriolated magnesia, 10 of sea salt, and 2.6 of aerated iron ‡. Persons who drink it at the well, are

* Elliot, p. 177 and 184.

† Ibid. p. 210.

‡ Dr. Marcard, in his *Description of Pyrmont*, on the authority of M. Westrumb of Hammeln, estimates the iron at somewhat more than eight grains to the gallon.

affected with a kind of giddiness or intoxication; owing, it may be supposed, to the quantity of fixed air with which the water abounds. The common operation of this water is diuretic; but it is also gently sudorific; and if taken in large quantity proves cathartic. When, however, it is required to have this latter effect, it is useful to mix some salts with the first glasses. It is drunk by glassfuls in the morning, to the quantity of from one to five or six pints, according to circumstances, walking about between each glass*.

Pymont waters are recommended in debilitated and relaxed constitutions, attended with indigestion, low spirits, and want of appetite.

SCARBOROUGH, in *Yorkshire*.—The waters of this place are chalybeate and cathartic; and they are more frequented and used than any other water of this class in England. There are two wells; the one more cathartic, the other a stronger chalybeate. Hence the latter (which is nearest the town) has been called the *chalybeate* spring, the other the purging; though they are both impregnated with the same principles, but in different proportions. The purging is the most famed, and is that which is usually called the *Scarborough* water. This contains fifty-two grains of calcareous earth, two of ochre, and two hundred and sixty-six of vitriolated magnesia, in the gallon: the chalybeate, seventy grains of calcareous earth, one hundred and thirty-nine of vitriolated magnesia, and eleven of sea salt. When these waters are poured out of one glass into another, they throw up a number of air-bubbles; and if shaken for a while in a close stopp'd phial, and the phial is suddenly opened before the

* Elliot, p. 226.

commotion ceases, they displode an elastic vapour with an audible noise, which shows that they abound in fixed air. At the fountain they both have a brisk, pungent, chalybeate taste; but the cathartic water tastes bitterish, which is not usually the case with the *chalybeate*. They lose their chalybeate virtues by exposure, and also by keeping; but the cathartic water soonest. They both putrify by keeping; but in time recover their sweetness*.

The properties of the cathartic and of the chalybeate spring are, as might naturally be supposed, very different. The former is useful in cases of habitual costiveness; the latter in disorders of relaxation and debility.

SPA, in the bishopric of Liege.—‘In and about this town there are several springs, which afford excellent chalybeate waters: and in Great Britain they are the most in use of any foreign mineral waters.

‘The principal springs are, 1. The *Pouhon*, or *Pouhon*, situated in the middle of the village;—2. *Sauviniere*, about a mile and an half east from it;—3. *Groisbeeck*, near to the *Sauviniere*;—4. *Tonnelet*, a little to the left of the road to the *Sauviniere*;—5. *Wairoz*, near to the *Tonnelet*;—6. *Geronstere*, two miles south of the *Spa*;—7. *Sarts*, or *Niverfet*, in the district of *Sarts*;—8. *Chevron*, or *Bra*, in the principality of *Stavelot*;—9. *Couve*,—10. *Beversee*,—11. *Sige*,—12. *Geromont*, all near *Malmidy*.

‘The *Pouhon* is a slow deep spring, and is more or less strong or gaseous according to the state of the atmosphere. The gallon contains ten grains of chalk, thirty of magnesia, ten of mineral alkali, and five of aerated iron. It yields of fixed air one hundred and thirty-two ounce measures. It contains more iron than any

* Elliot, p. 234.

of the other springs, and does not so soon lose its gas. It is in its most perfect and natural state in cold, dry weather. It then appears colourless, transparent, and without smell, and has a subacid chalybeate taste, with an agreeable smartness: at such times, if it is taken out of the well in a glass, it does not sparkle; but after standing a while, covers the glass on the inside with small air bubbles; but if it is shaken, or poured out of one glass into another, it then sparkles, and discharges a great number of air-bubbles at the surface. In warm, moist weather, it loses its transparency, appears turbid or wheyish, contains less fixed air, and is partly decomposed. A murmuring noise also is sometimes heard in the well. It is colder than the heat of the atmosphere by many degrees. It is supposed to contain the greatest quantity of fixed air of almost any acidulous water; and consequently has a remarkable sprightliness and vinosity, and boils by mere warmth. This, however, soon flies off, if the water is left exposed; though in well corked bottles it is in a great measure preserved. It is capable of dissolving more iron than it naturally contains, and thus becoming a stronger chalybeate. This is owing to the great quantity of fixed air which it contains. For the same reason an ebullition is raised in this water on the addition of acids, as they disengage its fixed air. It mixes smoothly with milk, whether it is cold or of a boiling heat.

‘ Of the *Sauviniere* water, a gallon yields 6.5 grains of chalk, 4.5 of magnesia, two of mineral alkali, 3.5 of kali, 2.2 of aerated iron, and 108 ounce measures of fixed air. At the well it has somewhat a smell of sulphur.

‘ *Groisbeeck*. The water is of the same nature as the *Sauviniere*, but contains a somewhat larger proportion of the several ingredients. It has a vitriolic taste, and somewhat of a sulphureous smell.

‘ *Tonnelet*.

‘*Tonnelet*. This is one of the most sprightly waters in the world. It is much colder than either of the other Spa waters; has no smell; is bright, transparent, and colourless; and from the rapidity of its motion does not foul its basin. It has a smart, sub-acid, sprightly taste, not unlike the briskest Champagne wine. From a number of experiments it appears, that this water is more strongly charged than any of the others with fixed air, on which the *energy* of all waters of this kind principally depends, but it parts with it more readily. It contains more iron than any of the springs, except the Pouhon.

‘*Watroz*. Its situation is lowest of any of the springs about Spa, and it is more apt to be foul: but when the well is cleaned out, and the water pure, it is found to be of the same nature as that of Pouhon. It is not cathartic, as some have asserted.

‘*Geronstere*. This water has much less fixed air than the Pouhon. It has a sulphureous smell at the fountain, which it loses by being carried to a distance. This smell is strongest in warm moist weather. The air, or vapour, of this water affects the heads of some who drink it, occasioning a giddiness or kind of intoxication; which goes off in a quarter or half an hour. The Pyrmont, and several other brisk chalybeate waters, are found to have the same effect. It is colder than any of the springs, the Tonnelet excepted.

‘*Sarts, or Niverfet*. It resembles the Tonnelet water, but is rather less brisk and gaseous. It is however more acid and styptic.

‘*Bru or Chevron*. The physicians at Liege have artfully decried this water, because it is not in the principality of Liege. But by every trial it appears not much inferior to any of the Spa waters. In the quantity of fixed air and of iron it contains, it approaches the Pouhon.

Couve and *Beversee*. The *Couve* nearly resembles the *Tonnelet* water; or rather, may be placed in a medium between that, and the *Watroz*. It hardly equals the transparency, smartness, and generous vinous taste of the first, but it greatly surpasses the latter. The *Beversee* agrees with this, only that it does not retain its smartness so well by keeping.

La Sige has some of the general properties of the *Spa* waters, but in other respects it is different. It is moderately subacid, smart and grateful, but has no sensible chalybeate taste. It sparkles like *Champaign* when poured from one glass to another. Upon standing it loses its fixed air, and throws up a thick mother-of-pearl coloured pellicle. It is much more loaded with earthy matters, and less impregnated with iron and fixed air, than the other *Spa* waters.

Geromont. As a chalybeate and acidulous water this seems to be nearly of the same strength with *La Sige*; but it contains a greater quantity of natron, together with a mixture of sea salt. The earthy matters, however, are less.

It appears, that these waters are compounded of nearly the same principles, though in different proportions. All of them abound with *fixed air*. They contain more or less iron, alkali, and calcareous and selenitical earths; together with a small portion of sea salt. These are all kept suspended, and in a neutral state, by means of the aerial acid, or fixed air. From a review of the contents of these waters, it cannot be imagined that their virtues principally depend on the small quantity of *solid* matters which they contain. They must therefore depend mostly on their *fixed air*. And they are probably rendered more active and penetrating both in the first passages, and also when they enter the circulation by
means

means of that small portion of iron, earth, salt, &c. with which they are impregnated*.

After all that has been alleged in favour of mineral waters, it must be confessed that their medical virtues are at best rather dubious. With respect to the metallic salts which they may contain, the quantity is too minute to be very efficacious in obstinate complaints; and the warm baths have probably no other effect than a quantity of common water heated to the same temperature would have, if applied by means of an artificial bath at home. Where good effects have been wrought upon a patient's resorting to a mineral water, physicians have not always considered the excellent consequences which in the common course of things might be expected from the exercise of the journey, the change of air, and change of scene; from cheerful company, and, though last, not least, perhaps, from the imagination of the patient.

* See Elliot, p. 249, &c.

APPENDIX.

TABLE OF SPECIFIC GRAVITIES.

D ISTILLED water	1000	Copper	- - -	8873
Calcareous earth	2723	Iron	- - -	7788
Magnesian earth	- 2155	Tin	- - -	7299
Barytic earth	- 3973	Bismuth	- - -	9823
Argillaceous earth	- 1669	Nickel	- - -	8660
Siliceous earth	- 2650	Arsenic	- - -	5763
Bottle glass	- 2732	Zinc	- - -	7191
White glass	- - 2892	Antimony	- - -	6702
Flint glass	- - 3329	Manganese	- - -	6850
Seves porcelain	- 2145	Cobalt	- - -	7811
China ditto	- 2384	Tungstein	- - -	6066
Lime stones, from	- 1386	Molybdena	- - -	4738
_____ to	- 2390	Vitriolic acid	- - -	2472
Common slate	- 2672	Nitrous acid	- - -	1682
Muscovy talk	- 2792	Muriatic acid	- - -	1085
Calcareous spar	- 2715	Fluor acid	- - -	1500
Fluor spar	- - 3180	Oil of olives	- - -	915
White marble	- 2716	Linseed oil	- - -	940
Diamond	- - - 3445	Burgundy wine	- - -	991
Ruby	- - - 4213	Bordeaux ditto	- - -	993
Topaz	- - - 3460	Malmfey madeira	- - -	1038
Emerald	- - - 3600	Cyder	- - -	1018
Hyacinth	- - - 3764	Woman's milk	- - -	1020
Garnet	- - - 3978	Mare's milk	- - -	1034
Tourmaline	- - - 3050	Cow's milk	- - -	1032
Opal	- - - 2764	Goat's milk	- - -	1034
Cat's eye	- - - 2240	Ewe's milk	- - -	1040
Onyx	- - - 2600	Elastic gum	- - -	933
Carnelion	- - - 2704	Naptha	- - -	708
Common flint	- - - 2700	Camphor	- - -	989
Jasper	- - - 2778	Spermaceti	- - -	943
Quartz	- - - 2654	Tallow	- - -	942
Agate	- - - 2590	Vitriolic æther	- - -	739
Gold	- - - 19640	Nitrous æther	- - -	909
Platina	- - - 22000	Muriatic æther	- - -	730
Mercury	- - - 13568	Acetous æther	- - -	866
Lead	- - - 11352	Purest spirit of wine	- - -	820
Silver	- - - 10474			

TABLE

TABLE of the weights of the different gasses at 29. 84. English inches, barometrical pressure, and at 54. 5° of temperature, according to Fahrenheit's thermometer, expressed in English measure, and English troy weight. From Lavoisier's Chemistry.— The weight of the five first were ascertained by M. Lavoisier himself; the last three were inserted by M. Lavoisier on the authority of Mr. Kirwan.

Names of gasses.	Weight of a cubical inch.	Weight of a cubical foot.		
		oz.	dr.	grs.
Atmospheric air - -	32112	1	1	15
Azotic gas - -	30064	1	0	39 . 5
Oxygen gas - -	34211	1	1	51
Hydrogen gas - -	2394	0	0	41 . 26
Carbonic acid gas - -	44108	1	4	41
Nitrous gas - -	37000	1	2	39
Ammoniacal gas - -	18515	0	5	19 . 73
Sulphureous acid gas - -	71580	2	4	38

END OF THE SECOND VOLUME.







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