Surgeon General's Office
LIBRARY.
ANNEX
Section,
No. 26864

LECTURES

ON THE

Elements of Chemistry,

DELIVERED

IN THE UNIVERSITY OF EDINBURGH;

BY THE LATE

JOSEPH BLACK, M. D.

PROFESSOR OF CHEMISTRY IN THAT UNIVERSITY;

PHYSICIAN TO HIS MAJESTY FOR SCOTLAND; MEMBER OF THE ROYAL SOCIETY OF EDINBURGH, OF THE ROYAL ACADEMY OF SCIENCES AT PARIS, AND THE IMPERIAL ACADEMY OF SCIENCES AT ST. PETERSBURG.

PUBLISHED FROM HIS MANUSCRIPTS

BY

JOHN ROBISON, LL. D.

PROFESSOR OF NATURAL PHILOSOPHY IN THE UNIVERSITY OF EDINBURGH.

FIRST AMERICAN EDITION FROM THE LAST LONDON EDITION.

VOL. II.

426664

PHILADELPHIA:

PRINTED FOR MATHEW CAREY, NO. 122, MARKET-STREET,
BY B. GRAVES, NO. 40, NORTH FOURTH-STREET.

1806.

Annex
QD
28
B627L
1806
v.2

LECTURES

ON

CHEMISTRY.

THE CHEMICAL HISTORY OF BODIES.

INTRODUCTION.

HAVING acquired some knowledge of the general effects of heat and mixture, the great chemical agents in nature, you are enabled to understand the more particular doctrines of chemistry. These comprehend the description of all the great classes of natural substances, and the peculiarities which are observed in the effects of heat and mixture upon each; which peculiarities serve as distinguishing characters of each, ascertaining what may be called their chemical nature, qualities, and powers. It is thus that we are able to distinguish gold from lead. The first bears the most intense heat of our furnaces, and the action of air, while thus subjected to heat, without any change in its qualities; whereas the same treatment will quickly change the lead into dross or glass. These peculiarities, being constant and uniform, give us certain marks of distinction, and also enable us to employ both substances for very interesting purposes.

If the peculiar effects of heat and mixture on an individual body be altogether peculiar to itself, the study of them would be endless. But there are certain classes of

natural substances, on which these agents produce effects so similar, that one of them may be taken as the representative of all the rest. Philosophers have taken much pains to class the substances that we see around us, by means of those resemblances in the effects of heat and mixture that have been observed; and have thus obtained a chemical arrangement of natural substances, which makes the study of their properties much more expeditious and comprehensive.

In thinking on a proper method, the one which occurs the most readily, and which appears at first sight the most proper, is to begin with an account of the elements, or elementary kinds of matter, of which all things are composed; and, after explaining the powers and properties of those elementary substances, to shew how, by their various combinations with one another, they give rise to the various productions of nature. nd, that there is some foundation for thinking of such an order or system, is sufficiently plain. It is evident that there are in reality certain elements, or elementary substances, which are few in number, and of such a nature as to be exempted from decay or change, but capable of being variously compounded together, and separated again, so as to give origin to the productions which we see daily arise, and to the perpetual changes of one form or state of matter into another.

This is evident from the constant regularity and general uniformity of the productions of nature. There is a certain succession and rotation of forms which the same matter undergoes, and through which it has repeatedly passed with regularity, from the beginning, or from the earliest account of time, of which we have any knowledge. At least, any examples of irregularity that occur are so inconsiderable in number, that they may be overlooked. The water arises in vapours from the ocean, chiefly to form the clouds; these again descend upon the dry land in rain, which, penetrating the soil, occasions and supports the vegetation of plants. The greater number of plants serve for the nourishment of animals; all of which, with the remaining plants, are dissolved again at last, and

return to the elementary substances from which they were originally composed, and from which similar plants and animals are to be produced.

This rotation has continued from the earliest accounts of time, in the most steady and regular manner. The productions of nature have not only succeeded one another in the same general order; but have been from the beginning, so far as our knowledge reaches, invariably the same. An oak of the present time has the same general nature, and the same properties, as those of all other oaks that have ever existed. We find the same texture in its wood and bark; a similar disposition in general in the root and branches; the leaves have the same form; the juices the same astringent power; the fruit is moulded to the same form of an acorn, and has the same invariable property of never producing any other tree than an oak.

All this shews that the elements of bodies are permanent and unchangeable. Had they been liable to any gradual change or decay, the oaks of the present times, composed of those changed materials, would not be found to have the same qualities as the oaks of remote ages: and the order and course of nature, as well as the qualities of her productions, would have been undergoing a gradual change, which, so far as our knowledge reaches, has not actually taken place.

Such obvious reflections on the course of nature have, in the earliest ages of philosophy of which we have any accounts, suggested the supposition of a certain number of unchangeable elements, of which it was imagined all things were composed, and on the successive separations and reunions of which, depended the decay and reproduction of the objects which nature presents to our view. This was the meaning of the opinion ascribed to Democritus, That all things were formed of atoms. And others of the Greeks, in consequence probably of their intercourse with the Egyptian philosophers, began to form and teach a system upon this subject. They assigned four elements, or elementary kinds of matter, viz. fire, or the matter of *fire*, *air*, *water*, and *earth*. And by the different combinations

of those elements, they supposed that all the different bodies in nature were formed.

These four supposed elements were accordingly considered, until very lately, as the primary elements of natural bodies; insomuch, that Mr. Macquer, in his System of Chemistry, thought it proper to begin by treating these four kinds of matter as elementary; and endeavoured to explain the nature and qualities of some of the productions of nature, which he first describes by assigning the number of these elements which he imagined entered into their composition. But it appears from the sequel, that he was not fortunate, nor sufficiently considerate, in choosing this method.

In the first place, chemistry gave, at that time, too little light into this subject, to enable him to form a system of this kind with any degree of assurance. On the contrary, there were many reasons for doubting, even at that time, that these four supposed elements were in reality simple, elementary, and unchangeable substances; and now, we have direct evidence from experiments, that most of them are not.

Atmospheric air has been demonstrated to be a compound mass of more than two or three different kinds of matter.

Water is also believed now to be a compound body.

And of the purest and most simple earthy matter, six or more different kinds are now reckoned, which we cannot reduce to greater simplicity by our operations.

The truth is, that our knowledge of nature is not yet brought to that state of advancement, which might enable us to follow, with propriety, an order of this kind. We have advanced a considerable way in our analysis of many different substances. But our knowledge of their composition and origin is far too imperfect, to give solid foundation for an attempt to arrange them, or to explain their different qualities, by beginning from their ultimate elementary principles. We should certainly be in danger of falling into many errors and mistakes by such an attempt.

To avoid this, therefore, I do not pretend to determine what are the ultimate elements of bodies. I content myself

with distinguishing and dividing the principal objects of chemistry into a number of classes, each of which comprehends substances that bear a remarkable resemblance or analogy to one another, in their chemical properties, and differ from those comprehended in the other classes. And I offer these classes to your consideration in what appears to me to be the most convenient order;....I mean the order in which the most independent, and I may say elementary *facts*, are first stated; and the rest are described afterwards, in that succession and order in which they can be explained and understood, by the knowledge of the facts and doctrines that have been stated before them.

An attempt to form classes, or assemblages, of the objects of chemistry, was made long since by the elder chemists, and their classes were three in number. They chose to give them the title of *kingdoms*. The *first* comprehended all animals and animal substances; the *second* the vegetables; and the *third* fossils. These assemblages may appear at the first view to have some foundation in reason, but they are in fact very improper. They bring together a great number of objects, which have no similarity in their chemical properties, and they separate others, which, being similar, or the same in a chemical view of them, ought certainly to be assembled and considered together.

In the arrangement which has prevailed for some time past among the chemists, and which I have found to be the most suitable to our purpose, the objects of chemistry are distinguished into five classes, which are, 1st, *The Salts;* 2dly, *The Earths;* 3dly, *The Inflammable Substances;* 4thly, *The Metals;* and 5thly, *The Waters.*

These classes take in a great part of the materials of which the animal and vegetable substances are composed. But yet there are some of these materials that do not, on a first consideration, easily find a place in any of these classes. And beside this, the animal and vegetable substances are compounded in such a particular manner, that they have some chemical qualities peculiar to themselves on that account alone. For these reasons, it is proper and

necessary to take a chemical view of the vegetable and animal substances, after the five classes already mentioned have been considered: and this shall accordingly be done in the end of this course.

N. B. It may perhaps be thought that we shall be guilty of an omission, if we do not constitute a class of AIRS or GASES, as they are now named. But there is no necessity for constituting such a class, and even the propriety of it may be called in question.

These gases are acknowledged to be various kinds of matter, combined with latent heat, or the matter of heat, the *calorique* of the French chemists. And why should substances of such very different natures be assembled into one class? For this reason alone, that they were combined with latent heat, and thereby reduced to a form or condition, to which many other bodies can be reduced by it. We might as well think of classifying the objects of chemistry into those that are hot and those that are cold, or into those that are solid and those that are fluid, which would be very improper, when it is in our power to make the same body hot or cold, or solid or fluid. It must be confessed that we have not been able hitherto to deprive some of the gases of their latent heat, and to reduce them to a condensed state, without combining them with other matter; but this is certainly in our power with regard to others; and means may possibly hereafter be discovered for condensing them all. But whether this should succeed or not, there is no reason for assembling into one class substances, which are, in fact, more dissimilar in their chemical properties than any substances that we know; and resemble each other only in a quality, almost purely mechanical (their elastic fluidity) merely because they derive this aërial form from heat combined in them.

But, although it appears improper to form such a class, I do not mean to leave these substances unnoticed. Very convenient opportunities will occur during this course for bringing them into view, and I shall not fail to make you thoroughly acquainted with them all. *(See Note 26, at the end of this Volume.)*

In prosecution, therefore, of the arrangement that I mentioned as peculiarly convenient, I begin with the consideration of CLASS FIRST.

CLASS I.

SALTS.

THIS class is placed first because the knowledge of their properties, both general and particular, is almost indispensably necessary for the investigation of the interesting properties of all other substances. They stand in very interesting relation to every chemical substance; and thus are considered as the most general agents in the way of mixture. This, of itself, raises a surmise that they are of a very simple nature, and nearly allied to the elements of which all are composed. This has been a very current opinion and has been supported by specious arguments. But I apprehend, that before we have gone over the five classes of our arrangement, we shall find the proofs becoming very weak indeed.

In describing the salts, I shall first enumerate the qualities common to them all, and afterwards take a nearer view of their several kinds. Moreover, as, in defining chemistry, I said that it is the study of the effects of heat and mixture on all bodies; so, in enumerating the chemical qualities of salts, and, indeed, of all bodies of whatever class, I shall first describe the effects of heat on them, and afterwards, the consequences of mixing them with one

another, and with other bodies. Moreover, in doing this, I subject myself to a rule which I shall endeavour to follow, with all reasonable strictness, through the whole of this course, namely, that while I am treating any particular substance, or class of substances in the way of mixture, I shall mix them with *those others only* which have been already described. If I cannot rigidly abide by this rule on every occasion, I shall be careful to consider the mixture with substances which are as far known to you as the argument proposed by the mixture may require. No quality of the other substance shall be employed in the argument, but such as is known with the fullest evidence, and understood, as far as I shall employ it in argument. The result of this caution on my part, will, indeed, be a slower progress than may be acceptable to some impatient minds: but the knowledge which we shall acquire will be more confident and satisfactory. Sir Isaac Newton said to a celebrated foreigner, who was complimenting him on his wonderful discoveries, and the greatness of his genius, which was able to comprehend such vast objects "Indeed, "Sir, you are in a mistake on both points. The objects "are, indeed, vast and magnificent; and therefore I made "a choice fortunate for my reputation. But they are "comprehensible by the most ordinary genius, if he will "take my method,....never to hurry. If I have any ad- "vantages over other naturalists, it is only in a more "patient thinking, in which I perhaps exceed many of "them. To this I am indebted for all my success." Let us imitate the patience of this great man, and hope that we shall have some portion of his success.

In compliance, therefore, with my rule, in the consideration of the saline substances, I shall, at present, take notice of such qualities only as they manifest in mixture with water, and with one another, deferring the effects of mixing them with earths, metals, and other bodies, till we consider those classes themselves.

OF SALTS IN GENERAL.

In the definition which is commonly given of a salt, an attempt is made to enumerate the qualities by which salts are known to agree with one another, and to differ from other classes of the objects of chemistry.

Thus, the *salts*, in general, are said to be *substances easily melted, or volatilized by heat, soluble in water, not inflammable, and sapid*, or, when applied to the tongue, producing the sensation of taste.

Some objections may be offered to this definition; but it is impossible to contrive a definition of them that will be free from all objections: and the same difficulty occurs in attempting to define any other assemblage or class of the productions of nature. There are, in reality, no classes in nature distinctly defined; the productions of nature are so very numerous, and so much diversified, and there is such a gradation throughout the whole, from one to another, that it has been found impossible to arrange them into classes precisely limited, and liable to no exceptions.

I shall not, therefore, be anxious to give an unexceptionable definition of the salts. I hope to give you better information of them, by entering into their history, and by enumerating their qualities.

The most pure state in which we can exhibit the salts, or the state under which they are the most free from admixture with all other matter that is not salt, is the form of a white, hard, brittle mass, more or less transparent, and, in some cases, perfectly transparent.

The effect of heat on salts is first to produce fusion, with an appearance like white wax. All the salts can be melted in this manner, but they require very different heats to their fusion. Most of them require different degrees of red heat. When cooled, they return to their former state: and it is only by fusion that they are brought to that now described.

Salts can also be made to assume the form of vapour, by heats under our command. But they differ still more widely with respect to the force of heat necessary to pro-

duce this effect. Some require the most violent heats that we can raise. Others are so volatile that they are disposed to assume the form of vapour even in the ordinary heats of the air. Their differences in this respect shall be mentioned when we are describing the different kinds of the salts. And this is all we can say in general of the manner in which salts are affected by heat.

In relating the effects of mixture upon salts, we can only mention at present the effects of mixing them with water, and some of those produced by mixture with one another. Water is the only body which, in the way of mixture, produces effects upon salts that can be considered as general, or which are similar in a certain degree on all the different salts. And one of these effects has been mentioned already in defining salts, when we said they are bodies soluble in water.

All saline substances, when thrown into water, dissolve in it more or less readily. This is so well known and familiar a property of all salts, that it is inseparably connected with the idea of salt in the mind of a chemist.

There is therefore an attraction between water and salts, a disposition to combine by chemical union. The only difference of salts from one another in this respect, is in the force of this attraction, which is very different in the different salts. It is in some so powerful, that they attract the humidity which is contained in an imperceptible state in common atmospherical air, and are dissolved by that humidity into a liquid. Such salts, therefore, are called deliquescent salts, as I remarked formerly: and it requires the utmost care to keep them in the solid form. They must be kept in vessels very accurately closed.

When we dissolve a salt in water, we have an opportunity of observing several phenomena :

1. The first which occurs, is the separation of part of the air which the water contains, and that which generally adheres to the salt. The moment the salt dissolves in the water, this fluid appears white or turbid. And when we examine the cause, we find numerous little bubbles of air, which in a short time rise to the top, and then the solution becomes transparent. This is an example of elective at-

traction or separation of two bodies by means of a third. *(See Note, 27, at the end of the Volume.)* This separation of the air from the water is more sudden and violent, if the water be made boiling hot before the salt is added; a violent momentary ebullition takes place, almost like an explosion.

2. A second particular observable when we dissolve a salt in water, is, that the sensible heat of the mixture undergoes some change. In the greatest number of cases, the mixture becomes colder than the materials were before: but, in some cases, it becomes warmer. Even the same salt, added in different states to water, will increase the sensible heat of the water at one time, and diminish it at another.

The late Dr. Irvine supposed that the capacity of the mixture for heat is changed; and it appears to be so from some late experiments*.

3. A third particular which comes under our observation in dissolving salt, is, that the more we dissolve in the water, the more slowly it dissolves the further additions of salt, until a certain quantity has been added; after which it dissolves no more. The water is then said to be saturated; and the solution is called a saturated solution. But this proportion of salt, which saturates water, is found to be very different, when we make the experiment, either with salts of different kinds, or with water of different degrees of heat. In trying the different salts, we find that each of them differs from almost every other. Some require twenty times their weight, or more, of the water, to dissolve them; while others are so soluable, as to dissolve

* The experiments on this subject were, in general, in this form: the heat required for changing the temperature of the materials one degree, was ascertained; as also the heat necessary for changing that of the mixture. In several cases, the last was found greater or less than the sum of the two others, according as the mixture produced cold or heat. Hence Dr. Irvine was induced to confide more in the truth of his general principle. But Mr. Gadolin, and afterwards Lavoisier, and De la Place, shewed that there was no steady connection between those phenomena, the exceptions being equally numerous, if not more so; and the phenomena appear, as yet, altogether, anomalous. EDITOR.

perfectly in less than an equal weight. And the greater number of those very soluble salts shew, by other particulars, that they have a stronger attraction for water than other salts. Such salts attract it from moist air, and run *per deliquium*, becoming perfectly fluid, with a very small quantity of water. Moreover, these salts, without exception, retain the water, more strongly than others, when we attempt to separate it by heat. The other salts, which are less soluble, or require much water, are not liable to deliquescence, and are more easily deprived of it by heat. But the solubility of most salts is greatly affected also by the heat of the water.

This is a curious subject, and the intimate knowledge of it requires, and leads to very nice speculations concerning the manner of chemical action. But I find that it will be long before we can safely proceed in this way. It is better for us to be contented with accurate and extensive observation of the facts. It will be no mean service to the chemist, to state, in a number of important cases, the proportion in which water dissolves salt at different temperatures. You will find a considerable collection of this kind by a Mr. Pfaehler, in Rozier's Journal for 1775, and occasional observations by almost every chemical writer.

The most simple and unexceptionable form of the experiment is to throw into cold water a greater quantity of salt than it can dissolve. Having made a saturated solution in that temperature, pour it off into a vessel, in which it may be made warmer to any degree. Pour into this solution more salt than it can dissolve in that temperature; and pour off the saturated solution, to be treated in the same manner at a higher temperature, and so on. Having noted the quantity of these solutions, (by weight) and knowing the strength of brines of different weights, we obtain the degrees of solubility corresponding to different temperatures. The difference in some salts is very great. A salt, which you will afterwards know by the name of S. de Seignette, requires an ounce of water, of the temperature of 50°, to dissolve 37 grains. But an ounce of boiling hot water dissolves 640 grains, nearly 18 times as much as the cold water. Nitre is about 7 times more soluble in

boiling water, than at 50° : Glauber's salt is about $3\frac{1}{2}$ times: green vitriol is about 8 times, &c. &c.

My friend Dr. Hutton engaged in a series of experiments of this kind, and conducted them in the form I have been describing. He did not content himself with trials in two extreme temperatures, but took three or four for each salt. This showed him that the progress of solubility was not equable in any salt, but that, in most of them, the solubility increased faster than the temperature : for, when he took a temperature half way between the two extremes, he found that the difference between the quantities of salt dissolved in the hottest water, and in that of mean temperature, was generally greater than the difference between this last and the coldest solution.

Hence it followed, that the salt contained in a pint of the hottest, and a pint of the coldest, was more than was contained in two pints of the mean temperature, (all three being saturated solutions); and, therefore, if the two extreme solutions were mixed, the mixture should not be able to keep the salt dissolved. He found, accordingly, that it did not, but made an instantaneous, and, sometimes, a copious precipitation. He also observed considerable deviations from the temperature which he expected on mixture. It were to be wished that he had prosecuted these curious experiments ; for this general law which he observed is a curious and important one. But his attention was called off by a most important consequence which he deduced from it, namely, if the solubility of water in air observes such a law, it follows, that two saturated strata of air, of different temperatures, cannot mix without precipitation. On this he has founded his Theory of Rain ; a theory which explains some of the greater changes in our atmosphere more perspicuously than any I know. *(See note* 28, *at the end of the volume.)*

This observation holds true with respect to most salts. Perhaps there is only one which we can say is an exception, viz. Common Salt. Macquer says that all deliquescent salts are exceptions ; but this is not just. Besides, it is not easy to determine what salts are deliquescent, and what not.

From some of the particulars already stated, as observable in dissolving the salts, you will perceive the foundation of an opinion of Sir Isaac Newton concerning those solutions. He supposed that the particles of a salt dissolved in water are equidistant from one another through the whole of the water, and, therefore, arranged in a regular order, or, as he expresses it, in rank and file. This arrangement is, in reality, a necessary consequence of some of the particulars we observed in the action of water upon salt. We find that water has a stronger attraction for salt, in proportion as it is purer, or contains less salt; for, in proportion to the quantity of salt it already contains, it dissolves further additions of salt the more slowly. This is all the proof that we can desire, that it is acting upon them with a weaker attraction, or dissolving power, until it have dissolved a certain quantity, after which it cannot dissolve any more. It is, therefore, evident, that if, in a solution of salt, any part of the water contain less salt than the rest, that part must have a stronger attraction, and must draw some particles of salt from the others into itself, until the salt be distributed through the whole with the most exact equality and regularity; and the particles of it are, therefore, equidistant throughout the liquor.

When we examine the solidity of this reasoning by an experiment, we have the pleasure to find facts agree exactly with the theory; for, however unequally the salt be distributed in the liquor at first, it is sure to spread from the parts which contain most, to those which contain less, until it is equally diffused through the whole.

But it is proper, however, to observe on this occasion, that when the liquor is preserved from external disturbance, this progress of the saline particles through it is excessively slow. This is the proof of the assumptions on the other side, namely, that an internal motion is necessary. It requires so long a time, that an impatient and inconsiderate observer will perhaps conclude that it does not take place. But it is easy to explain why it requires so much time. There are two causes of this: 1*st*, the weight of the saline particles, which are heavier than those of the water, generally about twice as heavy; and, 2*dly*, the very

small distance to which chemical attraction reaches round the particles of bodies. You will perceive the effect of these two causes, if you consider with a little attention what must necessarily happen, in a solution in which the salt is unequally distributed through the water. Let us suppose, for example, that I put into a glass a certain quantity of a saturated solution of salt, and a quantity of pure water, without mixing them together by agitation, which will be best done by introducing the saturated solution under the water, by means of a funnel and pipe reaching to the bottom of the glass ;...the solution being poured slowly into the funnel, will rise quietly under the water, and they will be separated by a surface perfectly even. The solution of a deep-coloured and heavy salt is the best for this purpose. Blue vitriol answers very well. It must immediately happen, that the lowest part of the pure water, which is in contact with the upper surface of the solution, while it draws up some particles of salt out of that upper surface, must form an horizontal stratum, or layer of fluid, which will be less salt than the saturated solution, and which will be interposed between it and the pure water. No sooner does this take place, than the lowest part of this stratum will draw up more salt from the saturated solution upon which it lies ; while at the same time, the pure water will draw up some salt out of the upper surface of the stratum. And thus innumerable strata will be produced within a very small space, and in a very short time,...all lying between the pure water and the saturated solution ; the lowest of which will contain less salt than the saturated solution, and each of the rest less than the one immediately below it. But when matters are in this condition, every two contiguous strata, which (on account of the extremely small distance to which chemical attraction reaches) are the only ones that can act on one another, must act with an extremely weak force. The upper one must draw salt from the one under it very weakly, for this reason, that they differ very little from one another in saltness, and therefore in attraction for salt. And, for the same reason, the pure water above will have but a weak power to draw the salt up from the uppermost and most

diluted stratum. And now, if we consider that the particles of the salt are heavier than those of the water, it is easy to conceive how their gravitation, together with the resistance they must meet with in moving through the fluid, must almost counterbalance the force with which they are drawn up, so as to render the motion excessively slow.

The slowness with which the equal diffusion of a salt in water is performed, when left to itself, is therefore evidently a necessary consequence of the very small and imperceptible distance to which chemical attraction reaches, and also of the greater weight or gravitation of the salt than of the water*. And I thought it was worth while to give a clear view of the matter, once for all, that you may understand better how to make solutions of salts, for different purposes, and the necessity of employing mechanical agitation to promote the equal distribution of the salts through the whole of the water, in a moderate time. In some of the arts, great mistakes have been committed sometimes, in consequence of the ignorance of this necessity. In the bleaching of linen, for example, and some other arts, the vitriolic acid is employed in part of the process, very largely diluted with water. A careless workman may think it enough to pour in the proper quantity of acid, not recollecting that its great weight will keep it at the bottom, and that if it be not stirred briskly about, it may be long ere it be equably diffused through the water. When goods are

* It is, indeed, the clearest proof of the nature of chemical action, and of the very small distance to which it extends. It shews that it does extend to some distance, otherwise there would be nothing to move a particle out of its place. However strongly particles attract one another in absolute contact, this may cause them to cohere, but will never move a quiescent particle out of its place. I must at the same time observe, that some solutions of saline substances manifest an inequality in their saturation, even after we have reason to think them perfectly uniform. When a strong solution of sal ammoniac, or of saccharum saturni, has been made perfectly uniform by agitation, it becomes unequal, in a small degree, by long keeping, the lower strata containing more salt than the upper. It is accompanied by a very curious circumstance. If the solution be poured into a hollow glass prism, having the angle downwards, and it be allowed to remain undisturbed for some months, it acquires a double refraction, like rock crystal.—EDITOR.

put in to be soured, they get into this very acid and corrosive part of the liquor, and are frequently eaten into holes by it.

Remember, therefore, when you dissolve or dilute salts in water, to quicken the equal distribution of the salt by agitation: and be assured, that if there be enough of water, the salt will remain for ever after equally diffused throughout the whole.

It is somewhat surprising that the solutions of many salts begin to boil with a less heat than pure water does. But they soon rise to a temperature considerably above that of boiling water, and nearly the same in them all. I observe that this first boiling is sudden and transitory; so that I think it probable that it is the disengagement of air which adhered to the salt. I observe, that on pouring boiling water on a solution of salt, or throwing salt into boiling water, there is a sudden puff of ebullition like an explosion.

Most of the salts may be separated from water by evaporation, because the greater number are much less volatile than water, and do not adhere with such great force as greatly to diminish the volatility of the water.

But this evaporation may be conducted in two ways, either briskly and uninterrupted, till all the water is dissipated; or partially, and by repeated operations. The consequence of the first method is, that the salt remains, forming a white mass like chalk, or hardened lime-mortar, adhering more or less to the vessel in which the evaration was performed.

This is called EVAPORATION TO DRYNESS; and is attended, in most cases, with the loss of some of the salt, which evaporates with the water, in consequence of their mutual attraction.

But the second method is that which is commonly followed, at least with regard to a number of salts which are prepared in large quantities for sale, such as Glauber's salt, saltpetre, alum, vitriol, and others. And the consequence of this method of proceeding is, that the salt is obtained in a different form. This method consists in evaporating a solution to a certain degree, so that though the water

which remains is still sufficient to retain all the salt dissolved, as long as it is kept warm over a fire; it is too little, however, to retain it all dissolved when it is cold. If it be taken off, therefore, and allowed to cool, a part of the salt must, and does separate.

A salt deposited in water in this manner is always formed into angular masses, having polished surfaces, more or less of a regular figure, and transparent. These masses are called CRYSTALS, from their resemblance to the natural stones of that name. And one of the most curious particulars belonging to this subject is, that each distinct species of salt has a figure of its own, which it affects in its crystals, not always with exact regularity, but with such a degree of it, that, upon the whole, a person well accustomed to view the crystals of different salts, will in most cases be able to tell, by the figure and appearance of the saline crystals, from what salt they were produced. Nevertheless, a judgment formed in this way is far from being so sure as has been imagined.

This method of separating salts from water is called CRYSTALLIZATION, from its effect: And as it is practised often, you will find in books several directions for performing it right. But it is difficult to give any that will suit all the different kinds of salts; as they require different conduct. The common direction is to evaporate TO A PELLICLE; that is, till the surface of the solution exhibits a thin film, which glistens when viewed obliquely; and, when narrowly examined, is found to consist of minute crystals. It is formed on the surface, because the gentle evaporation goes on there. But if you proceed so far with the evaporation, few of them will crystallize right; as too little water will remain, too much salt will be deposited, and the crystals will be small and confused. In general, it is usual to filtrate the solution, if it be foul; because a particle of solid matter any where in the fluid, becomes a centre of crystallization, (as may be observed in the threads hung in syrop for the manufacture of sugar-candy) and this happening all over a solution that is foul, makes the crystals small and confused. We must then evaporate it to a moderate degree, cool it slowly, and avoid disturbance; and,

pouring off the liquid, we repeat the same operation on it. Those who prepare very large quantities of particular salts for sale, as Glauber's salt, saltpetre, &c. have better, or at least larger, crystals, on account of the large quantity, and slow refrigeration, than can easily be obtained from small quantities in the way of experiment.

But some of the salts do not afford good crystals by this method, and agree better with an uninterrupted, but slow and insensible evaporation, with a heat like that of the human body, or with a spontaneous evaporation, merely by exposure to the air. In this way the water is diminished in so slow and gradual a manner, that the saline particles, in approaching one another, have full time and opportunity to assume that arrangement and mode of concretion, to which they are naturally disposed. The crystals, therefore, are formed more regular and fine than by other processes; but this method of obtaining crystals is far too slow for common use.

I am informed that some of the trading chemists in London, who prepare specimens for the curious, have particular secrets by which they procure large and fine crystals; and that these secrets consist in the addition of certain fatty matters, and making the solution in lime-water, and close vessels. It is certain, that in the great manufactures of salt-petre, alum, copperas, borax, &c. things of this kind are used with success. Urine is a very general addition; and I am assured that fine crystals of copperas and borax cannot be had without it. I have tried lime-water: and it certainly gives most elegant crystals of saltpetre, superior to any that I can obtain without it. But it seems to have no such effect on Glauber's salt, soda, or Epsom salt, the only other salts on which I have tried it.

Some authors speak much of the influence of light on the formation of crystals; but I observe none*. Others say that a mass of crystallized salt being placed in contact,

* Chaptal has, I think, proved it beyond contradiction, in a memoir presented to the Royal Academy, 1780. I am certain of its influence in the crystallization of the vapours of salt of hartshorn, and of camphor. These salts are also singularly affected by electricity. EDITOR.

or even very near the outside of the vessel, greatly affects the crystallization. I am persuaded that this is a mere fancy. The directions I have already given are the only rules that have been generally successful with me, and I think they are supported by any little knowledge that we have acquired of the internal procedure.

In evaporating solutions of salts, especially when the evaporation is very slow, an accident often occurs, which may create surprise, and may prove troublesome to a person who is not accustomed to it ;....I mean what is called the EFFLORESCENCE or VEGETATION of salts. This is a peculiar concretion of salts from water. When the evaporation is carried on in a deep vessel, so as the concretion cannot rise so high as to get over the lip, it shoots and spreads sometimes in the upper part of the glass into branched figures, resembling irregular foliage. And some of the more enthusiastic chemists have imagined that they perceived in it an exact resemblance to the leaves and ramifications of plants : and, if the salt was obtained from a plant, they supposed that it still retained something of the vegetating nature of the plant from which it was produced. But this is an imaginary, and perfectly groundless fancy. The resemblance between such concretions of salts and vegetation is accidental, like that of the frozen humidity which is condensed on the inside of glass windows in hard frost. This depends on the same cause as crystallization.

This vegetation, as it is called, is often troublesome to the chemist. After reaching the lip of the vessel, it creeps down the outside : and as soon as it gets as low as the surface of the liquor, the whole becomes an assemblage of syphons, and our solution runs over and is lost. This may be prevented by covering the vessel with a piece of tin plate, having a round hole cut out of it, about two inches less in diameter than the rim of the evaporating dish. This prevents the evaporation at the edges, and even occasions a dew, which will trickle down the side of the dish. I find this a complete preventive.

It happens sometimes, in attempting to crystallize some salts, that although the liquor be duly evaporated, and then

allowed to cool, it does not crystallize : the whole remains still fluid. This happens only with some of the salts, and only when the saline liquor is allowed to cool slowly and without being disturbed. If we disturb it when it is thus cooled, it suddenly crystallizes, and at the same time becomes warmer by several degrees. It is therefore evident, that its protracted fluidity proceeded from a quantity of heat, which it retained in the form of latent heat, in consequence, I am persuaded, of a chemical attraction which the materials of the mixture have for heat in that state. As this is a curious and instructive experiment, you will derive advantage from a few instructions for making it succeed in the best manner. Glauber's and Epsom salts are those which exhibit it to most advantage. Alum and copperas also do very well. Take crystals that have been formed in a solution carefully filtrated, that there may be no foulness ; put them into a flask with distilled water, a little more than enough for dissolving the whole with a boiling heat ; set the flask into a pan or tea-kettle of cold water ; and set the whole on the fire, and keep it boiling till all the salt is dissolved ; take out the flask from time to time to agitate the contents, otherwise it will consist of strata too unequally saturated : now cork the flask, and let it stand in the boiling water for some time. I think that this allows a small degree of more saltness towards the bottom, which I believe of service. Now set the whole in a cool place, where it will not be exposed to the tremor of persons walking in the room, or of carriages in the street. It will cool very slowly, and generally remains fluid. Lift the flask, with the utmost care not to shake it ; pull out the cork, and it shoots into crystals ; or, if it do not, drop into the liquor the smallest fragment of the salt in crystals, and thus it never fails. A thermometer will shew the emission of latent heat. There is in this experiment an equilibrium in the mixture, between its chemical attraction for latent heat, or the force with which it retains a certain quantity of heat in that form, and the cohesive attraction which tends to make it crystallize. These two attractions, the chemical and the cohesive, are always in opposition to one another : and here they are exactly balanced, or at least

the force of the chemical attraction for the heat, exceeds, by very little, the force of the cohesive, which tends to crystallization. A proof of this is, that if we give a little advantage to the cohesive attraction, either by sudden concussion of the fluid matter, or by dropping in ever so little of the same matter already concreted, the crystallization immediately begins, and the latent heat is expelled; the cohesive attraction having now prevailed over the chemical one. You will perceive, therefore, an exact similarity between this experiment and Fahrenheit's experiment with overcooled water*.

Salts are commonly exhibited and treated of by chemists in their crystallized state. But this is not the most simple state of saline matter. All of them contain water, separable by heat; and it is so copious in some, that they undergo WATERY FUSION, and spontaneous CALCINATION, improperly called Efflorescence. Glauber's salt, alum, copperas, and many other salts, when very suddenly heated, melt, boil, and foam, emitting much watery vapour; and, in a little, are changed into a dry spongy mass, much larger than the salt, but of much smaller weight. After this they bear to be heated red hot, before they take the true wax-like fusion which I described in the beginning. This is called the watery fusion of the saline crystal. It is really a solution again in water which had been enabled, by its combination with the saline matter, to bear a greater heat without evaporation. It therefore dissolves what it could not dissolve while of a lower temperature. But it is almost instantly raised to a temperature in which even this union cannot hinder it from boiling. It therefore

* I doubt much whether this reasoning be conclusive or explicatory. We can form no notion of a difference between a cohesive and a chemical attraction, viewing them merely as moving forces; a conception absolutely necessary for speaking of opposition and equilibrium. It will be seen presently, that what is here called a cohesive attraction, is an attraction as truly chemical as the attraction for heat; and indeed, in the opinion of many chemists, it is the only chemical attraction, uniting two bodies of different kinds, with mutual saturation, and the loss of the former properties of the ingredients. We shall at least see that more happens than the mere balancing of two attractions. EDITOR.

froths up, evaporates by bursting the saline bubbles, and leaves them shattered, and the whole a spongy mass.

But if the same salt be exposed to a very gentle heat, and the action of dry air, the water of crystallization evaporates from it without dissolving the salt, and leaves it a fine meal. It is this that is called EFFLORESCENCE. The particles of this dust appear, through a microscope, to be fragments of inconceivably thin plates. In all probability, a saline crystal is made up of ultimate plates of salt and water.* In other salts, the water occasions DECREPITATION; that is, the crystals retain the water with great obstinacy, till red hot, or near it, when it tears them asunder with a loud crack. Such, therefore, is the nature of the crystals of salts, that they must be considered as compounds of salt and water.

The manner in which saline crystals are produced, and the remarkable figures they assume, could not fail to attract the attention of chemists and others, and to occasion attempts to explain how they are formed.

The most obvious idea, and which first occurred, was, that the ultimate atoms of salts have similar forms to those of their crystals, being oblong, or angular, or pointed; and that, when they unite, they necessarily form a mass, the figure of which is somewhat similar to that of the constituent particles. This opinion appeared the more probable, as it was thought to explain the *dissolving* power of salts, with regard to earths, metals, and other bodies, which, it was imagined, they dissolved, or acted upon, in consequence of the pointed forms and sharpness of their particles. But as, when we considered the more general effects of mixture, we already found this an insufficient and unsatisfactory explanation of the dissolving power of solvents in general, so neither will it explain the crystallization of salts. It is certain, that, in the crystals of salts and saline compounds, the saline atoms do not touch one another.

* This structure is rendered more probable, by remarking that saline crystals are evidently striated transversely, and many of them have a double refraction, like some natural crystals, which we know to have a plated structure....EDITOR.

This is evident, in the first place, from the transparency of those crystals. Light passes through them in every direction. We have direct proof that the saline atoms do not touch one another. The crystals of fossil alkali, Glauber's salt, Epsom salt, vitriol, alum, and borax, contain a quantity of water more than thrice the bulk of the saline matter. Perfect crystals of fossil alkali contain $\frac{44}{100}$ of water, $\frac{16}{100}$ of fixed air, and $\frac{20}{100}$ of alkali. The form of the crystals, therefore, cannot depend merely on the form of the saline atoms.

Besides, this phenomenon of crystallization is not confined to salts. They are, of all other substances, the most easily disposed to crystallization. But most other kinds of matter, when passing from a state of fluidity to solidity, shew more or less disposition to concrete into regular figures. In mineral veins, we find many kinds of stones and minerals crystallized. Metals, in congealing, shew a disposition to crystallize, or to form regular figures. Pure water also crystallizes in snow and ice. Flakes of snow are formed of assemblages of small spicular or columnar crystals, like the crystals of Glauber's salt, often assembled together without order, but sometimes joined together into stars of six rays, &c. If we suppose, therefore, the figures of saline crystals to be a proof that the ultimate atoms of salts are angular and pointed, we must allow the particles of water to be so likewise.

Another principle was pointed out by Sir Isaac Newton, to explain the crystallization of salts; but it is insufficient. He supposed it to be a consequence of the regular arrangement of the saline atoms dissolved in water. This might explain the concretion of salts into a mass of uniform structure, and perhaps transparent; but it cannot explain why there are a number of separate angular masses.

In the first place, the cause which occasions the particles of salt to concrete together in crystallization, is undoubtedly the attraction of cohesion. In a solution of salt, this attraction, by which the particles of the salt have a tendency to unite, is counteracted and overcome by the chemical attraction of the water for the particles of the salt. But if we diminish the quantity of the water by evapora-

tion, it will act with less power, and the saline particles with more. *(See Note* 29, *at the end of the Volume.)*

Mr. Baumé's opinion is, that crystallization, that is, the separation of salts by crystallization, depends both on the attraction of the homogeneous particles for one another, and on the repulsion of the heterogeneous ones. And he thus explains how *perfectly neutral crystals* are formed in acid, or alkaline solutions ; or clean and transparent crystals in muddy and coloured saline liquors. And he thinks he has perceived, by experiments, both the attraction and repulsion, acting even at the distance of a foot, by placing beside a vessel, in which a solution of Glauber's salt was set to crystallize, either a vessel containing Glauber's salt, which occasioned the crystals to be all formed on that side; or a vessel containing salt of tartar, which occasioned the crystals to be formed on the opposite side. But Mr. Lavoisier has proved that there is not the least ground for thinking that the attraction and repulsion act at a sensible distance.

Consult, on this subject, the *Crystallographie* of Mr. Romè de l'Isle, edition of 1784 ; and the *Essai sur la formation des Crystaux*, *par* Mr. l'Abbé de Haüy. *(Annales de Chemie*, *Juni* 1793.*)* These authors, particularly the last, shew how, from a very small number of simple primitive forms, may arise a vast variety of figures of crystals. This subject is treated with great neatness and perspicuity, both mathematically and philosophically, in a work entitled *Crystallographie des Mineraux*, by Dr. Kramp, of Strasburg. It was printed at Vienna 1793 ; and is, I think, the most instructive work on the subject.

There is yet another way of separating salts from water, namely, by adding something with which the water is more disposed to unite. Thus, if to a nearly saturated solution of most salts in water, we pour some strong spirit of wine, we shall have an immediate precipitation of the salt in a crystalline form. This method is sometimes practised as the only way of procuring the salt in a state of great purity. It is surely somewhat extraordinary, that by the addition of a substance more strongly attracted by the water, we should produce, in an instant, the union of salt

and water in a crystalline form, so strong in some cases, that a red heat cannot separate them. And this is another proof how little we are able to judge of the comparative strength of chemical attractions.

Such are the general observations which it was proper to make on the relation of salts to water.

All the different kinds of salt may be easily mixed in the most intimate manner, in consequence of this relation,....this general quality of dissolving in water: for water can dissolve not only two kinds of salt at the same time, but many different kinds. And we have learned by experience, that when it is saturated with one salt, this does not hinder from dissolving a considerable quantity of another, and even of several others. You may see many examples of this collected by Muschenbroeck, Neuman, Watson, and others. Water will dissolve more saltpetre after it is saturated with alum than when pure.

When different salts are thus mixed together by being dissolved in the same water, some act immediately one on another, and unite together, so as to remain afterwards very strongly combined. Many others mix without any appearance of action, or any signs of their uniting together. These can generally be separated from one another again without much difficulty. The others, when we desire to separate them, require to be disunited by an elective attraction. The various cases, where elective attraction or exchange is necessary to separate salts which are strongly united together, will be fully considered hereafter.

But when the mixed salts have no attraction, or after that attraction has been overcome, we separate them by one or other of three methods, which will succeed in most of these cases. We take advantage either of their difference of volatility, if there be any considerable difference of this kind between them; or of their different solubility in water; or we separate them by crystallizing them.

The manner of separating them by taking advantage of their different volatility, when there is a considerable difference between them in this respect, is obvious. It is, to put the saline mixture into a retort, or other such ves-

sel; to join a receiver to this retort; and then to apply heat, which must be very slowly and gradually increased. Thus the more volatile salt may be raised to vapour, and condensed in a separate vessel, while the fixed salt remains behind. In no case does this process produce a complete separation. The volatile salt is always tainted with a little of the fixed one, and this always retains some of the volatile salt. We must often repeat the operation two or three times.

When the salts which we desire to separate, do not differ much in volatility, and this operation cannot be performed, it happens however in many cases, that they differ greatly in solubility; and this circumstance puts it in our power to separate them. Thus, if the one be of the less soluble salts, and require a large quantity of water to dissolve it, while the other easily dissolves in a small quantity of water, we may evaporate the mixed solution till no more water remain than is necessary to keep the most soluble salt dissolved. Allowing the solution then to cool, the less soluble salt will separate in crystals, and may be taken out, while the other remains still dissolved.

Or, if the salts be mixed together in a dry mass, we may add as much water as is just sufficient to dissolve the most soluble, and the less soluble will remain undissolved. When one of those salts has little solubility, and the other is so very soluble as to be deliquescent, we can obtain a more complete and exact separation by exposing the mixed mass to the air in a cellar, or some other damp and cold place, until the deliquescent salt be liquefied by attracting the moisture of the air. It is found by experience, that there is no method of dissolving it by which it is so effectually parted from the other. Sometimes the mixed mass is thus exposed upon a quantity of bibulous paper, or other porous absorbed substance, which sucks in the deliquescent salt as fast as it liquefies: and this is a most effectual and quick method.

Besides the difference of greater or less solubility in general, there is another difference of solubility, which is in some cases the foundation of *separability*, (if I may be allowed the term): I mean a difference of solubility in

hot or in cold water. Thus, common sea-salt differs from perhaps all the rest, by dissolving as readily, and almost as copiously, in cold water as in hot; and may therefore be very conveniently and effectually separated from many of them, upon this same principle. The saltpetre, in its native state, has always a great quantity of common salt mixed with it. In order to separate it, the whole is dissolved in water, and the solution evaporated to a certain degree, and then cooled. A quantity of saltpetre then crystallizes, and is taken out. The same operation is repeated with the remaining liquor, and some more saltpetre is thus taken out before any of the common salt crystallizes, because the common salt is generally the least copious of the two; and as it is also more soluble, the water must be considerably wasted before it begins to appear. But when the evaporation has been repeated a certain number of times, the remaining water comes to be saturated with common salt as well as with saltpetre. And now, the next time we evaporate, a part of the common salt will crystallize, but in a manner quite different from the saltpetre; for it crystallizes while the evaporation is going on, and while the liquor is hot on the fire; for the heat does not much increase its solubility, or prevent it from separating. But heat has this effect very remarkably upon the saltpetre. It is dissolved in greater quantity by far in hot water than in cold, and although the water is greatly diminished, it still remains dissolved as long as it is hot. The common salt which has grained, must now be taken out; and afterwards we must allow the solution to cool. While it cools, none of the remaining common salt separates, or excessively little; but a great part of the saltpetre now concretes in the form of crystals. And if these are taken out, the same operation may be repeated with the remaining solution, until the whole of these salts are alternately separated from the water, and from one another; the one always concreting while the fluid evaporates, and the other while it is cooled. And the very same operation may be practised to separate sea-salt from a number of the other salts.

Solubility in spirit of wine is also another foundation of separability; for some salts are dissolved by that fluid,

while the rest are not: but of this we shall speak more fully when we treat of spirit of wine.

In cases in which none of the methods hitherto mentioned will do, (which, however, are very few), the only remaining means is crystallization. Some of the former methods of managing might be classed under the title of crystallization, because the separated salts form crystals. But as the separation depends in reality upon difference of solubility, we have referred such cases to that head.

The cases in which the separation of salts depends on crystallization alone, are those in which the mixed salts do not differ considerably, either in volatility or solubility, and in which we cannot have recourse to any of the operations hitherto mentioned. All that is left in our power is to reduce the whole saline matter to crystals, in the best manner we can; that is, to give fair crystals, but this is the most imperfect mode of any. *(See Note 30. at the end of the Volume.)*

To conclude this subject of the separation of salts in general, we must remark, that some of these methods of working do not produce full and exact separation at first: but by repetition the separation can be made very complete.

You are now acquainted with the nature of the salts in general. We must next take a view of the different kinds of them. To do this in a proper manner, it is necessary first to divide them into two principal divisions: the first, that of the more simple; the second, that of the compound salts, which are formed by the union of the simpler salts with one another. We shall therefore consider the simpler salts first, and then shew how by combination they produce the compound: each of which shall be considered separately, as well as the means of resolving the compound again into its constituent salts.

Further, the simpler salts, that they may be considered more distinctly, must be divided into two orders, the alkaline, and the acid salts. You will be fully sensible of the propriety of this division as we proceed. At present we are to consider the alkalis.

GENUS II.

ALKALINE SALTS.

UNDER this general name are comprehended three salts, having similar properties, but, at the same time, other properties which are not interchangeable.

The only character which I need to give of them in common, at present, is, that when they are mixed, though in exceedingly small quantity, with infusions of purple or blue flowers of vegetables, they change the colour generally to a green, or, in some few cases, from purple to blue. The spiritous tincture of alkanet root is still more sensible to alkalis. Several other properties besides this are usually given to distinguish the alkalis ; but it is not necessary to notice them at present, It is better to delay the mention of them now. I may, however, add, that, when tasted as dissolved in water, they affect the tongue with considerable acrimony and pungency. The particular taste is much the same in the three species.* They are, moreover, noted detergents, and feel greasy to the touch, because they instantly dissolve the unctuous matters which adhere to the skin. They shew, indeed, an acrid and corrosive nature with respect to all animal substances, especially when we apply to them these alkalis in their purest and most active state ; in which condition they dissolve every

* This taste has not a name in our language ; nor is it indeed very familiar, being peculiarly disgusting, and is seldom to be met with, except in what we are accustomed to consider as offal, or refuse. But it is a taste as distinct and characteristic as the acidity which denominates the other class. Whoever touches, with the tip of the tongue, a little potash, or even lime, or lime water, will never afterwards forget the disgusting taste of an alkaline substance.....EDITOR.

thing into a soapy pulp. It is a state to which they are reduced on some occasions only, and to serve particular purposes. But it is better, for the present, to describe them in the state in which they are commonly kept for use, and in which you will most frequently see them in the shops. This is a more convenient and manageable form than their purest state.

I said that there are three species of them. These are the vegetable alkali, the fossil alkali, and the volatile alkali. The last is called volatile very properly; as it is incomparably more volatile than the other two, which, with reference to it, are therefore called the two fixed alkalis.

SPECIES I....VEGETABLE ALKALI.

The first, the vegetable alkali, or common potash, has all the qualities described as belonging to salts in general. It requires a red heat to melt it; and in a violent one emits vapours, and is gradually dissipated, especially if air be admitted to its surface.

This alkali, in its ordinary state, has a very strong attraction for water. It deliquiates in the air, and is with great difficulty kept dry. When thrown into water, it dissolves quickly; and can be dissolved in less than an equal quantity. The solution is generally accompanied with heat. The water is separated again with difficulty, and requires a strong heat; and it is not easy to obtain crystals from this salt in its ordinary state. It is not usual, therefore, to attempt to crystallize this alkali, in separating it from water. The common practice is to evaporate to dryness, which is done in an iron pot, as it has scarcely any power to corrode the iron. Hence it has got the name of potash.

When the greater part of the water is boiled away, the remaining matter is much disposed to foam and boil over. And at last the small portion of water which remains with the salt, forms with it a mixture like wet lime or soft mortar. A strong heat is then required to evaporate this last part of the water: and the salt must be stirred and scraped

from the bottom of the pot incessantly. If this be omitted, it adheres strongly in the form of a hard white crust, or indurated mass.

This alkali has its origin in the land vegetables, especially trees, the greater number of which contain, in their juices, a small quantity of this salt combined with others; and it is produced in the plant by the powers of vegetation.

It is extracted, for the most part, by burning the wood (or whatever plant we operate on) slowly, to perfect white ashes, or until all the inflammable matter be completely consumed. The alkali remains in these ashes, and is easily extracted from them by water; and when refined to a certain degree, is sold under the name of PEARL ASHES.

It is prepared in this manner chiefly in those countries where wood is exceedingly plenty and cheap. And for many purposes, they do not take the trouble to refine this salt: but, taking the solution of it which they have extracted by water from the ashes, they add to it a quantity of fresh ashes, which still contain a salt; and boil up the whole together into a coarse and impure mass, which is also called POTASHES, and from which the alkali is afterwards extracted by those who have occasion to use it.

The reason for selling some of it in this form is, that it is more easily preserved and transported. The purer alkali, called pearl ashes, is so deliquescent, that it would be impossible to keep it dry and solid, except by packing it up in very close and tight vessels; whereas the coarser or less pure kinds of potashes can be more easily preserved and transported without such expensive package.

The softer and more succulent vegetables do not contain so much of it as the hard woods. But some of them, especially ferns and some others, are burnt with great profit in some places, on account of the alkali which may be had from their ashes. And such ashes are sold under the name of weed-ashes.

It is also separated, in a great measure, from the other principles of vegetables, when they are completely putrefied: and in this way is produced the alkali, which may be had from the drains of dunghills, by a process described by

Dr. Percival of Manchester, in the Philosophical Transactions for the year 1779 or 1780.

There is now such demand for this salt in many manufactures as a detergent, that it is found highly worth while to recover it from the liquors in which it is mixed with all the sordes which it has dissolved. The water is boiled off: and the impure residuum is burnt to ashes; and the alkaline salt extracted from them by water.

Mr. Margraaf, in some memoirs in the Transactions of the Berlin Academy, on the waters used in Berlin, says that he found a small quantity of this alkali in some of their well waters. It probably had the same origin as the alkali contained in the drainings of dunghills; and had been extricated from vegetable substances by putrefaction, and been carried by the surface water into the wells.

The vegetable substance which yields it in the largest quantity and purest state, is the vegetable salt called tartar or wine-stone. And when this alkali has been extracted from the tartar, it has been commonly called *Salt of Tartar*.*

Sal tartari contains about 70 per cent. of pure, i. e. caustic alkali.

The best pearl-ashes contain about -	55
Dantzic ashes - - - - -	51
Ordinary - - - - - -	46

The names, therefore, by which this alkali was formerly known, were pot ash, pearl ash, weed ash, salt of tartar, salt of wormwood, and some others. But the names of the salts have been often changed of late. In a new set of names which were lately proposed by the French chemists, it is called *Potasse* in French, and *Potassa* for Latin; in the last edition of the London Pharmacopœia, *Kali;* in the Edinburgh Pharmacopœia, *Lixiva*. I shall take some notice of the names, when I have done with the description of the salts.

* There are strong reasons, some of which occur in these lectures, for believing that this salt is formed in the plants, by the powers of vegetation, of ingredients still more simple....EDITOR.

Uses of the vegetable fixed alkali.....It constitutes a part of several compound salts employed in medicine ; and is used by itself to correct acidity in the bowels ; to promote the secretion of urine ; and to give relief from the distress occasioned by gravel or the stone, in the kidneys or bladder ; which relief it very seldom fails to procure, when the disease is not of long standing. It is given for this purpose in different states, which I shall describe hereafter. It is used also in large quantities in the arts, as in making soap and glass, in bleaching, in dying, &c.

SPECIES II.....FOSSIL ALKALI.

The other fixed alkali, the fossil alkali, when examined in its ordinary state, resembles the vegetable alkali in some particulars ; but is very different from it in others. It requires the same heat to melt it, and make it evaporate. It has the same taste, but not so acrid. Its attraction for water is not near so strong ; and it is not deliquescent. It dissolves, however, readily in water, but not so quickly as the vegetable alkali does. And it requires five or six times its weight of the water to dissolve it, in the temperature 50°.

The fossil fixed alkali in solution is easily separated from water again by evaporation ; and in its ordinary state, it is easily crystallized. Its crystals have generally the form of a thin oblique lozenge, the narrow sides of which are reduced to an edge by oblique planes, like the edge of a ruler. (See Rome de l'Isle, No. 43.) Its crystals contain a large proportion of water, adhering loosely, nearly $\frac{64}{100}$ and $\frac{16}{100}$ of elastic matter in an unelastic state. Hence they are very liable to watery fusion and spontaneous calcination. The water quickly evaporates, and leaves the salt a white crusty mass, which may be dissolved in water, and crystallized again.

Such are the qualities of this alkali, that can be mentioned with propriety at present. It remains only to take notice of its origin. Upon this article we may remark, that it is one of the salts which have been longest known

and in use. It is this salt which is mentioned in several parts of the Bible by the name of nitre. It is once mentioned as a detergent, and once as making a turbulent or foaming mixture with vinegar; neither of which properties agree with the salt now called nitre. It appears that the ancients were supplied with this salt from Egypt, and some parts of Persia, where it is found on the surface of the soil, in particular places, in the form of small impure crystals, or composing a saline efflorescence, or crust, like hoar-frost, which is undoubtedly formed by the evaporation of water, which had dissolved and extracted it from the soil.

In the 55th volume of the Philosophical Transactions, there is mention made by Dr. Heberden, of a production of this alkali, somewhat similar to this, in the island of Teneriffe. And we are also informed by Dr. Donald Monro, in the Philosophical Transactions for the year 1771, of another source, from which it is probable the ancients derived in part their supplies of this salt. It is brought yearly to Tripoli, in large quantities from the mountains, and is called *Trona*. From its appearance, he concludes that it is found forming veins in the mountains of rock salt; for it is always in the form of cakes, of about half an inch thick, to one side of which there always adhere incrusted crystals of common salt*.

There is no example, however, in any part of Europe, of its being found in considerable quantity in any of these states. We have only a saline efflorescence, which is often formed on the plastered walls of cellars, and other damp places, which is mostly composed of this salt. We also find a small quantity of it dissolved in the water of some of our springs in Europe; but such spring waters are very uncommon.

Though, on the whole, we but rarely find this alkali in a separate state in nature, it occurs however, in grea quantities, in a state of combination with other salts. Common salt is a compound salt, of which this fixed alkali

* It is found in its detached state in all salt water fishes, and in some in considerable quantity. The earth round Ravenna, which is full of the remains of sea fishes, and even the stones, abound in it.....EDITOR.

composes the half. And common salt is found solid, in immense quantities, in the bowels of the earth, besides what is contained in the waters of the sea, and those of innumerable springs in all parts of the world. You will, therefore, understand why it has been called the fossil alkali. I have reason to believe that the fossil alkali that is found on the plastered walls of cellars, and other damp places, is produced by the decomposition of common salt.

But the great quantities of it which are made use of in different arts and manufactures in Europe, are procured from sea plants, and some particular plants which grow in the neighbourhood of the sea. The plant which affords it of the best quality, and is cultivated in Spain, Sicily, and Italy, for that purpose, is called Kali and Salsola. To obtain the alkali, these plants are burned to ashes, in which the alkali is found. Such ashes are accordingly prepared upon the coasts of the Mediterranean, and receive the name of Soda, or Soude, or Barilla ashes. They form large and hard lumps, like stones, of a dark gray or blackish colour. The hardness is occasioned by a fusion which these ashes undergo in the end of the operation, in consequence of the heat produced by the burning of the vegetable. Upon our coasts also, we burn certain kinds of sea plants, and melt the saline ashes of them together into one mass, called Kelp, which also contains a small quantity of this alkali.

The purest fossil alkali, obtained from the efflorescence on plaster walls, contains about 60 per cent. of its weight of alkali in crystals.

Alkali manufactured at Liverpool,	49
Fossil alkali from India,	28
Best Alicant Barilla,	$26\frac{1}{2}$
Sicilian Barilla,	23
The richest kelp made in Norway, the Orkney Islands, and Skye,	$6\frac{1}{2}$
The general produce of Scottish kelp,	$2\frac{1}{2}$

The sea-weed, varech, or wreck, is either taken as it is tossed ashore by the storms, or is cut and pulled from the

rocks with rakes, at low water. It is brought ashore, and spread on the beach to dry and wither. As soon as it will burn, it is burned in little pits lined with stone, feeding the fire scantily with the dry plant. When the pit is nearly full of the ashes, which are but slightly burnt a great quantity of weed, well dried on purpose, is thrown in at once; and a very hot fire kept up, and the whole stirred, to bring all the charry matter to the air, that it may burn. This melts the whole into an impure heterogeneous mass, of a dark, dirty, gray colour, containing much common salt, vegetable earth, brimstone, and the alkali.

It may also be had by decompounding common salt, by particular processes to be described hereafter, and some of which are actually practised in the way of business at present.

The names which have been given to it, therefore, are, Natrum or Nitrum by the ancients, Trona in Africa, Soda and Barilla in the Mediterranean, and Alkali of common Salt, or Fossil Fixed Alkali. In France they prefer the name of Soda or Soude: and the same name has been adopted in the last edition of the Edinburgh Pharmacopœia. In the London Pharmacopœia, it is named Natron.

It is employed chiefly in the composition of soap, in making glass, in bleaching linen, and in other arts. It is also an article of the materia medica. It has the same powers in medicine as potash, or alkali of tartar.

SPECIES III.—VOLATILE ALKALI.

The last of these salts, the volatile alkali, differs more from the two former than they do from one another. It shews great volatility when exposed to the most gentle heat: and, even in the ordinary heat of the air, it is constantly emitting vapour, not visible, but pungent to the nose, and of an urinous smell. It is commonly known by the name of volatile salts, and salt of harsthorn. When exposed to heat, it does not melt, but is totally evaporated before it arrives at the melting heat: and when the vapour of it is condensed in a receiver, it forms a saline crust. It

has a good deal of acrimony and pungency; and if confined upon the skin, will certainly inflame and corrode it. It is easily combined with water, and sometimes crystallizes. But it is incapable of being separated by evaporation, as other salts, by employing heat.

With respect to its origin, it is not found in a separate state in nature, except in putrefying animal or vegetable substances, or in the air which is immediately over them. It is contained in all animal and vegetable substances, and is extricated from them by putrefaction, and by a destructive heat. There is also a little of it in fossil coals. Hence it appears in the vapours which arise from these different substances, when they are destroyed or consumed by fire, or by a heat strong enough to dissipate all their volatile parts. In Lord Dundonald's process for obtaining a tar from pit-coal, a quantity of water is produced with the tar, which water contains some volatile alkali. Soot, which is a matter produced by the condensation of some of the vapours arising from heated coal or wood, also contains it, combined with some other saline substances, which repress its volatility to a certain degree. It is therefore extracted in large quantity in some manufactures from soot. Urine also, when putrefied to a certain degree, yields a good deal of it: and this is the cause of the pungent alkaline odour felt in stables. Some manufacturers therefore prepare it from urine: and the chemists formerly did so too, and called it salt of urine. It is this alkali in putrid urine which makes it detergent.

There are also other animal substances which afford it in great quantity, when they are heated and scorched to a black coal in close vessels. It is procured most plentifully in this way from the horny parts and the bones. Formerly the horns of the hart were preferred to other animal substances: and the volatile alkali which they afforded was called salt of hartshorn. There is still a volatile alkali so called in our shops; but it is prepared from bones of all kinds that can be collected. They are put into large distilling vessels of iron, and exposed to an increasing heat, until all their volatile parts are extracted; and among these is found a volatile alkali, which is precisely of the

same nature with the volatile alkali of hart's horns. It has a very fœtid odour, proceeding from a burnt and volatile oil, which arises from these substances during the process, and which cannot afterwards be completely separated from the alkali without too much expence.

The best way to have this alkali free from such offensive impurities, is to extract it from a compound salt called sal ammoniac, the process for which is to be shewn hereafter. Thus prepared, it is called spirit of sal ammoniac, or sal ammoniacum volatile, or sal volatile.

The other names that have been given to it are *ammonia*, in the London and Edinburgh Pharmacopœias, *spirit* or *salt of urine*, *spirit* or *salt of hartshorn*, *volatile alkali*. The French now give it the name of *ammoniac*.

In the course of our examination of chemical bodies, we shall have frequent occasion to speak to this alkali, and will also be able to form a more distinct notion of its origin and nature.

It is much used in medicine, as a powerful and grateful stimulant and diaphoretic of quick operation; and is reckoned an antidote against the bites of venomous animals. It is also employed in some of the arts, as in the manufacture of sal ammoniac; in the manufacture of alum; and in cleansing wool, silk, and other substances, to prepare them for receiving colours in the art of dyeing.

GENUS II.

ACID SALTS.

YOU must next be made acquainted with the acids, so denominated from their taste.

Of the salts belonging to this order, there is a much greater number than of the alkalis. But there are three, which, on account of the eminent and distinct manner in which they possess the distinctive properties of acids, claim our chief attention, and greatly assist us in investigating the properties of the rest.

These three have commonly been distinguished by the title of FOSSIL ACIDS; and are now specified by the names of the SULPHURIC or VITRIOLIC, the NITRIC, and the MURIATIC ACIDS. Their common properties are these:

1st. They have a very strong attraction for water; and being at the same time very volatile, a consequence of these qualities is, that the only form in which we can have them for use, is that of watery fluids, or united with water, which represses their volatility, and renders them manageable.

We cannot separate the water entirely from them by evaporation, or otherwise. They retain it too strongly, and are themselves too volatile to admit of this. But when they are much weakened or diluted with water, we can separate a part of this water by distillation, and thus strengthen, or, as we say, *concentrate* the acid to a certain degree: and in this strong state they are commonly kept for use. I shall, therefore, describe them as they appear when in this strong state, or as united with as little water as possible.

In this state they have a powerful attraction for more water. They attract it from the air more quickly, and in greater quantity, than the vegetable fixed alkali does. And when mixed with water in its ordinary state, they unite with it rapidly with violence, and produce heat. Upon this account, it has been thought the more extraordinary, that, when mixed with ice or frozen water, they produce a considerable degree of cold. But I formerly gave an explication of this phenomenon, as depending on absorption of heat.

Although these acids, therefore, are always exhibited and used in the form of fluids, we may consider their fluidity as depending upon the water that is mixed with them, and conclude that they are salts dissolved in water: for that the saline matter which they contain is capable of appearing in the form of solid salts, is plain from several facts.

One of these is the solid form which the sulphuric acid actually assumes upon some occasions. The whole of it congeals into a mass resembling ice, which, on account of its appearance, is called Glacial Vitriolic Acid.

The nitric acid also, when exposed in its strongest state, to a cold of 40° of Fahrenheit's scale, assumed, in part, a solid form. A considerable part of it crystallized into spicular crystals.

With respect to the muriatic acid, the same experiment has not been made with it. But it is probable that it also would crystallize in the same degree of cold, or in a greater *.

At any rate, there is an easy method by which we can reduce these acids to a solid form, which serves to shew that they are capable of solidity. The method I mean is to combine them with the fixed alkalis. They are disposed to unite readily and strongly with the alkalis, and form with them compound salts, which can easily be separated from water, and made to appear in a solid form, as we shall see hereafter.

2dly. A second quality, which the acids are possessed of in common, is, that, like the alkalis, they change the colour of infusions of the purple or blue flowers of vegetables: but

* It does crystallize....EDITOR.

whereas the alkalis change them to a green, or abolish the red, and deepen the blue; the acids, on the contrary, change them into bright red, or into a scarlet: and an extremely small quantity is sufficient. And this effect they produce upon the same juices, although they have been previously tinged green or blue by an alkali: while the alkali, on the other hand, will produce a green colour in those juices, although they have been previously tinged red by an acid. We can, in this way, change the colour of the same infusion to a red or green alternately, for a number of times, by adding the one or the other kind of salt.

The chemists are, on many occasions, much interested in ascertaining the presence of an alkali or an acid; and keep in readiness phials of coloured tinctures of vegetables. They also use for this purpose slips of paper stained with those juices, called TEST-PAPERS. These tests must be carefully kept from the action of the air and the light.

Different tinctures have different degrees of sensibility to acids and alkalis. The tincture or dye called archil, cudbear, or litmus, is the most sensible to acids. The juice of the scrapings of red cabbage and radish is also very sensible to acids. March violet, convolvulus, viola tricolor, and cyanus, are less affected. Mallow flowers, march violet, convolvulus, and alkanet, are much more sensible to the alkalis.

3dly. A third quality of the acids in general is, that they readily unite with any of the alkalis: and if these are in their ordinary state, a violent effervescence is produced. This effervescence was formerly reckoned a criterion of acids or alkalis.

This mixture is a true chemical combination. All the distinguishing qualities of both ingredients are gone. The acid or the alkaline taste is no longer perceived; and one different from both is induced. The mixture makes no change in the colour of vegetable infusions. This gives us the first employment for our tests and test-papers. By these we discover the exact saturation of the ingredients, which is another proof of the chemical combination. The great attraction for water is gone: and the compound is easily separated from it

by crystallization. The great volatility of the ingredients is also repressed; and this, in one instance, in a most unaccountable degree. The marine acid, and the volatile alkali, in their utmost state of purity, are so volatile that we cannot condense their vapours. Yet these vapours, when united, instantly form a dry powder, which requires a very considerable heat, approaching to ignition, to convert it into vapour. *

4thly, and lastly, The acids are powerful solvents of a number of different substances, as chalk, limestone, marble, and metals; and they also shew a solvent and destructive power, when applied to animal and vegetable substances. Taken internally, in their strong state, they would prove instant poison. Applied externally, they immediately occasion sharp and violent pain, and very soon destroy the part, as burning coal would do. All this is to be understood of them only in their strong state; for if they be very greatly diluted, they are not corrosive; and their most general effect is then to prevent or retard fermentation and putrefaction. They are often taken in this diluted state as medicines, and are cooling and astringent, and impress upon the tongue, in a very distinct and lively manner, the particular taste which their name implies.

These therefore are the qualities which these acids have in common. We shall now consider the peculiar nature of each of them separately.

VITRIOLIC ACID.

The vitriolic acid has this name from vitriol, a compound in which it is contained, and from which it was formerly extracted. At present, all that is brought to the market is prepared from sulphur; for which reason, and others, the French chemists have lately proposed that it shall be named *Acide Sulfurique*, Sulphuric Acid. And it must be acknowledged

* This almost overturns all our mechanical explanations of chemical phenomena....EDITOR.

that this is a more proper name than the other; for even the acid which we find in vitriol has its origin from sulphur.

When pure, it is a colourless heavy fluid, in specific gravity to water as $18\frac{1}{2}$ to 10. This great weight gives it some appearance of sluggishness like oil; for which reason, it has been common to call it oil of vitriol.

It is also much less volatile than water. It therefore does not emit any sensible vapours or effluvia, in the ordinary heats of the air; nor has it the smallest perceptible odour.

It is congealable by cold, and the more easily as it is stronger. It is then called Glacial Oil of Vitriol. When of the gravity 1.78, it congeals at 32°; and requires 45° of Fahrenheit to thaw it. This shews that it is not a simple congelation, but, in some measure, also a crystallization. If undisturbed, it will remain fluid below 32°, and freezes and emits heat when stirred. (*Phil. Trans.* 1787, Part 2d.)

When very strong, it shews the powerful attraction it has for water, by the violence and rapidity with which it mixes with that fluid; in mixing with which it grows very hot, and contracts greatly in bulk. The heat produced, by suddenly mixing strong vitriolic acid and water, will split any thick glass vessel. The mixture should, therefore, be made gradually, by small additions, and agitating the mixture after each addition; otherwise the heavy acid will collect below and when you agitate, you will mix a great deal, and produce much heat. The bleachers often pour the acid carelessly even into hot water; and it breaks out into steam, and scatters the acid about on the goods.

The contraction of bulk is very great. Twenty-eight measures of water, mixed with four of acid, make only 29 measures of mixture, instead of 32.

Its attraction for water likewise appears from the quickness with which it attracts it from the air, and the quantity it will attract. Dr. Gould, Professor at Oxford, found that three drachms attracted more than a drachm of water in one day, and in 56 days, $6\frac{1}{2}$ drachms; the quantity which it attracted always diminishing. Newman tells us that one ounce of it in a year attracted $6\frac{1}{4}$ ounces of water.

When this acid is diluted, or mixed with too much water, it can be strengthened, or the superfluous water separated, by distillation in the retort and receiver. If the quantity of water with which it is diluted be considerable, the first vapours that arise are pure watery ones, or little else: and it does not require much more heat to raise it than water. But, as the operation goes on, the water that remains, in proportion as the quantity is diminished, is more strongly retained by the acid: and a stronger heat is required to continue the distillation, until it rise to near the 600th degree. 546, or 550, may be accounted the boiling point of the strongest vitriolic acid that can be made. The vapour, too, that arises during the progress of this operation, is found to contain the larger proportion of acid, the farther we advance in the distillation, until at last what distils is as strong as what remains in the retort; the small quantity of water which it retains being so strongly attracted by the acid, that they cannot be separated from one another by heat, but arise in equal proportions.

I may notice, by the way, that this operation, by which we clear a fluid of a volatile ingredient, which we consider as diluting it, is called Concentration. When we clear a volatile fluid of a more fixed ingredient, we are not said to concentrate it, but to rectify it. We concentrate vitriolic acid; but we rectify vinous spirits.

This acid, as first produced in the manufactory of it, is always much diluted with water. And it must be concentrated by distillation, before it can be carried to the market, or delivered to those who make use of it. And the concentration is always carried on so far as to bring it up to the specific gravity I mentioned, viz. 18½ to 10.

Such are the properties of this acid with regard to water. But, before we quit it, I find it necessary to take some notice of its relation to inflammable substances, the effects of which upon this, as well as some other acid salts, must be known before we can understand the processes by which some of the compound salts are decompounded.

The vitriolic acid acts powerfully on most inflammable substances. If some olive oil, for example, be poured on vitriolic

acid in a glass, heat is generally produced, and the touching parts immediately become of a very dark coffee colour. Fœtid steams soon arise, as the mixture goes on, and become at last very offensive and suffocating. The mixture becomes thick and black, like tar. If we mix the acid in the same way with oil of turpentine, the mixture is more remarkable, with violent heat, and bursts of suffocating steams: and the viscid mixture foams and froths over the brim of the vessel. The oil acquires a very particular smell; and some of the spongy matter becomes hard and charred.

One phenomenon observable in all these mixtures of vitriolic acid with common inflammable substances, is the very dark or black colour produced. This occasions the brown colour which this acid acquires when kept in a negligent manner. The acid of vitriol that is to be found in the shops, is often of a dark brown or black colour, although, when fresh or new, it is perfectly colourless and transparent; and if kept in close vessels with a glass stopper will remain so. But if any dust be allowed to get into it, or if the phial be stopped with a cork, or other vegetable inflammable matter, the acid dissolves and corrodes it, and acquires more or less of a brown tinge or even black colour. The way to restore a vitriolic acid thus tainted, is to distil off a small part of it in a retort and receiver, or boil it in a matrass under the vent. When we do this, a small part of the acid arises in the form of volatile steams, which have the suffocating odour of burning sulphur. The rest becomes clear, and free from colour or smell.

When we have had the curiosity to apply heat to such mixtures as these, and to subject them to distillation, we have obtained several products:

1*st*, A great deal of the acid arises in that volatile and suffocating state which I just now mentioned, in which state we call it the sulphurous acid; and along with it the water which was combined with it at first, and also a quantity which is contained in the composition of the oil.

2*dly*, After this water and suffocating sulphurous acid have arisen in considerable quantity, vapours next arise, which are vapours of perfect sulphur or brimstone; a part of the acid

being changed into this form by the action of the inflammable matter and it on one another. We also frequently obtain a dry black powder, which, on examination, is a pure charcoal. This rises, or at least is brought off from the black mixture with a very moderate heat, and appears to have been merely floating in it, having probably been the cause of its blackness.

A great variety of other inflammable substances may be employed, as well as these oils, for producing these changes on the vitriolic acid. I shall just mention two instances, which exhibit classes of appearances somewhat different, and lead the philosophical chemist to a variety of different conclusions.

The first is a very simple one. Dr. Stahl, observing the sulphurous fumes obtained in the process which I have just now described, and the genuine sulphur sometimes produced, and that this sulphur did not appear till towards the end of the process, when the matter in the retort was of a burning heat, wished to force the acid to bear this heat from the beginning, while it acted on inflammable bodies. For this purpose, he took the acid as it is found combined with another substance in the form of a salt. He chose alum, of which it is an ingredient. He mixed dry alum with powdered charcoal. Applying a very great heat, he sublimed a quantity of pure sulphur. a prodigious volume of air was produced, which could not be condensed by cold, and would have burst the vessels, if not allowed to escape.

The other example is the distillation of the acid from dry vegetable matter, such as sugar or straw. If this last be put into the strongest sulphuric acid, it is *immediately* blackened, and after some time, dissolved into a dark brown or black pulp. No smell or suffocating fumes are produced in the cold. If we now dilute with water, a considerable quantity of impalpable black powder is thrown down after a long standing. This, when examined, is very pure charcoal or carbone. It is remarkable, that this great addition of water to the strong acid produces but a moderate heat. It produces, however, a distinct smell of vinegar. If we now proceed to distillation, we obtain real vinegar from it, and a much smaller proportion

of the sulphurous acid and brimstone than in the process with oil.

We shall return to this process, when we shall have acquired a clear knowledge of the agents which are concerned in these changes.

In these processes, therefore, the acid undergoes a most remarkable transformation; for that it is a part of the acid which is thus transformed into sulphur, cannot be doubted a moment. When we examine this sulphur, and make experiments with it, we find that it has every quality of common sulphur, and among the rest, that of being convertible into vitriolic acid by inflammation in the free air.

I have been somewhat minute in the account given of this action of vitriolic acid on inflammable substances, because it may be affirmed that it was the observation of these phenomena by the celebrated Stahl that first introduced any thing like philosophical discussion into chemistry. The vague and obscure notions of Geber, Becher, and others, about their sulphur and sulphuric principle, do not deserve such a name. But Dr. Stahl founded, on the observations which I have now related to you, a body or system of very precise and perspicuous doctrines, whose influence connected all the great and important phenomena in chemistry. Observing that the mixture of vitriolic acid with *every* inflammable substance produced the same sulphur, and that the substance *was no longer inflammable*, he inferred, with great propriety, that all inflammables imparted one and the same substance to the acid. Moreover, as those bodies resembled only in inflammability, and as none but inflammables produced sulphur with the acid, he has properly concluded that the thing thus imparted was the cause or principle of their inflammability. He called it the PHLOGISTON. "*Materiam et principium ignis ego phlogiston appellare incepi: nempe, primum, igniscibile, inflammabile, directè atque eminenter ad calorem suscipiendum habile, principium.*" Adding this to any body that attracts it, renders it inflammable; and taking it away, renders it uninflammable. Inflammation is its dissipation; therefore the remains are uninflammable. It may also be taken away by another body which at-

tracts it more strongly: and this transference is not accompanied by inflammation. It is thus that vitriolic acid takes it from charcoal.

Such is the famous doctrine of Stahl. And its immediate and interesting consequences explain all the operations of metallurgy. It was received with great applause. And Germany became the great school of chemistry.

Such being the state of our science at the beginning of the century, all the chemists were accustomed to conceive and explain these phenomena according to the doctrine of Dr. Stahl, by supposing the volatile suffocating acid, which arises before the sulphur, to be a part of the vitriolic acid, combined with a certain proportion of their supposed phlogiston or principle of inflammability; and the sulphur, which is formed afterwards, to be the rest of the acid, combined more perfectly, or saturated with a larger proportion of the same principle. The effect of this is to make it assume the form of an inflammable substance, namely sulphur; which sulphur may be inflamed and burned, so as to dissipate its principle of inflammability, and thus to give us the acid again in its pure state. This, I say, was the manner in which the chemists were accustomed, until lately, to understand the facts I have narrated.

But a great number of important discoveries, which have been made of late, have occasioned these facts to be now viewed in a different light. It has been discovered, that while the vitriolic acid undergoes these changes into suffocating acid and sulphur, there is extricated from the materials a very great quantity of air, or elastic aërial matter: and, on the other hand, when sulphur is changed again into acid by inflammation, a quantity of air, without which it cannot be burned, is absorbed, so as to enter into the composition of the acid, and make up a part of it; the quantity of vitriolic acid obtained being, in fact, of much greater weight than the quantity of the sulphur burnt, nearly $2\frac{1}{2}$.

It is therefore concluded now, that the vitriolic acid is a compound of sulphur and air; and that, when the acid is mixed with inflammable substances, and, by being distilled

with these, is converted into sulphurous acid and sulphur, these changes are not produced by the addition of any matter which it receives from the inflammable body: but that, on the contrary, by a decomposition which it suffers, a great quantity of its air being separated from it by the superior attraction of the inflammable body for that air; and that part of the acid which has lost a *portion only* of its air, becomes, by its redundancy in sulphur, sulphurous acid, or volatile suffocating vitriolic acid; while that portion which loses the whole of its air, becomes perfect sulphur.

On the other hand, when sulphur is set on fire and made to burn, and by inflammation is converted into acid, it unites with a part of the air which is in contact with its flame, and which is necessary to the inflammation; and by uniting with, or attracting to itself, this air, it becomes vitriolic acid again, or a compound of sulphur and air.

That a quantity of air is absorbed by sulphur, when converted into acid by inflammation, is now acknowledged by every chemist. The most direct proof of this is had by burning sulphur in a known quantity of air, in the following manner:....In a cistern of water, or mercury, set up a stand, rising some inches above the water; and on the top of it put a small quantity of sulphur; have ready a glass jar, and having kindled the sulphur, instantly cover it with the jar, whose mouth must dip an inch or two in the water. The heat will expand the air a little at first, and the water will be pressed down: but by and by the water will rise in the jar; and, when the brimstone ceases to burn, and the whole has grown cold, the water will have risen considerably in the jar; that is, air has been absorbed. By attending to all the circumstances which affect the result, it is found that the weight of the air absorbed is equal to that gained by the sulphur consumed by inflammation.

It is also completely proved that a great quantity of air is extricated, when we convert the acid into sulphur by the action of inflammable substances. Of this you had an example in the process lately shewn with alum and charcoal. For, unless an exit be allowed, the vessels will be burst. And if

the vapour be collected in another vessel, it will be found aërial, that is, incondensable by cold. It is, therefore, no longer disputed that the acid is a compound substance, having air, or the basis of air, for one of its component parts. But some of the chemists still maintain that sulphur also is a compounded substance, as well as the acid: that there is a specific matter in sulphur, which matter, when combined with air, forms vitriolic acid, and when combined with the principle of inflammability, forms sulphur; and that while this specific matter unites with air, it loses the principle of inflammability; and that when it unites with the principle of inflammability, it loses its air. This opinion, however, is not supported by direct experiments as the other is. And until those who maintain it can shew this specific matter in a separate state, and make us acquainted with its nature and properties, there is reason to suspect that their opinion proceeds rather from the old habits of thinking, than that it is founded on fact. They think it is necessary to suppose a principle of inflammability in sulphur, in order to account for the light and heat which it gives in burning. But, by the French theory, this light and heat are supposed to proceed from the latent and specific heat, the *calorique*, as they call it, which is separated from the air, while this air is condensed by the attraction of the sulphur.

From the whole of the facts, it is manifest that sulphur and the vitriolic acid are very nearly allied. Each of them is easily convertible into the other: and yet their properties and powers are very different. The acid is extremely acrid and corrosive with respect to animal and vegetable substances: sulphur, or the contrary, is mild and harmless. The acid has a strong attraction for water: sulphur has not the least. The acid mixed with alkalis unites quickly and violently, and is strongly combined, and difficultly separated: sulphur added to alkalis does not exhibit any such phenomena. Sulphur, however, has a considerable degree of attraction for alkaline salts, and is disposed to unite with them. To see this, however, and make them actually unite, it is not enough that we mix them together in the form of dry powders. In this case,

as in most others, it is necessary that one of the bodies, the alkali or the sulphur, be fluid, before they will act on one another, or unite. But this fluidity may be obtained in two ways, either by using water to dissolve the alkali, or by applying heat to melt the sulphur. In the language of chemists, the one is called the dry way, and the other the humid.

1. Sulphur, in the form of a dry powder, being mixed with an equal weight of vegetable alkali, must be exposed in a crucible to a heat gradually increased. This melts the sulphur, which then unites with the alkali, forming a compound, fusible in heat, and soluble in water. When it cools, its colour greatly resembles that of liver. Hence it has been called LIVER OF SULPHUR, HEPAR SULPHURIS. This is the compound prepared, *viâ siccâ*.

2. A strong solution in water of vegetable fixed alkali in its purest active state, will dissolve powdered sulphur, with the assistance of a moderate heat. This is the preparation of liver of sulphur, *viâ humidâ*.

This combination of sulphur and alkali emits a most disagreeable smell, thought to resemble that of rotten eggs. But it has nothing putrid or cadaverous. It perfectly resembles what you perceive in the washings or scourings of a fowling piece: and this smell is really occasioned by *hepar sulphuris*.

The sulphur, when thus combined with an alkali, by either of these processes, and dissolved in water, shews a much greater disposition to unite with air, and to be changed into an acid by the action of the air, than when it is pure. We need only to expose it to the air of the atmosphere for a few weeks. Thus, by an imperceptible action of the air upon it, the sulphur is gradually changed into acid, which however remains combined with the alkali: and we have at last a compound salt in place of the *hepar sulphuris* which we exposed.

This conversion of *hepar sulphuris*, a deep coloured, strong smelling compound, into a pure white inodorous salt, by the simple exposition to the air, is a curious fact, and naturally excited the attention of the chemists. When the experiment is made in closed vessels, that is, in a vessel set under a jar inverted in a cistern of water, we discover that the change is

effected, or at least is accompanied, by the absorption of a quantity of air; for the water of the cistern will gradually rise into the jar. We shall find that about one fourth part of the air inclosed with the *hepar sulphuris* can be thus absorbed. Whatever quantity of hepar is thus exposed to a given quantity of air, no more air can be absorbed: and the quantity of salt produced is thus limited.

We learn by these experiments that the air of our atmosphere is not homogeneous; that there is only a certain part of it disposed to unite with sulphur, a little more than the fourth part. The rest has not the least disposition to unite with sulphur, either when exposed to it in the form of *hepar sulphuris*, or when we attempt to fire the sulphur in it. We cannot either inflame the sulphur, or change it into an acid, or perceive that any of the air is absorbed.

We owe this most important experiment, and the conclusion deduced from it, to Mr. Scheele, of Koping, in Sweden, one of the most penetrating, judicious, and accurate chemists of the present age. It is to be seen in detail in his Publications on Air and Fire, and in the Memoirs of the Academy of Stockholm.

Much about the same time, and without any knowledge of the other, Dr. Priestley had discovered this elastic fluid, which appeared to Dr. Scheele as a residuum of atmospheric air. The train of Dr. Priestley's experiments led him to form a very different opinion of it. He conceived it to be atmospheric air combined and saturated with the principle of inflammability or phlogiston: and therefore he called it *phlogisticated air*. Scheele called it *foul air*, which we should translate, not tainted, put putrid, corrupted. It is now named by the German chemists *stick-stoff*, i. e. suffocating or choking air. When Dr. Priestley learned Scheele's method of obtaining it, he was confirmed in his opinion, and said that the phlogiston, which had quitted the vitriolic acid, had united with air. But however specious and perspicuous this explanation is, and although the opinion was adopted by the most intelligent chemists of Europe, it is now found to be a mistake. The specific gravity of this phlogisticated air was ascertained by

several chemists. And when this was compared with the diminution of bulk, it was observed that the absolute weight of the air had been diminished as much as its bulk. This seems incompatible with the notion of the remainder being a compound of the whole original air and phlogiston. Few chemists could admit phlogiston to be a substance which diminishes the weight of the substances with which it unites. Moreover, experiments were afterwards made, which completely refuted Dr. Priestley's opinion. Dr. Priestley and Dr. Scheele had discovered a method of purifying air from every thing that could be supposed phlogiston: and Dr. Priestley therefore called it *dephlogisticated air*. It was indeed his greatest discovery; and has produced a total and extensive change in the chief doctrines of chemistry, as you will very soon see. Now, if this experiment of Scheele's be made with dephlogisticated air, that is, if the jar in which the *hepar sulphuris* is exposed, be filled with this instead of atmospheric air, the separation of the sulphur and alkali is effected with great rapidity: and the dephlogisticated air is *completely* absorbed, and disappears. Here there is no longer room for doubt: and it is perfectly agreeable to Scheele's view of the matter. There is no foul air in the beginning, and therefore none can remain.

These experiments succeed exactly in the same manner when we make use of the fossil alkali in its purest state. And sulphur is also capable of being joined to the volatile alkali, but by a very different process, of which we shall speak hereafter.

From the experiments you have now seen, you have gotten some knowledge of the nature of sulphur, and of the origin of the vitriolic acid, and you see the propriety of the new names. *Sulphuric* denotes its origin: and *sulphurous* (sulphurosus) denotes a redundancy of sulphur in the volatile suffocating acid.

Of this last, it is proper to remark, that it is much less eminently acid; and when combined with sulphur to the utmost, has little sourness of taste. Its attraction for water, and for alkalis, is also prodigiously diminished. It even seems to unite with water reluctantly: and exposure to air takes away

the peculiar smell, and gives us simple sulphuric acid. There are even some curious experiments, where the suffocating vapour is made to deposit the sulphur it contains in a snow-white dry powder. The weakest acids dislodge it from an alkali.

The change of sulphur into acid is performed by the chemical artists as a manufacture. It may be effected by different processes: but only one of them produces the acid in its most perfect and most active state. This process consists in an inflammation of the sulphur. A process for this purpose was prescribed formerly in our Pharmacopœias, under the title of *Spiritus Sulphuris per Campanam;* and had this name from the apparatus employed, which was a large glass bell hung over a wide dish, in the middle of which stood a small vessel with burning sulphur. By this process, however, a small quantity only of the acid was obtained. By far the greater part arose fnom the flame of the sulphur in the form of the sulphurous acid, which was very difficultly condensed; and when condensed, afforded an acid liquor, which continued to have the same suffocating odour, and was very different in several respects from the strong vitriolic acid.

It is evident that this proceeded from an imperfect inflammation, and incomplete change. Processes have since been contrived, by which the inflammation is made more complete, and the sulphur is changed into a large quantity of perfect vitriolic acid. I shall mention the manner of doing this hereafter.

This much is sufficient at present with respect to sulphur, of which it was necessary to take some notice, on account of its connection with vitriolic acid. We are to take farther notice of it hereafter, in treating of inflammables.

Let us next turn our attention to the natural history of this acid. Some time ago, it was very generally supposed among the chemists, that this acid abounds in the air, or at least that there is some of it always mixed with common air. It was called the *Acidum vagum Aëreum*. Nay, some of the most eminent chemists conceived it to be the primitive acid, and called it *Acidum Primigenium*, affirming that

it made the basis of all acids. But the experiments to prove these points are not satisfactory: and there are others which are incompatible with them.

The place in which this acid is in reality found, is the interior parts of the earth. Sometimes, if we may credit observers, it is found combined with water alone, in some mineral waters. But this I think very doubtful. The bad air, or vapour, by which miners have been sometimes suffocated, has also been supposed by some to be vitriolic acid, on account of the steams of burning sulphur being also suffocating. But all accounts of those vapours shew them to be a very different matter; of which hereafter.

Upon the whole, we have no clear evidence that this acid ever occurs in a separate state, except in the steams and smoke of volcanoes and volcanic ground; which steams are said often to have a very perceptible and suffocating odour of burning sulphur. But it is found in great quantity combined with other matter; as in gypsum combined with lime; in bitter purging salt combined with magnesia; in alum and aluminous stones or clays; and in vitriol, green, blue, and white; the origin of all which, and the processes for obtaining the acid from them, shall be considered as we proceed.

Uses.....This acid is itself employed as a medicine, and is necessary in the preparation of a great number. It is used in the arts; in the process of making aquafortis; in separating copper from gold; also in the bleaching of linen, the tanning of leather, and the art of dying. The sulphurous acid is used for whitening woollen stuffs and silks, &c. &c. And vitriolic acid has been the great instrument in the hands of the chemist for detecting other acids, by dislodging them from the compounds in which they were contained.

SPECIES III.....

NITROUS AND MURIATIC ACIDS.

The nitrous and muriatic acids derive their names from the nitre and sea-salt, from which they are commonly ob-

tained. In their strongest state, they are not so heavy as the vitriolic acid; and are therefore supposed to contain less saline matter and more water. The salt which they contain appears to be of itself very volatile, and to have its volatility repressed by the water with which it is joined. This appears when we attempt to prepare those acids of extraordinary strength. They arise in the form of fumes, which cannot be condensed, except we apply a receiver with some water, by which the acid particles are strongly attracted and condensed, and brought into the form of a fluid, more or less manageable, according to the quantity of water with which the acid is combined. If the quantity of water be moderate, it will not be sufficient for totally repressing the volatility of the acid, some of which is always disposed to fly off in vapour whenever the fluid is exposed to the air. But if much more water be added, the disposition to smoke in that manner will be diminished, until it is entirely taken away; the greater quantity of water having more power and effect in suppresing the volatility of the acid.

But it is proper to observe here, that both of them appear sometimes in a more volatile, sometimes in a less volatile state; the causes of which shall be explained hereafter.

When they are diluted with a large quantity of water, we can distil off part of this water, and render the acid again moderately strong. For it is very remarkable, that when they are moderately diluted only, they compose, with the water, a fluid that is rather less volatile than either the water or the acid particles in their separate state. If we therefore subject them to distillation in a largely diluted state, a part of the water distils over at first by itself, or with very little acid, and the acid in the retort becomes stronger. But they can be strengthened in this manner to a certain degree only, which falls considerably short of the strength to which vitriolic acid may be brought by this operation. This proceeds from their being more volatile than that acid.

What has been said so far, therefore, is applicable to both these acids. But we must consider more particularly the nature of each by itself.

NITROUS ACID.

First, therefore, the nitrous acid, when very strong, smokes if exposed to the air; and emits ruddy fumes, of a highly disagreeable suffocating smell, which tinge the air in the phial in which it is kept, with a deep orange colour, but perfectly transparent. When this vapour gets out, and mixes with the air, it forms a dense cloud of ruddy mist, sometimes as red as blood. The acid may be cleared of these fumes, by distilling off a small quantity, and is now called Nitric Acid. What remains is equally, perhaps more acid than before, but does not smoke. Yet if this acid be exposed to the light of the sun, in a phial close shut by a glass stopper, it immediately begins to tinge the air above it, and to produce the same fumes.

The most eminent and distinguishing property of this acid is the strong action which it exhibits on inflammable bodies, and the violent effects which it produces, when mixed with a number of those substances. They are among the most surprising phenomena that chemistry exhibits. You have a good example in its action on the aromatic oils. If one of these, such as oil of caraways, or even oil of turpentine, be put in a small dish or cup, and about two ounces of the strongest smoking nitrous acid (usually called Glauber's spirit of nitre) be poured into the middle of it, the mixture immediately grows hot, smokes, boils, or froths up, and bursts out into a bright flame. The experiment is attended with some risk of being bespattered with the burning stuff, and should therefore be performed in a particular way. Some little circumstances must also be attended to for insuring success. Let the oil be in a dish, in form of a cup; and put the acid into a three-ounce phial, of which the neck is cut off; this must be fastened to the end of a long stick as a handle. The quantity of the acid should be about half of the oil. Pour in about two thirds of it; and as soon as the violent boiling begins, pour in the rest, where the boiling stuff appears blackest and driest. The oil of turpentine should either be thick by long keeping, or be thickened a

little by some turpentine. Mixing about a third part of the strongest vitriolic acid with the nitrous acid is thought to make the success more certain.

This surprising experiment was first published by Dr. Hoffman, with respect to one kind of oil. But others have since shewn that the nitrous acid produces the same effect upon a great number of the oils, and even upon charcoal; when finely levigated, it fires it instantly; only, that with some of those oils the mixture must be made in a particular manner; and, in general, the acid must be used as strong as possible.

As the vitriolic acid is blackened, and made to yield suffocating vapours, by the smallest addition of inflammable substances; so such addition to the nitric acid causes it to assume the orange colour, and give out those ruddy fumes; and it is then in the state called NITROUS ACID.

From the late discoveries in chemistry, there is reason to conclude, that this power of the nitric acid to act with such violence on the inflammable substances, depends on its containing a large quantity of the same sort of air which makes a part of the vitriolic acid,....a particular kind of air which I shall soon make known to you. In the nitric acid it is more loose and active than in the vitriolic acid; and there is a strong attraction between this air and the inflammable substances. The nitric acid, therefore, in acting on some of them, produces elastic fluids, and violent explosions, and very bright and rapid inflammations. All these particulars, in the constitution of the nitric acid, and their relation to the phenomena of combustion, will open upon us by degrees, as we proceed in our examination of chemical bodies.

This acid mixes with water, producing heat, ebullition, red fumes, and a green or blue colour, which, by adding more water, is weakened, and disappears. This blue colour, also appears to be owing to the action of inflammable substances; for, when it is diluted, and has lost its blue colour, it may be restored by a single drop of spirit of wine added to several ounces of the diluted acid. N. B. This diluted acid is the *aquafortis* of the shops.

You may remember that, on another occasion, I mentioned the remarkable effect of this acid on water, in the form of ice or snow, especially the last. It melts them into an acid brine, and the liquefaction is accompanied with most intense cold. But I then explained the cause of this sudden disappearance of heat. It is no way inconsistent with the production of heat by the mixture of the acid with water. Vitriolic acid produces the same effects : but the cold is inconsiderable ; because the freezing or crystallizing temperature of the acid is not very low ; whereas the nitric acid has never yet been congealed by cold, when moderately strong.

Natural History.....All the nitric acid we have is extracted from a compound salt, namely, common nitre or saltpetre; with the natural history of which I shall soon make you acquainted. There is also unquestionable evidence, by experiments of Mr. Kirwan, Milner, Berthollet, and others, that it may be produced by mixing air with pure volatile alkali. You will see, as we proceed, how this may happen, although neither of those vapours contain this acid.

This acid is employed in pharmacy, in preparing a number of the articles of the materia medica ; and is necessary or useful in many other arts, as parting of gold and silver, etching, scarlet dye, and others.

SPECIES III.....MURIATIC ACID.

The muriatic acid, in its ordinary state, is a light yellow, or citron-coloured fluid, which, being exposed to the air, emits fumes that do not tinge the air, but are colourless and transparent in the phial; and when allowed to exhale, and mix with the air of a chamber, they render it misty. These fumes also are noxious to the lungs of those who are much exposed to them. But their smell is very different from that of the nitrous acid, and is thought by some to resemble the smell of saffron.

These are the characters of this acid in its more fixed state. But I must not omit to inform you, that it is also

liable to great difference in the degree of its volatility. As obtained by the process usually prescribed for preparing it strong, it is of a paler colour, and sometimes has hardly any tinge of yellow. It is then in a much more fuming state; and the fumes are much more disagreeable and suffocating. Yet with all these appearances, it is not, as an acid, so strong as when less fuming. If we distil away the half, the fuming, or most volatile part, comes over, while the stronger and more fixed remains in the retort. This more fuming state seems to depend upon the same cause as in the nitric acid: but we cannot demonstrate this so clearly by extemporaneous experiments*.

In mixing with water, it does not produce so much heat as the former two fossil acids; and its colour is only diluted, and the fumes suppressed.

It has very little attraction for inflammable substances. It acts upon them but very slowly and weakly, never producing heat or ebullition. Its action is best observed when it is digested with them. It is then found to darken in its colour, and thicken in its consistence.

Origin.....Margraaf observed that a minute quantity of it exists in the air; but it is found no where else in a separate state. Great abundance of it, however, is found in a state of combination. Common salt, which, as we observed before, is formed in such great quantities in the earth, as well as in the sea, and one half of which is composed of fossil alkali, has this acid for its other half; and from it this acid is always obtained.

The preceding observations may suffice for giving you a preparatory knowledge of the general characters of the mineral acids, as far as is necessary for understanding their manner of acting on certain great classes of chemical bodies. In the consideration of those bodies, and of the

* I confess that the two cases seem to me to be remarkably different. The vitriolic and nitric acids are most eminently acid, when they have no redundancy in their distinguishing ingredient. The muriatic acid is most eminently acid, when it has the greatest proportion of its distinguishing ingredient. This anomaly still remains a mystery.....EDITOR.

way they are affected by their union with these acids, we shall learn by degrees much more concerning the nature and constitution of the acids themselves.

I observed before, that there are many more acids than these: I do not propose, however, to take notice of them all at present; but will confine myself to the description of three of them, of more frequent occurrence. They are distinguished from the former, or mineral acids, by being much less powerful as acids, and less perfect as salts.

These three are called,

The Acetous Acid;

The Acid of Tartar; and

The Sedative Salt, or Acid of Borax.

The acetous acid, and acid of tartar, are called the vegetable acids, on account of their being obtained from vegetables only. The acetous is got from fermentable vegetable substances, by fermenting them in a particular manner; and it seems to be formed by the fermentation. The acid of tartar also is obtained chiefly from fermented vegetable juices; but appears to exist in the vegetable matter before the fermentation, which does not form this acid, but only extricates it. The nature of fermentation, and the particular kinds of it by which these acids are obtained, shall be considered on another occasion. At present we shall attend to the properties of these two acids thus obtained.

SPECIES IV.....ACETOUS ACID.

The Acetous Acid, or Vinegar, is of all the acids the most commonly known, and from it even the fossil acids derived their name. It resembles them in several particulars. Like them, it is a watery fluid; and, in its original state, is always unavoidably diluted with a very great quantity of water; so that if we compare its strength with that of the fossil acids, we shall find that it has hardly equal acidity to a mixture of these with 40 or 50 times their weight of water. It is, in fact, a mixture of the true saline matter and water, in the same manner as the fossil acids. It may be freed from a very considerable portion

of the water by freezing. The ice which is formed scarcely retains any of the acid. Having done this by a moderate frost, the liquor which remains, and which contains almost the whole acid, may be exposed to a more intense cold, which will separate still more water, and leave the acid of very great strength, not less than ten times its former strength. However, this method cannot be practised except in the coldest climates. But you will learn other methods by which it may be freed from a great portion of this superfluous water, and made equal in acidity to some of the mineral acids.

But besides this great proportion of water in which it is diffused, we find it mixed with a quantity of mucilaginous and inflammable matter, and some other saline bodies beside our acid. When we desire to render it purer for chemical purposes, we separate these impurities by distillation, the purer acid being so volatile as to rise by a moderate heat, very little exceeding that of boiling water; while the other matters, which are not disposed to rise at this heat, remain. It is then called distilled vinegar. By the same operation too we can free it of some part of its water: that is, having first separated it by distillation from those extraneous matters which are less volatile, we separate some of the water that dilutes it, by another distillation, in which the dephlegmated acid remains in the retort. By this method, the acid is pretty well separated from the slimy, tartarous, and other fixed matters. But the separation of the water, or the dephlegmation or concentration of vinegar, as it is called, can be carried only to a very imperfect length by distillation alone, on account of the small difference in point of volatility between the acid and the water. Other ways, therefore, have been attempted, 1*st*, By freezing, as has been already mentioned; 2*d*, By joining some fixed substance, which diminishes its attraction for water, and fixes it so as it can be reduced to a dry mass; and then it may be separated by heat alone, if it be not too strongly retained, or with the assistance of some addition, such as charcoal

dust*. At present, I can only notice the general principle on which those additions are made, namely, to force the acid to bear a considerable heat. But this alone would not be enough. It only comes in aid of elective attractions, which of themselves are too weak. The particular modification of each of these additions not being yet familiar to you, I need not name them at present. They will occur in course.

Thus it may be made as strong as the fossil acids; for though it is more easily elevated by heat applied, it is not so elastic as the nitric and muriatic acids. In this very concentrated state, the acetous acid crystallizes, and its vapours are inflammable, as also the acid itself, if made pretty warm. This operation, however, is not necessary to prepare the acid for the common uses to which it is applied. For common uses, it is only purified by distillation: and it is then known by the name of *distilled vinegar*. It resembles the fossil acids by effervescing with alkalis in their ordinary state, and by uniting with them, and with absorbent earths, and some metals, though weakly. Like those acids, it changes vegetable colours to red. But it has little effect upon inflammable bodies; though it may be combined with them; nor is it so acrid and corrosive, even when equal in strength.

But there is another remarkable particular by which it differs from the fossil acids, viz. by being easily destructible by the action of heat, if the heat to which it is exposed ever rises to the point of ignition. We may observe the effects of this heat upon it, by joining to it some fixed substance that can retain it, and repress its volatility with proper force, such as a fixed alkali. If it be united to one of these, and the compound exposed to heat in close vessels,

* Mr. Lowitz, an eminent chemist at Petersburg, found that charcoal acts on acetous acid, so as to make it resist a heat somewhat exceeding that of boiling water. Therefore, by managing the distillation with great care, all the water can be expelled, and what remains in the retort is the charcoal, combined with the acetous acid. This state of things must be indicated by the cessation of drops from the neck of the retort. The receiver must now be changed, and the heat raised a few degrees. The acid will now come over in the most fragrant, pure, and concentrated state that can be produced.....EDITOR.

as soon as the compound salt approaches to a red heat, the acid begins to be totally destroyed. The principles of it are disarranged, and made to enter into new combinations with one another, so that we never can recover it again. It is scorched, burned, and destroyed by the heat, and converted into fœtid, watery, and oily steams, and a black coaly matter adheres to the alkali.

The same change is produced by fire on all vegetable matter in general. And as all other vegetable matter is inflammable, so is also this acid.

SPECIES V.....ACID OF TARTAR.

The other species of vegetable acid, which is known by the name of the *acid of tartar*, or the *tartarous acid*, is still more gross, and farther removed from the nature of the more pure and perfect salts. For although we can reduce it to a dry state, and crystallize it, it is neither a fusible nor a volatile substance. I mean that, except a watery fusion, which the crystals can undergo, it is not capable of being melted, or converted into vapour by heat, like most other salts, so as to resume its natural appearance and properties, when it is cooled. When heat is applied to it, no sooner does the heat rise above that of boiling water, than this acid begins to be scorched and burned by the heat acting on it, as happens to vegetable matter in general; and as the heat is increased, fœtid, oily, and sooty steams arise from it, which may be set on fire. A black coal remains, which may be burned to ashes; and thus the acid is totally lost and destroyed; that combination of its principles upon which its properties depend, being now so completely undone, that it never can be restored again.

Water applied to this acid, dissolves it easily and in great quantity. The solution, when very strong, is thick like a sirup, and has an agreeable acid taste, like that of lemons. It effervesces with alkalis, and unites with them as other acids do: but it does not affect the vegetable tinctures so much.

Origin.....It is extracted from the vegetable salt called tartar, which contains this acid combined with an alkali, and

which is found in the juices of many of the vegetables, particularly in that of the grape. The nature of this compound salt, which was not thoroughly understood, until it was investigated by Mr. Scheele of Sweden, shall be explained when we treat of the compound salts.

Beside the tartar commonly known and used in medicine, there are other kinds, a little different from it, in the juices of other vegetables; as sorrel, tamarinds, &c. The difference of them from common tartar depends upon their acid, which is a little different, though it agrees in its nature upon the whole; all of them being totally destructible by a burning heat, and with the same phenomena as those that accompany the destruction of the tartarous acid of wine.

For a great variety of vegetable acids, many of them newly discovered, see Fourcroy's Preliminary Discourse to the second edition of his Elements.

SPECIES VI....SEDATIVE SALT.

The sedative salt, the next in order, was so called from some virtues in medicine, which it was supposed to have when it was first discovered. Its powers as an acid are still weaker than those of the vegetable acids. We can hardly perceive any acidity in it by the taste; and it has very little effect on the vegetable colours. But it effervesces with alkalis, and unites with them in the same manner as the acids: and it can be combined with some of the earths which have attraction for acids in general. It is obtained from a compound salt, called borax. And the nature of the operation by which it is extracted from the borax, is such, that the sedative salt is obtained in a crystallized state; the crystals which it forms being mostly flat and thin like the scales of fish, and feeling slippery between the fingers. When we make experiments upon it in this state, we find two things very remarkable in it:

The first is the manner in which it is affected by heat applied to it. When exposed to heat in the open air, it generally emits white fumes, and seems to melt; but this is only a watery fusion, and it soon becomes dry and spongy. If it be

heated in a retort, it first undergoes the watery fusion; then water is distilled from it; some of the salt sublimes; and the rest remains perfectly fixed. Were we to form a conclusion too hastily from this experiment, we might imagine that this salt is not homogeneous; but that part is fixed, and part volatile. But we shall be undeceived if we pursue the experiment. If we collect the sublimed matter, and examine it, we find it to be precisely the same as the sedative salt was at first, only formed into smaller, thinner, and lighter scaly crystals. When these are exposed to heat in the same manner, they shew precisely the same phenomena which have been mentioned above. On the other hand, the fixed part, which remains in the retort, is hard and transparent, like glass or horn. But it dissolves in hot water, and crystallizes on cooling, and undergoes the same changes as that which was sublimed.

These experiments, therefore, shew that there is no difference between one part of this salt and another; but that the manner in which a part of it sublimes is this: the crystals of it, like those of many other salts, contain a good deal of water. When heat is applied to these crystals, watery fusion takes place; and the water is gradually driven off in the form of vapour. While the quantity of the water which adheres to the salt is thus diminished, the remainder is retained the more strongly; the greater proportion of saline matter with which it is combined, acting upon it with a greater power of attraction. And when the heat increases to such a degree as to force it to rise, a part of the salt rises with it. They cohere too strongly to be completely separated by heat. At last, however, so much of the water is separated, that none, or scarcely any, remains with the salt in the bottom of the retort. The saline matter then shews its natural relation to heat. It is fixed in the fire, and melts into a transparent viscid fluid like glass. But this glass-like matter can all be made to sublime by repeated additions of water.

In this manner is the sedative salt affected by heat. The other remarkable particular observable in it, is the effect it produces on spirit of wine. Sedative salt dissolves very readily in highly rectified spirit of wine, especially if previously de-

prived of all water; and, in this state it may be taken up by the wick of a lamp, or any bibulous substance. The best way of observing its effect on the flame, is to dip some paper into the solution, and hold it upright while burning. The flame is of short duration, but very large, and of a beautiful green colour, especially at the top.

Although this salt shews strong attraction for the water which it contains in its crystals, it has but little disposition to unite with more water, or to dissolve in it. Cold water dissolves very little of it. Hot water has much more effect: but when the solution cools, the greater part crystallizes.

The origin and natural history of the sedative salt was, until of late, very obscure. All that we knew of it was, that it is a part of a compound salt called Borax, imported from Boutan and Thibet, in the East Indies. But when inquiry was made about the origin of the compound salt, we could obtain no distinct accounts of it; reports only bearing that it was procured from certain mineral waters. This, however, was not satisfactory; because nothing like it was known in Europe or America.

At last, however, two or three years ago, some hot mineral waters were discovered by Hoefer in Italy, in the neighbourhood of Siena, and also in the Duke of Tuscany's dominions, which, beside other ingredients, contain sedative salt. (*Extrait des Observations sur les Lagonis au pais de Siena, et celui de Volterra en Toscan, par Paul Muscagne. Observations de Phys.* 1780.) The description of the neighbourhood of the ponds where the sedative salt is found, and the account of the changes incessantly going on there, in which the firmest flinty rocks are continually mouldering away and forming new compounds, is extremely curious, and will lead the philosophical chemist to very important reflections. In these places, the sedative salt is sometimes found in considerable masses, generally adhering to a schist or slate, in crystals considerably differing in form from what I have been describing. It is also frequently found combined with other substances, such as lime, clay, volatile alkali. But Hoefer has not found it in that state in which it is gotten in India.....See also *Experiences sur les*

sels sedatifs, nitreux, marin, et aceteux, par M. Cadet, Ac. Roy. 1780.

It is also found in a very hard stone at Luneburg in Germany, and may probably be found in others.

As I have already observed, there are several other substances having the chemical properties of acids. Amber furnishes one; ants yield another. Several plants contain acid juices; such as sorrel, rhaponticum, and the whole family of the rumices or docks. Most of the pulpy and fleshy fruits of trees and shrubs yield it in abundance. These are all of a very complex nature; and are eminently distinguished from the mineral acids, in their being destructible by fire, in such a way that they cannot be recovered. You are not yet prepared for understanding their distinguishing properties. Indeed these are not yet very fully investigated, having but lately attracted much attention.

Besides these, there have been discovered two other acids, which are not destructible by fire; namely the acid of phosphorus, and the acid of fluor or spar. These have very distinct and very remarkable properties, and shall be duly noticed as we proceed.

GENUS III.

OF THE COMPOUND OR NEUTRAL SALTS.

HAVING now given some account of two of the most active classes of chemical bodies, the alkalis and the acids, and having taken some notice of their disposition to unite and combine with each other, I take this first opportunity of making you familiar with the most important part of chemical science and art,....the composition, and decomposition of bodies. The relation of the alkalis and acids affords the best example of this. The phenomena are simple and precise: and therefore are the most proper specimens. Besides, the union and separation of acids and alkalis occur in almost every other chemical investigation.

I have considered three alkaline salts, and six acids. And I am now to explain, how these nine salts, or saline substances, unite with one another to form the compound salts, which have been a long time known and in use.

A person who knew nothing more concerning the compound salts which we are now to describe, but that they are formed by different combinations of the nine simpler salts which you have seen, might naturally suppose their number to be very great; for, were the simpler salts capable of being combined in a great variety of ways, in respect of number and proportions of the ingredients, the different compounds producible from them would amount to a very great number indeed. But when you call to mind the nature of chemical union in general, and the account which I have given of the different simple salts, with respect to their power of combination, that is, the limited manner in which alone they are disposed to

unite, you will perceive that we can produce from them but a very moderate number of compound salts.

For, in the first place, it appears by mixing them variously together, that no acid has any attraction for any other acid, nor any alkali for other alkalis. Acids may be mixed intimately with acids, and alkalis with alkalis; because they can be applied to one another in the form of watery fluids: but thus mixed, they do not shew any chemical attraction for one another. The volatility and other properties of the volatile acids are not in the least diminished by mixture with the fixed acids, nor the volatility of the volatile alkali, by the fixed alkalis. The only manner in which we can obtain compound salts, is by mixing the acids with the alkalis. These, upon all occasions, shew a chemical attraction for one another, and are strongly disposed to unite. And their union, when we employ them in their ordinary state, is always accompanied with that violent effervescence which you have seen.

But what still farther limits the number of salts producible in this way, is, that almost in every case the acid and alkali are capable of uniting firmly together, in one certain proportion only. What the nature of this proportion is, we cannot pretend to say. Whether it consists of an equality in the number of the atoms of the two salts; or whether there must be two acid particles or atoms to every one of the alkali, or two of the alkali to one of the acid; or what other proportion, different from either of these, may be necessary to constitute the compound salt, cannot be determined. But, in order to explain the formation of these salts more distinctly, I shall suppose that the proportion in which the acid and alkali are disposed to unite the most strongly, is that of equality. Let us then take an acid and an alkali dissolved separately in water, and add a small quantity of the acid liquor to the alkaline one. Every atom of the acid that has been added is united with a respective atom of the alkali, so that a certain quantity of the alkali is changed into a compound salt, which, if there be water enough to dissolve it, is equally distributed through the liquor, and blended with the remaining alkali. But this remaining alkali still retains all its properties, and is precisely the same

as before. If we go on to add more acid by degrees, we shall successively change more of the alkali into a compound salt, until such a number of acid atoms have been added as are sufficient to change the whole of it. Then the mixture is complete. If we add more of the acid, it will suffer no change. It will be uniformly diffused through the liquor, but will remain disengaged, and retain all its properties. Or, if a small quantity of it sometimes attaches itself to the particles of the compound salt, its adhesion is loose and imperfect, and easily overcome. This is not only the case with regard to the same acid which enters into the composition of the compound salt. But even although we add any other acid, it will either produce no effect whatever; or, if it does unite itself to the alkali, it is sure to separate the first acid, so as to produce a different compound salt, but one of a similar nature to the former, in so far as there is a limit to the proportion of acid and alkali of which it is composed. What has now been said with respect to the mixture of different acids with the same alkali, must be understood also of different alkalis mixed with the same acid. As the same alkaline atoms are incapable of being strongly united by attraction with two or more different species of acids at the same time; so the same acid particles are incapable of being united at the same time with more than one species of alkali.

I have been thus particular in explaining the manner in which acids and alkalis unite to form compound salts, for this reason, that the simpler salts, and especially the acids, are among the most active of the objects of chemistry. They dissolve a variety of earths, metals, and other bodies; and unite with these in a manner very much similar to their manner of uniting with alkalis; upon which account it was proper to explain this once for all at full length. On this subject I recommend to your serious perusal Mr. Kirwan's dissertation on the attractive forces of the mineral acids, published in the Philosophical Transactions, and also in a separate volume. You will there meet with many important observations on the proportions of the ingredients, and the variations to which this is subject, and many other instructive particulars. Mr. Ber-

thollet has also considered this subject with peculiar care and great judgment.

The compound salts, however, are not always produced by joining together artificially the pure acid and alkali which they contain. Some of them are found ready formed by nature. Others are produced accidentally, in chemical processes, in which their constituent salts are mixed together, although their union is not the principal object of the operation. But there are some which we never obtain but by mixing, on purpose, the acid and the alkali necessary to their composition.

When we produce a compound salt in this way, and gradually add the acid and alkali to one another, in order to attain the due proportion, this is called saturating these salts with one another. And when the due proportion is found, we say they are mutually saturated, or that we have attained the point of saturation. This point is judged of commonly by the gradual diminution and cessation of effervescence. But there are other marks which are more certain and exact signs of saturation. If we trust to the cessation of effervescence alone, we may commit mistakes, especially if we do not take care to agitate the mixture very frequently and very briskly, while we are adding the one salt to the other.

Thus if we add an acid to an alkali by degrees, till the effervescence ceases, we shall afterwards find that we have added too much acid ; for the liquor will now effervesce by the addition of alkali. The same effect will take place, if we begin by adding alkali to an acid. It was proper to take notice of this circumstance, because it is a general fact in all effervescing mixtures. Nothing will secure us against the danger of exceeding in one of the ingredients, but frequent and brisk agitation of the mixture, especially as we approach to the term of saturation.

But better proofs of exact saturation may be had by examining the state and qualities of the mixture : for the compound salts thus produced have very different qualities from either acid or alkali. The acid in a separate state has a strong sour taste : the alkali has a different one peculiar to the alkaline salts. The acid gives a red colour to the blue or purple tinc-

tures of vegetable flowers: the alkali gives a green. But when they are properly united, the compound salt which they produce has not the taste of either acid or alkali, but one much milder, and of a quite different kind. Moreover, it occasions no change of colour in the vegetable infusions.

By these marks, therefore, we can bring the mixture to more exact saturation, particularly by vegetable colours. And the best manner of using the vegetable colours is to have some paper or fine linen stained with them, little bits of which being dipped into the mixture, will immediately shew, by the change of colour, whether there be any superfluous acid or alkali in the mixture: and it is best to have different kinds of these for different purposes. Thus the juice of the flowers of the March violet is the most sensible to alkalis. And the infusion of the dying drug, known by the name of Litmus or Lacmus, is the most sensible to acids, though little affected by alkalis. There is also a coloured infusion prepared from red cabbage, which is recommended by Mr. Watt, in a paper in the Philosophical Transactions, as a most delicate trial of the presence of acid. And the purple skin of the common radish, when scraped off with a knife, gives a juice with which paper may be stained for this purpose, so as to afford a very nice trial of acid or alkali in liquors.

In some cases, however, it is not necessary to be extremely nice; because the nature of the particular salt produced is such, that though the acid or alkali be redundant, the compound salt is easily separable from this redundant acid or alkali, by crystallization or otherwise. Thus, when we compose a salt of an acid and the volatile alkali, we choose rather to add a little too much than too little of the volatile alkali; because this alkali is so volatile, that when the water is afterwards evaporated, we are sure that all that is superfluous will fly away. And we shall see afterwards that crystallization likewise, in some cases, will purify a compound salt from acid or alkali.

The other particulars by which compound salts differ from acids and alkalis, are, 1*st*, A weaker attraction for water; so that in general they are easily separable, and dried or crys-

tallized ; 2*d*, Much less acrimony than either of them. Most of them do not act at all, and the rest but weakly, on metallic and earthy bodies, and inflammable substances. From this variety of effects, the acids and alkalis have been considered as contrary or opposite in their nature, and as qualifying and counteracting one another in the compound salt. Hence have arisen the names of *neutral salts* and *sales medii*; though, when they are considered more attentively, there seems to be but little foundation for this supposition of their contrariety. The whole is perfectly agreeable to that general observation, given formerly, with regard to mixture, that when two bodies are united by a strong attraction, their activity or acrimony, and their attraction for other bodies, is very much diminished, or entirely disappears. The epithet, neutral, is applied to the compound salts with considerable propriety; because the compound has neither the properties of the one nor of the other ingredient. Middle salts is a less proper name.

From the view which I have given of the nature of compound salts, you must now perceive very plainly, that all the varieties producible from the nine simpler salts already described, amount only to eighteen: for each of the alkalis is only capable of being combined with any of the six acids; so that with three alkalis and six acids we can produce only eighteen compound salts. Even of these eighteen, some have not been examined, or applied to any use; and therefore are not commonly prepared or treated of in chemical books.

By thus considering the possible number, you perceive that they can be reduced to the form of a table, in such a manner that the place of each shall point out the acid and alkali of which it is composed:

TABLE OF NEUTRAL SALTS.

	Vitriolic Acid.	Nitrous Acid.	Muriatic Acid.	Acetous Acid.	Tartarous Acid.	Sedative Salt.
Vegetable Alkali.	Vitriolated Tartar.	Nitre.	Sal Digestivus.	Sal Diureticus.	Tart. Solub. and Tartar.	
Fossil Alkali.	Glauber's Salt.	Cubical Nitre.	Common Salt.		Sal Rupellensis. Rochelle Salt.	Borax.
Volatile Alkali.	Vitriolic Ammoniac.	Nitrous Ammoniac.	Sal Ammoniac.	Spiritus Mindereri.		

The neutral salts may be decomposed, and the simpler salts of which they consist separated from one another, in some cases, by heat alone, but in most cases by elective attraction, or the addition of some third substance, which attracts one ingredient of the salt more strongly than the ingredients attract one another; and, therefore, unites with that ingredient, and separates the other, or throws it loose. In most cases, an addition of only one of the simpler salts is required: for it has been discovered by experiments, in mixing neutral salts with several kinds of the simpler salts, that the different acids have different degrees of attraction for the alkalis in general, while the alkalis, on the other hand, have different attractions for the acids in general. If, therefore, we wish to have the acid of a neutral salt pure, it is in our power, with regard to most of the salts, to obtain it by the addition of another acid and heat. On the other hand, we can likewise obtain the pure alkali of a compound, by the addition of another alkali.

It is very advisable for a student of chemistry to have this table very familiar to his mind. Much more may be learned from it, than merely that such a compound salt is made by the mixture of such an acid and such an alkali: for the table, when properly constructed, may be made a picture, as it were, of a great train of chemical relations and operations, and tell us what will result from the mixture of a compound salt, with other acids or alkalis than

those of which it consists. For it fortunately happens, that the elective attractions of any acid for the different alkalis proceed in the same order. The same thing obtains in the elective attractions of an alkali for the different acids. Therefore the columns of the table may be arranged according to the elective attractions of an alkali for the different acids: and the horizontal rows may be arranged by the attractions of an acid for the different alkalis. Or the columns may be arranged by the attractions of the acids, and the rows by those of the alkalis. I have chosen the first method. The first column and the first row contain the strongest, and the last of both contain the weakest attractions. In the space allotted to each compound salt, I have inserted the name by which it has been most generally mentioned by the systematic writers, till of late. They are mentioned by different authors by a great variety of names, according to the particular views of the writer, whether medical, philosophical, or otherwise. It is proper, therefore, to subjoin to this table a complete list of synonima, in the manner of the natural historian. The new systematic names, and a different arrangement of the compound salts, will be laid before you after this, when we shall have understood the principles which have given rise to them.

I shall now describe the compound salts in the order in which they stand in the table.

SPECIES I....VITRIOLATED TARTAR.

First, therefore, we consider vitriolated tartar, so called because composed of vitriolic acid and salt of tartar, which last is now known to be the purest form of the vegetable alkali. Hence it is named in the Edinburgh Pharmacopœia, *Alkali Fixum Vegetabile Vitriolatum*, a denomination rather long and cumbersome. It is now called *Sulphat of Potash*.

Its taste is a little pungent and bitterish; and half an ounce of it purges. Smaller doses are given as laxatives, and to promote the other secretions: and it is sometimes

useful in scrophulous cases. As it contains a fixed alkali, and the least volatile of the fossil acids, and as these two salts are united in it by the strongest elective attraction, they cannot be separated from one another by heat alone; nor can any simple salt be employed in this case to produce their separation. It was, therefore, sometime ago, reckoned a very difficult problem to separate the vitriolic acid from the vegetable fixed alkali: and Dr. Stahl raised much emulation among the chemists, when he boasted of his knowing a method so easy, that he could perform it in the hollow of his hand. This occasioned many attempts, and produced a discovery of several methods for decompounding this salt, which may be performed more or less perfectly in the hollow of the hand. Most of these depend on cases of double elective attraction, which it will be more proper to explain hereafter than now. The manner of doing it which Stahl seems to have meant, depends upon a preparatory operation, by which the acid is converted into sulphur. I have already mentioned this preparatory experiment, when treating of the vitriolic acid. Stahl's mixture of vitriolic acid and alkali (to be exposed along with charcoal to a red heat) was this very salt. Sulphur was produced; and, therefore, some of the alkali was left separated. The sulphur unites with this composing *hepar sulphuris*. The union is so weak, that vinegar will separate the sulphur, and form a compound salt with the alkali. Then are the two ingredients completely separated. They may even be had pure; for we can burn the sulphur, and thus obtain the acid. And, the compound salt being exposed to a red heat, the vinegar is destroyed; and thus we obtain the alkali.

This experiment has been very instructive. Being attempted in a great variety of ways, it brought many things to light; and was particularly useful, by explaining the frequent appearance of sulphur in mixtures of substances which did not contain it. They were all cases of vitriolic acid urged by red heat in contact with imflammable bodies.

This compound salt has not a strong attraction for water. It dissolves but slowly, and in small proportion, in cold

water: and even of hot water a considerable quantity is required to its dissolution. It readily crystallizes: and its crystals are of the decrepitating kind, and contain but little water in their composition. According to Bergmann they contain,

Alkali	52	in 100 parts by weight.
Acid	40	
Water	8	

The form effected by the crystals is a hexangular prism, terminated by a pyramid. But this is distinguished with difficulty, by reason of their grouping together. Crossing at right angles is a pretty distinguishing mark of this salt*. But although they shew so little attraction for water, it will carry off a good deal of the salt with it, if we evaporate too hastily.

Origin.....It is not found as a fossil production. There is some of it in the ashes of vegetables mixed with the alkali: and it is probably formed in their juices by the powers of vegetation. It is commonly prepared for the purposes of medicine by art. We shall soon see an example of this in a process in which the production of it is not the principal object. In order to obtain it in its fairest form, with the largest and most regular crystals, it is advisable to have the acid, predominant in the mixture. Although it be considerably acid, the crystals will be perfectly neutral. Some chemists, however, choose to call such a compound a super-sulphurated salt.

SPECIES II.....GLAUBER'S SALT.

Glauber's salt is called *Soda Vitriolata*, in the Edinburgh Pharmacopœia. Its new name is *Sulphat of Soda*.

This salt is much more easily melted in the fire than vitriolated tartar: and it is also more soluble in water. Its crystals are in the form of long hexagonal prisms, terminated by pyramids. The prisms have two broad and four

* The crystals of vitriolated tartar form a double prismatic spectrum by refraction, in the same manner as several kinds of rock crystal.....EDITOR.

narrow faces. They are very watery, and subject to watery fusion, and fatiscence. Hence for a purgative dose of it, an ounce is required. 100 parts of it contain 15 of alkali, 27 of acid, and 58 of water. It cannot be decompounded by heat alone; but, like vitriolated tartar, by sulphurification and vegetable acid; and by some other processes which depend on double exchanges. We can also decompose it, though not conveniently, by the action of the vegetable alkali. *Oleum Tartari per Deliquium*, which is the mildest form of the vegetable alkali, must be digested on Glauber's salt for a long while: and we shall then find a vitriolated tartar, and a fixed fossil alkali in the mixture. The attraction of the vegetable alkali for the acid does exceed that of the fossil alkali, as may be gathered from many experiments; but it is so little, that it was long doubted. Even the present decomposition of vitriolated tartar does not prove it; because, as we shall soon see, it is assisted by a double exchange.

Origin.....This salt is no where found, that we know of, as a natural production. Many, indeed, say that it is contained in the waters of the sea, and in those of purging mineral springs. But this is a mistake: and the substance which we take for it, is the bitter purging salt, which was long mistaken for Glauber's salt, even by chemists of great eminence. Mr. Model of Petersburgh relates a number of experiments made by him on a salt found in many waters in that neighbourhood, and describes the salt so exactly, that we now know beyond any doubt, that what he calls the Sal Miraible is nothing but Epsom salt.

All of it that is used in medicine is artificially made, by decomposing common salt with vitriolic acid: and the manufacture of it forms a considerable business in the hands of trading chemists. Some of it is formed from kelp. The following process for making it is published by the Society of Arts:....Put a pound of kelp into an English gallon of boiling water, so as to extract the salts. Decant, &c. and add as much vitriolic acid as is necessary to saturation. Two ounces are commonly enough. Then filtrate, evaporate, and crystallize, &c. and you will have about half a pound of Glauber's salt.

SPECIES III.....NITRE, OR SALTPETRE.

This salt is well known, and is very useful and necessary in many arts. It has occasioned a total change in the art of war; for the use of it in that art was unknown to the ancients.

I have already observed, that the salt mentioned in some parts of the Bible by the name of nitre, was an alkaline salt. This appears from the contrast or incongruity remarked between it and vinegar, and also from its being employed as a detergent or cleanser. In most of the passages also of Pliny, where he speaks of nitre, he plainly means an alkaline salt. It is very clear, however, that our saltpetre was known by that name, and also by the name of nitre, in the earliest ages of scientific chemistry. It is frequently mentioned, and with characters which give us no room to doubt of its identity.

In pursuance of my general method of examination, I shall first consider the most simple relations of nitre to heat, and its mixture with water; and then proceed to relations of the same kind, but more complicated in their circumstances. I shall employ a good deal of time in this examination, both because the chemical properties of nitre, and the phenomena which it exhibits, are the most remarkable that occur in the chemical history of nature, and also because these properties and phenomena afford, in the easiest manner, the steps of investigation which lead us through almost the whole philosophy of our course. You will find the greatest part of our important doctrines to be little more than the gradual detection of the properties of nitre and its ingredients. I could begin by stating all those properties at once, in their full influence, and from thence deduce the chemical doctrines synthetically, as Newton explains the colours of natural bodies from the properties of light, or the motions of the planets by universal gravitation. But, to give you the conviction that such are in fact the properties of nitre, would require the narration of facts concerning many substances with whose properties you are altogether unacquainted. I am certain

that your conviction will be much more forcible, and your knowledge more palpable, and, as it were, at your fingers' ends, by allowing those properties of nitre to open upon you by degrees, as we come to consider those other substances, whose appearances, as affected by nitre or its ingredients, are the very arguments by which the properties of those ingredients are ascertained. The great doctrines of modern chemistry will thus be the result and fruits of your own induction and analysis. Add to this, that you will thus have formed the habit of philosophical investigation by experiment; and will perceive its immense superiority over all synthetical theory, however specious and extensive in its application. I may add, that were I to treat these subjects in the pure synthetical method, which is thought attainable, and which seems, at present, to be most acceptable to the chemists, (especially on the Continent), I should leave you ignorant of the ingenious labours of the most eminent chemists of Europe, and unable to read and understand their writings.

When nitre is exposed to heat in an open vessel, such as a crucible, we find very little water in its crystals. It neither shews watery fusion, efflorescence, nor decrepitation. Its water escapes insensibly. If the heat be very hastily applied, some nitre sublimes, very little changed. But a slow and gradual increase of heat melts the nitre quietly, before it be so hot as to shine in the dark. It looks like melted white bees-wax. If the heat be increased a little, the fluid begins to simmer gently, by the escape of very small bubbles of elastic matter. If this be long continued, the disagreeable smell of nitrous acid is perceived; and fumes are emitted of a deep blood-red, perfectly resembling those already described, when I was considering the nitrous acid. By this process, the nitre gradually wastes: and what remains frequently dissolves the glass or earthen vessel in which the nitre was contained. The residuum, when examined, is found to be strongly, and sometimes entirely, alkaline, and quickly deliquiates in the air.

From this it would appear that nitre is decomposed by heat, the acid being driven off in these red vapours. We

are naturally led, therefore, to try the effect of distillation in close vessels. But we shall find it extremely difficult to condense the vapours; and the quantity of acid obtained in this way is frequently almost nothing: in all cases, it is fuming and deep coloured, and the vessels are filled with blood-red vapours. They are incoercible, and would burst the vessels; yet the acid is gone from a part of the nitre at least. Since we cannot collect it in the receiver, we must conclude that it is somehow destroyed or decomposed, or converted into these permanently elastic fluids. Accordingly, Dr. Hales obtained from a cubic inch of nitre in this way, (that is, by distilling it in a gun-barrel, and collecting the vapour in a jar standing inverted in water) 180 cubic inches of air. Dr. Hales explains, by means of this air, the explosion of gunpowder and other nitrous compositions. In the preceding century, something like this had been done by Dr. Mayhow of Oxford, in 1674. He collected the nitro-aërial spirit, as he called it, in bladders tied on the spout of the retort. [See *Jo. Mayhow Opera Medico-physica*, published at the Hague, 1681; also his *Dissertatio de Salnitro et de Spiritu Nitri Aëreo.)* This author wrote in an obscure mysterious manner, as was too much practised in those days. But he has made many experiments, most ingeniously contrived, and has deduced from them conclusions which are nearly the same with the doctrines which have been more clearly established of late years. In particular, he considers this nitro-aërial spirit as the cause of combustion, the support of animal life, and the source of animal heat. Since that time, and even before, there has been much vague speculation and discourse about a vivifying nitrous spirit in the air. Muschenbroeck and others ascribe to it the spicular form of snow and hoar-frost; but all this was mere talk, without any distinct thoughts on the subject. *(See Note* 31, *at the end of the Volume.)* I shall very soon give a more particular account of this elastic matter.

The relation of saltpetre to water offers nothing very remarkable. It dissolves readily in six times its weight of cold water. Boiling water, however, dissolves an equal

weight. In both cases, a considerable absorption of heat takes place. It is easily separated from water by crystallization; and the absorbed heat again emerges. The crystals are slender hexagonal prisms, of equal sides, terminated by irregular pyramids, having one face much broader than the rest. They are thus distinguished from Glauber's salt, whose prisms have very unequal sides. Nitrous crystals contain very little water, but so strongly united as not to be separable without a red heat.

The most remarkable properties of nitre appear when it is treated in great heats in contact with inflammable substances. When charcoal, or sulphur, or any inflammable matter, which is not so volatile as to rise before it acquires a red heat, is put into melted nitre, the nitre, which was quietly fluid, is immediately thrown into violent agitation, and bursts out in explosions of elastic matter and dazzling flame. This continues, with a whizzing noise, as long as inflammable matter remains. And, if the quantity be considerable, and intimately mixed, the whole explodes in a moment, with almost irresistible force, a bright flash, and loud noise. If a lump of charcoal be laid on nitre, just hot enough to act on it, the deflagration takes place only in the touching parts; and it continues whizzing, and throwing out streams of fire, till the coal is expended. Great heat is produced, and the nitre will all become of a bright red. Even although the nitre be not so hot as to set fire to the charcoal, if only a bit of the coal be red hot, it will there be acted on by the nitre, and the heat produced will suffice for making the adjoining parts act on each other: and the detonation will continue till the charcoal be expended, and the whole nitre be melted and become red hot.

This effect of nitre on combustible substances is called DEFLAGRATION, or DETONATION. No wonder that chemists have attempted to explain the grand operations of thunder and lightning, by supposing mixtures of this salt, or of its nitro-aërial spirit, with inflammable substances in the air. Indeed it was those phenomena of nature, in all probability, which gave rise to the notion that such a spirit was diffused through the atmosphere. But thunder and

lightning are now well known to depend on very different principles.

By repeated additions of charcoal, the deflagration, and the fusibility of the nitre, are diminished, and the deflagration at last ceases entirely. When the salt remaining is examined, it is found to be pure vegetable alkali, in quantity just equal to what we know the nitre to contain.

This fact gives an explanation of the whole phenomenon. It is produced by the violent action of the nitrous acid and inflammable matter. This is already known to you. The acid quits the alkali to act on the combustible matter: and the action is such, that both are converted into elastic aërial fluids, so completely, that no part of the acid can be recovered in its former state. Indeed, it is decompounded and destroyed. Of this we obtain clear proof, when the operation is performed in a stoppered earthen retort, with a receiver for condensing the volatile matters. We find no acid in those vapours, but, in the place of it, a large quantity of air, of a complex kind. It will not support flame nor animal life; and it was therefore imagined to be of that kind that is met with in coal-mines, and is called choak-damp, and in vessels where charcoal has burnt till it is extinguished for want of air. But when we had learned an exact test of such air, and the method of abstracting it from any mixture, it was then found that the air produced by deflagrating charcoal with nitre did contain a considerable portion of it, but that another portion was of that kind that is left unabsorbed by *hepar sulphuris* exposed to atmospheric air, and is called *faul* air by Scheele, and *phlogisticated* air by Priestley; and, besides these two, it usually contains some common air. This was extricated from the materials, and it is evident, by the alkaline residuum, that the acid alone contributed to the production. We shall soon understand the change thus produced on the acid: and I only observe at present, that a red heat is necessary for occasioning this action. The acid, having a strong attraction for the alkali, is thus weakened in its attraction for inflammables: but the union with the fixed basis enables it to stand the red heat which is necessary. In a separate state, we have seen it act most

violently, and even excite them to inflammation; but we are not therefore to suppose that the heat produces this deflagration by first decomposing the acid, and changing it to elastic gas, which we have seen that it really does. Yet, no doubt, this favours the detonation: for when nitre is melted, and red hot, and its acid escaping in red fumes, if a bit of charcoal be held close above it, but not touching, it will presently take fire, and burn with rapidity and dazzling brightness; an evident proof that it is the elastic matter of the nitre which causes the charcoal to burn, and that the acid must be in that form, but not yet decomposed, when it produces the effect.

When nitre is deflagrated with sulphur, the consequences are considerably different. The deflagration is equally violent with the other, and the flame somewhat more brilliant. The acid is destroyed in the same manner. But the elastic matter produced is different in some respects. The most of it is the *foul air* of Dr. Scheele; a circumstance deserving particular notice. We have an evident smell of *hepar sulphuris*, as we might expect, from the combination of the sulphur with the alkali left behind in the deflagration. The residuum of the process is not alkali, but vitriolated tartar. Before its chemical nature was thoroughly known, this residuum had gotten a high name as a medicine, useful in a variety of disorders. It was, therefore, called *Sal Polychrestus*, *Arcanum Duplicatum*, *Sal Prunellæ*, and other fanciful names.

The *rationale* of this process is obvious. There is a double exchange, and the acid of the vitriolated tartar proceeds from the sulphur, which unites with part of the air disengaged from the nitrous acid.

This faculty of deflagration is a most valuable property of nitre to the philosophical chemist. It enables him to discover inflammable matter where it could not otherwise be supposed to exist. It is a property no less important to the world on other accounts. Nitre becomes the basis of many compositions for producing violent explosions, or a dazzling light, which may be seen at a great distance.

Gunpowder is the most generally known of all these exploding compositions. Its many uses, besides those in

the art of war, are well known. It is formed of nitre, charcoal, and sulphur, so intimately mixed, that a spark fires an atom or two: and this fires the rest in a moment.

The best proportion for strong gunpowder is about seven parts of pure nitre, one of charcoal, and one of sulphur, all by weight. Others recommend eight of nitre, two of charcoal, and one of sulphur. The usual impurity of saltpetre is common salt, disengaged alkali, and Epsom salt. These, by attracting moisture, weaken the powder exceedingly, and make it apt to cake in the barrels. But saltpetre, sufficiently pure, is an expensive article, and is stinted as much as possible in the manufacture. Common gunpowder has a much smaller proportion, even so little as three or four parts to the above quantity of the other ingredients.

The charcoal and sulphur are ground separately in mills, and levigated to most impalpable fineness. On this depends much of the strength of the powder. And let me just observe, that gunpowder, washed from its salts and sulphur by caustic alkali, affords the finest powder of charcoal for experiments. The nitre is dissolved in pure water, and the solution mixed with the ingredients in wooden troughs, where it is carefully kneaded and incorporated, in form of a thick paste. It is kneaded, for two or three days, with wooden pestles, adding a little water as it evaporates. It is granulated by forcing it through sieves; then sifted, and the dust returned into the kneading troughs. Lastly, it is superficially hardened and smoothed, by tossing it horizontally in shallow boxes, which get a brisk reciprocating motion by machinery. The dust being again sifted from it, the powder is now fit for use. The granulation makes it keep better, and also kindle more rapidly in the chambers of fire-arms, by allowing a free passage for the flame among the grains.

When gunpowder is fired, and the fluid in a state of incandescence, it is as elastic as common air would be if compressed into $\frac{1}{10}$ th part of its bulk; or is 1000 times more elastic than common air. But when it has grown cold again, its bulk is vastly less, not being 300 times bigger than the gunpowder. (*See Robins's Essay on Gunnery.*)

There is another composition which explodes with still greater force than gunpowder. It consists of three parts of nitre, two of fixed alkali, and one of sulphur. When heated slowly on a plate of metal, it first melts, and becomes black, or of a dark liver colour; and then explodes with a loud crack. Hence it has got the name of *pulvis fulminans*.

The cause of its loud and smart explosion must undoubtedly be the instantaneous conversion of it into elastic vapour; not in succession, however rapid, like gunpowder, but at once. The effect of this simultaneous conversion appears even in gunpowder. This, if fired in a train, makes no noise. *(See Note 32. at the end of the Volume.)*

Another service derived from this property of nitre is the production of a brilliant light, fit for making signals to be seen from a great distance. The Chinese *blue lights* are esteemed much superior to any made in Europe. A gentleman who made very curious inquiries about their fabrication, and saw them made by the Chinese fireworkers, informs me, that the composition consists of twenty-eight parts of nitre, seven of sulphur, two of arsenic, one-half of rice-flour, and as much water as will knead them into a stiff paste. This water and the flour retards the inflammation. The paste is rammed into little earthen pots, and kept in pitched cloths.

Nitre is very easily decomposed, so as to obtain either the acid or the alkali in a pure state. It is from nitre only that the nitrous acid is obtained. You have seen that mere heat will not give us the acid in a perfect state. We must employ some intermedium, which shall lay hold of the alkali, and allow the acid to rise from it by the action of heat. Looking at the place of this salt in the table of compound salts, you see at once that the vitriolic acid may be employed for this purpose. This acid, having both a stronger attraction for the alkali, and less volatility than the nitrous acid has, must be a very fit intermedium.

The preparation of the nitrous acid is a considerable business, carried on by particular chemical artists. As they prepare it for the market, where it is not in general wanted very strong, they usually sell it much diluted with water, and of-

ten adulterated with vitriolic acid, which is a much cheaper article. Some arts, however, require it of its utmost strength, and very pure. The process for accomplishing this was first distinctly given by Glauber: and the acid so obtained has got the name of *Glauber's spirit of Nitre.*

This process requires certain rules of procedure, and exhibits several very instructive phenomena. The nitre must be very pure, and must be prepared by melting, and keeping it in that state for some time. It is then broken into middle-sized pieces, and put into a coated glass or an earthen retort, already set in the sand-pot for distillation. Two-thirds, or three-fourths of its weight of the strongest colourless sulphuric acid must be poured on it speedily, by means of a crooked or retort-funnel. The receiver is immediately joined to the retort, with fire lute, and then a hole pierced through the luting with a wire. The mixture soon grows hot; and, if the nitre had been in powder, or even in very small pieces, the heat might chance to be so great and sudden as to split the retort. The salt gradually melts, and acquires a deep orange colour, and ruddy steams obscure the whole vessels. These steams are caused by small air-bubbles, which form all over the mixture, and come to its surface, where they break. The vile smell of nitrous acid now fills the laboratory, proceeding from the vapour which comes through the hole in the luting. This must be allowed to continue till it abates. The fire may now be kindled, and allowed to heat the retort very slowly. The ruddy vapours cease, and the vessels grow clear. Let the hole in the luting now be stopped. The distillation goes on; and the receiver soon grows too hot, and must be kept cold by snow, or by a flannel covering, on which a stream of cold water is constantly trickling. The fire may now be raised considerably, and kept up in proportion as we can promote the condensation in the receiver. When the distillation is far advanced, the vessels again become dim, and ruddy clouds appear. The process is now drawing to a close. The matter in the retort has but little fluidity, and is very apt to burst into violent ebullitions, and to drive the contents over into the receiver. But, by due care, the distillation may be carried on

till the retort is red hot. But, from the first appearance of the ruddy clouds, which become so thick that we cannot see through them, much incoercible vapour must be allowed to escape. Twenty-four ounces of nitre will require eight hours for the distillation, reckoned from the time of kindling the fire.

The acid thus obtained is of the most fuming kind, and of a deep orange colour: but, if put into a retort, and a gentle heat applied, and a little water put into the receiver, the ruddy fumes and orange colour will soon cease, and the acid in the retort become colourless, like water. The small quantity of vapours condensed in the receiver tinges the water which condenses them with a deep blue or green. We get here a diluted acid, and, in the retort, the nitric acid in its purest form and greatest strength. It is sometimes tainted with sulphuric acid; but it is easily freed, by distilling it from a little pure nitre. A taint of muriatic acid is more difficult to be removed: we shall mention the most effectual method as we proceed.

The fuming acid has been called the *nitrous acid*, (*acidum nitrosum*) and the colourless acid is called the *nitric*, (*acidum nitricum*). It is intended by this last name to denote the origin of the acid, and by the other to denote a redundancy in the principle peculiar to nitre. We shall very soon see the principle on which this opinion of a redundancy is founded.

It is plain that the residuum in the retort must be the compound of sulphuric acid and vegetable alkali, perhaps mixed with a portion of undecomposed nitre. Before a perfect knowledge of the procedure of nature was acquired, it was thought to be a peculiar salt, and had fanciful names; *Arcanum duplicatum; Sal de duobus; Sal enixum*, &c. But it is now perfectly understood to be vitriolated tartar. Indeed, this is the only way in which vitriolated tartar is prepared. The manufacture of nitrous acid furnishes more than there is any demand for.

Such is the process for obtaining the nitric acid in its strongest state. It is much more generally wanted, in various manufactures, in a far weaker state, called AQUA FORTIS, consist-

ing of nearly equal parts of Glauber's spirit of nitre and of water. In preparing it of this strength, other methods were formerly practised. Intermediums, which have some, though perhaps not very great, affinity with the alkali, and which are fixed in the fire, are employed; also substances containing vitriolic acid weakly united to some other base. Of this kind are vitriol, alum, clay, &c. These substances enable the salt to stand a great heat, in consequence of which the volatile ruddy fumes are very copious: and much would be lost, did we attempt to produce a strong acid. But, by employing much water in the receiver, the steams are pretty well condensed, and a weak acid is obtained, which can be concentrated by another distillation *. This difficulty arises from the decomposition, which I have said that the nitrous acid seems to undergo, when urged by a very great heat.

And this leads me to take notice of some other products of our process for Glauber's spirit of nitre, besides the acid in the receiver, and the vitriolated tartar which remains behind in the retort: I mean the incoercible fumes which escape in the beginning and the end of the process.

I have already observed that nitre, when urged by a red heat, wastes, and is rendered alkaline; and yet, that we obtain little or no acid by condensing the vapours. Nitre melts, then simmers, and emits red vapours. Also, in our process, similar vapours are produced. There is, however, a very important difference in the two cases; in the one we obtain acid, and in the other nothing but incoercible vapours. This must evidently arise from the intermedium, which, by detaching the acid, allows it to come off with a partial decomposition; whereas, when no intermedium is used, the different parts of the acid seem to come off in the order of their volatility and attraction.

Notwithstanding the ingenious experiments of Mayhow, and his important inferences from them, and the no less ingenious experiments of Dr. Hales, nearly to the same pur-

* Mr. Lavoisier says (*Ker's translation of Lavoisier's Chemistry*, Lond. Edit. p. 215.) that nitre, decomposed by clay, both yields a stronger acid, and with less loss, than by employing the sulphuric acid. EDITOR.

pose, no notice was taken of the air obtained from nitre in those experiments, till about 1772. Dr. Scheele, whose experiments with *hepar sulphuris* I have mentioned to you, began to take notice of this air. He it was who observed that a bit of charcoal, held above the red hot nitre, burnt with a dazzling flame. Recollecting his experiments with *hepar sulphuris*, in which it appeared that only a part of our atmospheric air will support flame and combustion; and now observing that this vapour from nitre supported it in an eminent degree, it struck his imagination that this might be the *only* part of atmospheric air fit for this purpose, and *eminently fit*, because unmixed with the rest. It immediately occurred to him to try the effect of this air on *hepar sulphuris*. He expelled it from nitre in a small retort, by a strong red heat, and collected it in a jar. Now putting a quantity of *hepar sulphuris* into this air, as he had before done into common air, he found that it was *wholly absorbed*, and this with great expedition. He was now fully convinced, that our atmosphere consisted of two airs, one of which supported flame, and appeared to him to be a constituent part of fire itself. He therefore called it FIRE AIR, which his translators have changed into EMPYREAL AIR.

Much about the same time, and without any knowledge of Dr. Scheel's labours, Dr. Priestley made the same observations. Exposing, to a red heat, substances containing, or moistened with, nitrous acid, he obtained an air, in which bodies burnt with dazzling flame and great rapidity. He conceived this to be *pure air*, and that the other portion, which extinguished flame, has been originally the same, but that it is now saturated with phlogiston, and cannot support flame by receiving more. He therefore called this depurated portion DEPHLOGISTICATED AIR. Other philosophers, observing that it also supported animal life, called it VITAL AIR.

These experiments have, of late years, been repeated in a great variety of forms, with the same results. In particular, it is found that when nitre is exposed to violent heats, adding a little slaked lime, which imbibes the melted nitre, and hinders it from corroding the vessel, and enables the acid to stand

a very great heat, the quantity of air obtainable from it is prodigious. Four ounces of pure nitre, treated in this way, furnished to Mr. Ingenhouz 3000 cubic inches, which is about 650 times the bulk of the nitre. Moreover, when we compare its power of supporting combustion and animal life, with that of common air, it appears that one cubic measure of it will be as effectual for either of these purposes as four or five of common air.

You will recollect that when considering the vitriolic acid, and its production from sulphur, and the reciprocal production of sulphur from it, I said that it seemed necessarily to result from all our experiments, that, in the inflammation of sulphur, a quantity of air disappeared, and that the acid produced exceeded the sulphur in weight. I also observed, that when sulphur was produced from substances containing vitriolic acid, by urging them with violent heats in contact with inflammable substances, there was always a quantity of aërial matter extricated: and lastly, that when *hepar sulphuris* was exposed to the air, it was decomposed, that is, the sulphur was separated from the alkali. Morever, this alkali was not recovered in its pure form, but saturated with vitriolic acid, of which there was none in the mixture. At the same time, air was absorbed, and the remainder was unfit for maintaining flame. It appears, from a combination of all these facts, that the air thus absorbed contributed to the formation of the vitriolic acid. *Now* it appears that the air which is absorbed, is of the same nature with that which is emitted by nitre, and is furnished by its acid.

From a collective view of these facts, it would seem that the *same* air which is contained in nitrous acid, is also contained in the sulphuric. Farther, as the sulphuric acid appears to differ from sulphur in nothing but by the combination with this air, it seems to derive its acidity from it: for we find that nothing more is necessary for converting sulphur into sulphuric acid, but the absorption of vital air in inflammation, and that it will absorb it completely. Analogy should lead us, in like manner, to suppose that the nitric acid derives its acidity from the same source....from vital air,....and consists of vital

air united to a certain basis, which may be considered as the characteristical radical of nitrous acid, as sulphur is of the vitriolic.

These considerations, joined to many others of the same kind, have introduced Mr. Lavoisier to consider vital air as the cause of acidity, and to call it *oxygen* gas. We shall find the proofs of this general property of vital air multiplying on all hands as we advance. There is no acid substance from which we cannot obtain much pure vital air, and the weight of the air obtained is equal to that lost by the acid. All compounds, indeed, are not acid, or sour to the taste, but all have chemical properties analogus to those of the undoubted acids. I, therefore, admit the propriety of the name oxygenous gas, and shall use it without hesitation in the rest of this course.

You have heard how the nitre is affected by the simple exposition to strong heat: and the explanation of the change, by the escape of the oxygenous gas, is very obvious. But the vapours are not nitric acid: and, therefore, nitric acid does not consist of oxygenous gas alone, but contains it, combined with some radical: and this combination is destroyed, or decompounded, during the escape from the nitre. But, in the process for nitrous acid, an intermedium is employed, to loosen its combination with the alkali, so that it gets off in a more moderate heat without decomposition. Yet the appearances in the process should make us suspect that this is not altogether the case: for the ruddy clouds, at the beginning and end of the process, look very like some tendency at least to decomposition; and the situation of things at the end of the process is not very different from that of nitre simply exposed to great heat. It is then almost dry, and the retort almost, if not altogether, red hot. This did not escape the notice of the sagacious Scheele. But he found appearances which puzzled him. When he held a candle to the spout of the retort during the appearance of his last clouds, it burnt with a most vivid flame, confirming the opinion that the acid was then suffering a decomposition. But, when he did the same thing during the appearance of the first clouds, the candle was extinguished in an instant. This last event hap-

pens, partly because the portion of oxygenous gas which is now escaping, is very small; and chiefly because it is accompanied by another substance in the nitric acid, which has not yet thrown itself in our way as one of its constituent parts. You will soon become acquainted with it. And, in the mean time I imagine that you are now convinced that vital air is *one* of its ingredients, and that, in all probability, it is the cause of its acidity, as it unquestionably is of the acidity of the sulphuric. Mr. Lavoisier attributes the oxygenous eruption observed by Scheele to the strong attraction of oxygen for caloric in high temperatures, which decomposes the nitric acid.

I may now take notice of another resemblance in the union of the oxygenous gas, with the characteristic ingredients of the two acids. The fuming Glauber's spirit of nitre may be rendered still more fuming, by the addition of a very minute portion of inflammable matter. It is observed, that, as this quality is increased, the activity as an acid is diminished. The small quantity of acid obtained in clearing Glauber's acid of its fumes, is not only weak by dilution, but is weakened in its attraction for alkalis, and can be dislodged from them by vegetable acids and sedative salt, without the assistance of heat. It may be made so fuming as to be scarcely coercible, and scarcely acid to the taste. Now, when it is converted into nitric acid, it is plain that its proportion of oxygenous gas is increased; and when the nitric acid is made fuming, its proportion of the radical is increased. It is with propriety therefore called nitrous *(nitrosum)* as abounding in the characteristic ingredient. All this has its counterpart in the sulphuric and sulphurous acid; the latter containing more sulphur, or less oxygenous gas, has less acidity, and less attraction for alkalis.

This process for decomposing nitre, in order to obtain the acid, has been very instructive, as I said it would, opening to our view a new connection of chemical substances. It has not, however, completely explained all the phenomena, but has rather rendered the subject more complicated, by shewing that the acid itself is a compound substance, without informing us of its characteristic ingredient. I might tell you now that this is nothing else than that portion of the atmospherical air

that is not absorbed by the *hepar sulphuris*, or that is left behind by the inflammation of bodies, and may also be obtained in a variety of easy ways. But I cannot yet demonstrate this by fairly educing it from the acid, nor confirm the doctrine, by recomposing the acid by their mixture. We arrive at this by a very circuitous process, which requires the knowledge of several things with which you are unacquainted. I may, however, mention one fact, of which you can see the value without farther acquaintance with chemical substances. This is an experiment by the honourable Mr. Cavendish, described in the philosophical transactions for 1785 and 1788. He mixed a quantity of oxygenous gas, and Priestley's phlogisticated air, in the bend of a glass syphon, the two legs of which contained a solution of vegetable alkali. When he had, after many trials, obtained the due proportion of the two airs, he found that, by passing a succession of electrical sparks through the mixture, they united, and the compound was absorbed by the alkaline solutions. This, when examined by evaporation to dryness, or by crystallization, gave a small portion of true saltpetre. Hence it unquestionably follows, that the union of these two airs composes nitric or nitrous acid. Many questions arise on this occasion, which I am not yet in a condition to answer.....And therefore, we shall quit the subject for the present, and proceed with our decomposition of nitre.

Margraaf first mentions the decomposition of nitre by the muriatic acid. We are not yet in a condition to explain this completely. I can only observe at present with propriety, that this happens very readily when the nitre has been kept for some time in a melting heat. Now, in this case, we know that the acid has a smaller portion of its oxygen, and that in this condition it has less attraction for alkalis. It is for the same reason, as we shall soon learn, that this anomaly in elective attraction obtains; namely, in consequence of the muriatic acid depriving the nitrous of a portion of that principle. (See Bergmann on Elective Attractions, VI.)

If we desire to decompound the nitre to obtain the alkali alone, we must deflagrate with charcoal or some vegetable inflammable matter. The common method with charcoal is

inconvenient, by being tedious and imperfect. Newman's method is to take seven parts of nitre, and one of charcoal. These are pounded, mixed, and projected into a red hot crucible. This method is not bad, but the deflagration is too violent, and some alkali is lost. It is better to moisten this mixture with a little water, and then to project it into a red hot crucible, and to melt it in the end, and pour it out. I may take this opportunity to remark, that when the chemists have occasion to throw different materials into a heated crucible or other vessel, in order that they may act on one another, they say that they PROJECT the subject of the operation, or perform PROJECTION. I suspect that the words projector and project, are derived from this chemical term.

If a sufficient heat be applied, the alkali is in a melted state at the end of this operation, and must be immediately poured out into a warm mortar, or other vessel that is warm and dry. The alkali thus obtained, was called *nitrum fixum*, or *nitrum fixatum*. When the operation is properly performed, the quantity obtained is very considerable; generally two-thirds, sometimes three-fourths of the nitre.

The vegetable salt tartar is also often used as a substance to be deflagrated with nitre, in order to dissipate or consume its acid. The acid of the tartar being destructible by fire, and inflammable, or containing a quantity of inflammable matter, serves in the place of charcoal. And thus we obtain not only the alkali of the nitre, but also that of the tartar itself. This method, therefore, of obtaining alkali for particular purposes is often used, because the alkali both of nitre and of tartar is very pure. The common method is to mix and fire them like a squib. It is not necessary to add water; because tartar contains water and other volatile matters, the gradual dissipation of which keeps the mixture cool, and hinders the deflagration from going on too violently. The usual proportion of the substances is to take equal parts, but in this there is too little tartar. I find six parts of nitre, and seven of tartar better for complete decomposition; though the alkali is not then so sharp and acrid as in the other way, for reasons to be explained hereafter. Exact mixture is necessary. This pre-

paration, however, must be dissolved in water, filtrated, and evaporated to dryness, in order to free the alkali from the earthy ashes of the tartar.

Thus we can separate the two salts of which nitre is composed, and can satisfy ourselves that the analysis of it is complete, by joining them together again; by doing which properly we can obtain an entire and perfect nitre again.

Origin.....There are considerable quantities of nitre produced in different parts of Europe. But the greatest quantities of it are imported from the eastern parts of Persia, from many parts of China, and also from India. The general accounts of its origin in those parts of the world are, that it is obtained from the vegetable mold, or superficial soil in particular places or districts, called *saltpetre grounds*, which have generally a loose, open, and marly appearance.

These accounts appeared for a long time unsatisfactory, and even improbable; as it was not then known that nitre was produced in this manner in any other part of the world. But since the science of natural history has been so much improved as it has been of late, saltpetre is known to be produced in a similar manner in many other countries, particularly in North and South America, and in Podolia, Walachia, Spain, and Italy.

In Spain and Italy, there are districts in which the land is very fertile, and produces very fine wheat: but it happens frequently, in dry seasons, that the crop is lost for want of rain. The farmers then indemnify themselves by extracting saltpetre from the soil which should have afforded them wheat.

Much the greater part, however, of what is manufactured in Europe, is got either from artificial composts, or accidental mixtures, in which animal and vegetable substances have been thoroughly rotted, and exposed long to the air, with a large proportion of any spongy and loose earth, of the chalky or absorbent kind, as lime, rubbish, or marle.

In a part of Poland (Podolia) where the country is an extensive and rich plain, now deserted, though formerly, very populous, nitre is extracted from the soil of little hillocks

which are the remains or ruins of former habitations, and in which the wood of the buildings, and the dung of cattle, have been long thoroughly rotted, and intermixed with rubbish and earth. In France, too, they extract nitre from the lime and rubbish of old ruinous buildings, and from the floors of stables and pigeon-houses. And sometimes they take the richest part of the mold from the surface of the common soil, in particular places. The same practice was common in North America during the last war. The earthen floors of their tobacco houses were also found to be very rich in nitre.

These are, therefore, examples of the extraction of nitre from natural or accidental mixtures, in which it is found. To give you, in the next place, some knowledge of the artificial composts which have been observed to afford it, I shall first recommend to your notice an author upon whom we may fully depend. Cramer advises any person who desires to make experiments upon the production of nitre, to choose out or build a little hut, exposed to the fresh air of the country, and covered with thatch, to keep off the rain and sun, but not otherwise close: on the contrary, unless the air can come in pretty freely through the walls, it must have one open window at least upon the north side. It must be furnished with shallow boxes, about one foot deep, for different mixtures. But the only mixture which he mentions, and he speaks of it with the air of one who has tried it, is lime-rubbish, garden mold, and ashes. These are to be lightly moistened with urine, well mixed, and placed in one of the boxes to rot and dry. As soon as they are dry, they are to be moistened afresh with urine, stirring and mixing them well up, to expose all the parts to the air, which is found to be of great importance to the production of the nitre. If we thus proceed, always moistening and stirring while drying, when the mixture is dry, a considerable quantity of nitre will be produced; so that, in a month or two, each pound of the mixture will hold two ounces of nitre, or one-eighth.

In whatever manner, or in whatever materials, the nitre is produced, the extraction of it from these materials is generally performed by a particular set of people, who make it their sole

or principal business, and travel from one part of the country to another in search of materials in which nitre is already produced. After having examined materials of this kind by a small essay, and having found them to turn to account, they throw them into a large wooden vessel, and intermix some quick-lime and vegetable ashes. The vessel has a false bottom with holes, which is covered with straw; and, under the perforated bottom, there is another, which is water-tight. A stop-cock is placed between these two bottoms. After the upper part of the vessel is full of water, it soaks through, dissolves the nitre in its passage, and filtres through the straw leaving the earth behind. The solution is then drawn off, and the water evaporated to such a degree that the nitre crystallizes. In this state it is impure, of a brown dirty colour, and mixed with some sea-salt, which is always found in the materials affording the nitre. It is separated by crystallization, and by quick-lime and ashes. A brown liquor remains, which does not crystallize; and when examined, is found to consist chiefly of some lime and nitrous acid.

Thus it appears from this history of nitre, that it can hardly be counted with propriety among the fossil productions. It is always found in the earth, it is true, but always at the surface. There is no example of its being found at any depth, or the examples are rare, and the circumstances of them particular. Margraaf and others have found a little in the wells of great cities; the origin of which can be easily accounted for. Dr. Withering, in his translation of Bergmann's Sciagraphia, says, some of his friends assured him they had got nitre from the waters of some coal-pits. But it is highly probable that it had been washed down into the coal-pits from the superficial soil, by the rain-water soaking downwards through the earth. It never occurs in mineral waters. Some authors imagined they found it in these; but they mistook another salt for it, and judged of its presence by the form of certain crystals which they had obtained. But the form of crystals is never to be trusted. As it is therefore found only at the surface of the earth, or not far below it, it has long been a very general opinion that it is deposited or formed there by the air. Some have supposed that the air furnished at least the principal part

of the nitre, to wit, its acid; which, finding in corrupted animal and vegetable substances the other necessary ingredient, the alkali, united with it to form a nitre. Others have supposed that the air afforded, not the nitrous acid, but vitriolic acid. But these opinions have not been supported by experiments. When pure alkali is exposed to the air, it is not changed into nitre.

Another idea, which occurred to some of the chemists in France, had a greater appearance of probability; I mean, that the nitre has its origin in vegetables, being produced in them by the powers of vegetation, and is only extricated from their other principles by putrefaction, during which natural process all the principles of animal and vegetable substances are gradually separated from one another. Many plants have been long known to contain some nitre in their juices, separable by crystallization. Tobacco sometimes contains so much, that its stalk burns as a squib: but they were supposed to have received this from the soil in which they had been nourished. It is now reported, however, that some of those plants, though made to grow in earth from which all saline matter has been completely extracted, and, though watered with pure water only, will still be found to contain nitre; which, if true, shews plainly enough, that the plant generates the nitre, by combining some of the elements together in a particular manner.

Many other opinions were formed on this subject at different times: but we never acquired a decisive and satisfactory knowledge of the formation of nitre in soils, and other mixtures, till the French government directed to it, in a particular manner, the attention of the able chemists of that nation. This was done under the administration of that patriotic minister, Mr. Turgot. Distinctions and rewards were offered to those who should best illustrate the origin of nitre: and the Royal Academy of Sciences were appointed judges of the merit of the attempts.

A number of essays were accordingly offered, many of them describing ingenious investigations, and trains of experiments, to decide different questions relating to this subject. The gentlemen who distinguished themselves the most are M. Thouvenel medicin, and M. Thouvenel commissaire, des poudres et saltpetres de Nancy; Mr. Lorgna; M. Chevraud; M. Ga-

vinet. An abstract of their discoveries has been published by the academy, with some remarks, to shew what particulars have been cleared up and decided, and what still remain obscure. It appears from the whole, that nitre is formed by the action of the atmospherical air; and of the exhalations of rotting animal and vegetable substances, applied at the same time to alkaline earths, as chalk, or lime-rubbish, or marle; and that the putrid exhalations do not produce their effect, except atmospheric air be allowed to mix with them in certain quantity. It appears further, that the nitrous acid is formed most readily, or soonest, and the alkali afterwards. The acid first joins with the alkaline earth. The alkali which is formed afterwards dissolves the union, by taking the acid to itself.

Several other particulars have been discovered, which will be useful and instructive to those who have the conduct of saltpetre works. But they are only facts which point out the methods by which saltpetre may be produced with the greatest success. They do not yet explain its production. Other experiments since that time have thrown much light on the nature and constituent parts of the acid of nitre, and have occasioned the contrivance of new methods of producing it and nitre. But of these we shall speak more fully hereafter.

Uses.....Nitre is an article of the materia medica, and is reckoned the most cooling antiphlogistic of the salts; but it is often very disagreeable to the stomach. It also promotes the secretion of urine. In the arts it is highly useful, by being the only subject from which we can get the nitrous acid; and it is by means of nitre that the vitriolic acid is procured in quantity or perfection from sulphur.

SPECIES IV....CUBIC NITRE.

The cubic nitre resembles common nitre exactly in its most striking properties. The only difference is the form of its crystals and the consequences of decomposing it. The form which its crystals affect, is that of oblique parallelopipeds; though they generally concrete together, and adhere to one another; so that hardly any of them have this form perfect.

It melts with the same heat as common nitre, and dissolves in the same manner in water. It deflagrates with inflammable substances precisely in the same manner, and is decomposed by the same means, viz. by vitriolic acid. The only difference is, that Glauber's salt is produced instead of the vitriolated tartar. It is decomposed by deflagration with charcoal for the alkali, which is not the vegetable alkali, as in the case of common nitre, but the fossil alkali. Therefore it is improper to use tartar for the deflagration. But we must employ charcoal with water, as the charcoal of fir (as Margraaf directs), or we may take common flour, which contains a sufficient quantity of inflammable matter, and enough of water and other volatile ingredients, to keep the rapidity of inflammation within due bounds. When deflagrated with sulphur, it is plain that Glauber's salt must be produced.

It remains now only to mention the origin of cubic nitre. It is not produced naturally in a quantity worth notice, (though I suspect it is contained in some vegetables ;) but is prepared artificially by chemists, when they have occasion for it in their experiments; for it is not employed in medicine or in the arts. It may be obtained either by decomposing common salt with the nitrous acid, as shall be noticed hereafter, or by joining together the alkali of soda and the nitrous acid.

SPECIES V.....DIGESTIVE SALT.

As digestive salt is the produce of art only, and is prepared by mixing its two ingredients, the knowledge that we have already acquired of these will naturally suggest to us all its general properties, and the manner of decompounding it for either of its ingredients.

Its external appearance so much resembles that of common sea-salt, that chemists of eminence have imagined it to be the same. Boerhaave calls it *sal marinus regeneratus*. The London Dispensatory avoids deciding, by calling it *Spiritus salis marini coagulatus:* and even the author of the New Dispensatory was long before he imagined it any how

different. It differs, however, from sea-salt, in becoming a much more transparent mass after fusion, but less white, and toughish like horn. Even the crystals have this property, and are pounded with difficulty. Its most remarkable difference from sea-salt is, that it dissolves in much greater quantities in hot than in cold water; and, by this property alone, these salts may be pretty well separated. Its analysis is already foreseen. It may be decomposed for its acid, by employing the vitriolic acid; and the residuum must be a vitriolated tartar instead of a Glauber's salt. I was perfectly convinced of the difference, by decomposing it with the nitric acid. The residuum shot into hexagonal crystals; a sufficient proof that it consists of the muriatic acid and the vegetable alkali. To decompose it for its alkali, we must follow the process, and deflagrate the nitre we have obtained by it.

The only other origin of digestive salt, is the decomposition of sal ammoniac by means of potash. This being the cheapest process for obtaining it, is practised by the trading chemists for supplying the druggists and experimenters with all of it that is wanted.

SPECIES VI.....COMMON SALT.

Common salt requires a full red heat for its fusion, and, soon after fusion, begins to evaporate in white fumes. It has a pretty strong attraction for water, so that it deliquiates in moist air. It dissolves in less than three waters, and equally in cold or hot. Hence it has a different manner of crystallizing by evaporation. A pellicle is formed, if the evaporation be hasty; if slow, cubes are first formed, then a sort of hollow pyramids, formed by steps, superadded on all sides to the step last formed. The first cube, formed at the surface, being a very little heavier than the water, begins to sink: and the adhesion, or viscidity of the water, causes it to drag the adjoining water down with it; and thus it makes a depression on the surface, as when a square brick is laid on a feather bed; only the saline cube is wholly under water, hanging by its upper surface. The

water being thus exposed to evaporation in a greater surface on the sides of this pit, the next crystallization takes place there, preferably to any other place. Thus a first step is formed, and the solid sinks deeper, again hanging by its upper edges. A second step is formed in the same manner, and so on, till the crystal becomes too heavy, and it then breaks its hold and sinks to the bottom. It is amusing to observe this operation with a magnifying glass. Each step is formed in an instant all round,....yet it consists of distinct cubes; for it will only break into cubes; or clusters of cubes.

The crystals of sea-salt are of the decrepitating kind. If it be frequently dissolved, evaporated, and dried thoroughly with red heat, it is diminished in quantity, and a portion of earth is produced from it. And this is one of the chief instances adduced to prove that salts are composed of earth and water. But the quantity of earth is so small, that its origin is doubtful.

Common salt is easily volatilized by fire, and by putrefaction, along with substances disposed to that process. By repeated solutions and calcinations, it may be totally destroyed, or converted into earth.

Although its acid be very volatile, this salt cannot be decomposed by heat alone. In some of the processes by which it was attempted formerly to prepare this acid from common salt, they trusted principally to the force of heat. Common salt, mixed with clay, and exposed to a fierce heat, is in part alkalized: but it afterwards becomes neutral by exposure to the air.

The best way of decomposing it for its acid, is by another acid, of which there are two that will answer the purpose, ...the vitriolic acid, and the nitrous. But the vitriolic is best; and is even necessary if we desire to have the muriatic acid pure. It is best, as having greater superiority of attraction for the alkali than the nitrous acid has; and therefore expels the muriatic acid more readily. Indeed this acid is in a manner necessary for obtaining the muriatic acid pure; because it is fixed, and does not emit any fumes; whereas the nitrous acid emits them very copiously. Further, in using the vitriolic acid, it is necessary to use

likewise a certain quantity of water. If the strong acid be added to the dry common salt, the muriatic acid is expelled so pure, that it is not accompanied with water sufficient for its condensation; so that a great part must be allowed to escape; for the fumes will burst the vessels if we attempt to confine them. And thus we lose much of the acid, and are incommoded too with the fumes; because the water contained in the crystals of the salt, and in the vitriolic acid, is too little to repress sufficiently the volatility of the muriatic acid thus detached. We must therefore dilute the vitriolic acid with about an equal quantity of water, before it is added to the salt in the retort.

With all our care and skill, the separation of the muriatic acid is a very difficult process. In its pure state, it is too volatile to assume the liquid form, even in our most intense colds. Dr. Priestley reckons it a species of air, calling it marine acid air. But it seems to differ from the other acids, chiefly by its smaller attraction for water, of which it requires a greater quantity to repress its volatility, and also by the very great quantity of heat which its vapour holds latent. If we proceed with a simple retort and receiver, we may use nearly equal weights of salt and vitriolic acid, and dilute the acid, before mixture, with as much water: and we must employ a large receiver, and keep it very cool. The tubulated retort containing the salt, being set in the sand-pot, and the receiver joined and luted, the diluted acid is then poured in, and the hole shut with a ground stopper. The disengagement of the marine acid commences immediately, even though the fire has not been kindled. Some chemists think it better not to dilute the vitriolic acid, but to put the water into the receiver, where it absorbs the vapour very fast, and soon grows extremely hot. The distillation must be conducted very slowly: and it is proper to let it proceed, for a while in the beginning, without any fire. As we must use a porous lute, much vapour escapes, with great loss of acid, and much inconvenience from the fumes, which corrode every thing in the laboratory. It is chiefly in this process that the great value of Mr. Woulfe's apparatus, described

in the Phil. Trans. 1767, appears; and it is so employed by all the trading chemists. Mr. Woulfe found that the condensation of about four ounces of vapour heated seven or eight pounds of water up to the boiling temperature. When the water has acquired an equal weight of acid vapour, its bulk is increased in the proportion of two to three. I recommend to your perusal the dissertation just now mentioned, by Mr. Woulfe, as containing many very curious as well as useful observations. I observe that some foreign chemists proceed in another way that is pretty singular. Two retorts are employed, communicating with one receiver. In one of them the distilling substances are contained; and the other has only water. The two vapours thus meet in the receiver, and unite very rapidly. I doubt not but this process will be very manageable and productive.

The salt which remains in the retort when the distillation is finished, is Glauber's (as may be seen from the table.) And this is the usual manner in which Glauber's salt is prepared by chemical artists, the process being performed much oftener for the sake of the Glauber's salt than of the muriatic acid; except in some manufactories, in which they employ the muriatic acid to make sal ammoniac.

If we desire to decompound common salt to obtain the fossil alkali pure, we cannot have recourse to inflammable substances here, as in the case of vitriolic and nitrous salts. When the experiment is made with common salt, it does not succeed; nor is there any reason to expect that it should. The muriatic acid, in its ordinary state, is very little affected by inflammable bodies, and will not quit the alkali to act upon them. But we can separate the acid by the vitriolic or nitrous acids, which, when joined to the alkali in its place, will not be so difficult to remove. The nitrous acid is the most convenient, and most easily managed.

When the nitrous acid is employed to separate the muriatic, a cubic nitre is formed: and it is easy afterwards to deflagrate with charcoal to obtain the fossil alkali, which is the purest alkali we have. But the first part of this

process requires a little attention to perform it well; and Mr. Macquer's directions are very bad. The nitric, and not the nitrous acid, should be employed, and in a diluted state, or about the strength of aquafortis. This must be poured on the common salt, in fine powder, but retaining its water of crystallization. The distillation of the muriatic acid should be conducted very slowly. The first fumes are ruddy, and condense into a ruddy liquor, and the fumes of mixed acid, or aqua regia, are very perceptible in the laboratory. Towards the end the vessels grow clear, and the liquor is yellow, and floats on the ruddy liquor. If the whole be returned and slowly redistilled, we have less of the ruddy fumes and liquor.

The acid obtained from a pound of nitre, of whatever strength, will completely decompose about eight ounces of common salt. The cubic nitre is easily separated from the undecomposed salt by crystallization, because it dissolves in much greater quantity in hot than in cold water. The earthy matter of the charcoal with which it is deflagrated will separate by the filtre, and leave the soda perfectly pure.

Common salt is well known to be the most universally useful, and the most necessary to mankind of any. The qualities by which it is so useful are its antiseptic power, attended, at the same time, with a wholesome or innocent quality with regard to our constitution; in consequence of which qualities, we can, in case of necessity, preserve our animal food in wholesome condition, for a long time, by means of this salt. And it is further much more extensively useful and valuable, in consequence of another quality, by which it assists or promotes the digestion of our food, and proves a most agreeable seasoning to it. It is well known to be, on this account, one of the necessaries of life with regard to man: and there is reason to think it necessary or useful to the greatest number of other animals also. In these islands, [Great Britain and Ireland] and in the greatest part of Europe, which is not far from the sea, as well as in other similar situations, this truth is not very obvious. We think, on the contrary, that we see numbers of animals live and thrive very well without eve

tasting salt. But they do, however, get salt, though in an imperceptible manner. Our most inland situations in these islands are at such moderate distance from the sea, that some salt is communicated to them, either by the finer part of the spray, dashed into particles perhaps too small for sight, and which must necessarily fly in the air afterwards for a very long time, or by an evaporation of the sea-salt in small quantity along with the water.* In whatever manner sea-salt arises into the atmosphere, and to the upper parts of the land, it is certainly found there. A small quantity can be obtained from our purest and freshest natural waters. But it does not equally reach all countries and all situations. There are some far removed from the sea, or other large collections of common salt, in which the animals plainly languish for want of it, and shew very strong desire to have it. In Germany, and some other parts of the great continents of Europe and Asia, they give it to their cattle, as necessary to their health and thriving. In the inland parts of America, the wild animals are observed to flock in incredible numbers, and from great distances, to places where they may have an opportunity of licking salt, or of drinking salt water. Salt is often used there as bait for deer, to entice them into places where the hunter can reach them: and an offer of salt is a greater temptation to horses running loose in the American woods, than an offer of corn. These facts have occasioned some speculations concerning the manner in which this salt can be so useful to animals in general; and a discovery made by the late Sir John Pringle has been thought to throw some light on this matter. Sir John discovered, by experiments, that it has a power of promoting the putrefaction of animal and vegetable matter, when applied in small quantities to those substances. And, as the change which the vegetable food undergoes, in passing through our bodies, is supposed to have some analogy

* I have frequently observed at Glasgow, which is a great way from the sea-coast, that, after a strong gale from the west, the hedges, in winter, are very salt to the taste. One would imagine that the twigs had been dipped in salt water. One very dry spring, I found it crystallized like hoar-frost.... EDITOR.

with putrefaction, it has been thought that common salt had the power of promoting this change as well as putrefaction. Animals that are purely carnivorous do not agree with salt added to their food. In whatever manner it acts, its usefulness to animals in general is sufficiently evident.

Origin.....As, upon these accounts, common salt seems the most important and the most extensively useful of the salts; so it is most abundantly produced by nature. For, first, it is found constituting deep and extensive masses in the bowels of the earth, from which it is dug up by mining, as coal or other minerals, and is called rock-salt. Many mines of this kind are wrought in England, Muscovy, Poland, Germany, Calabria, Transylvania, and Stower in the Upper Hungary, Spain, particularly Catalonia, Italy, and other parts of Europe, in the East-Indies, and in America. Salt, as thus found in mines, is a solid hard substance, and is not dissolved so readily as sea-salt. It is generally more or less transparent, but tinged to a brown, yellowish, or reddish colour, in consequence of the mixture of some earthy matter with the salt. Sometimes it is pretty bright and pure; whence it has got the name of *sal gem*. Many of those mines contain amazing quantities of salt. The most astonishing are some Polish and Hungarian mines, of which there is an account in the Philosophical Transactions, No. 61. and 413. The mine of Cracow in Poland, near Wieliczka and Bochna, is computed to hold salt enough to suffice the whole world for many thousands of years. The works in it are of great extent; and there are houses, chapels, and other buildings under ground, all built of salt or salt stones. Very large masses are often met with, free from considerable flaws, and of more pleasant colour, and more transparency than ordinary, which are cut and turned into pillars and other ornaments of architecture,...sometimes into toys. And the whole of these mines, as illuminated artificially, have a most uncommon, surprising, and brilliant appearance.

These immense and massy collections of salt are found, in several parts of the world, to project above the level of the ground, and form hills and even mountains. Of this

kind are two mountains in Russia, near Astracan; several in the kingdoms of Tunis and Algiers, in Africa; several in Asia; and a great part of the island Ormus, in the Persian Gulf, is said to consist of salt.

There are, likewise, in different parts of the world, innumerable springs, ponds, and lakes, containing this salt, produced by the flowing of water through fossil salt, or soaking through salt earths. These waters are of very different richness. Thus, in Germany, where they have most of their salt from springs, some are so weak, that there are only two drachms of salt in the pound of water. The spring at Halle is the richest, and contains three ounces and three drachms to the pound: but in England there are pits much richer than these. The springs of Droitwich contain four ounces: and several pits at Norwich, and at Barton in Lancashire, contain six ounces in the pound, which is a saturated solution.

Lastly, The sea, which covers such a large proportion of the surface of this globe, contains this salt in very considerable quantity, and renders it easily procured for the use of man, in almost all the inhabited parts of the world.

These are the only, though very plentiful sources from which salt is obtained,...the masses or strata which it forms in the earth; the salt springs or fountains, and the sea. And it has therefore been often divided into these three species,....of rock-salt, or sal gem,....fountain-salt,....and sea-salt. But this division is of no use; because, from whichever of these sources it is obtained, if it be pure naturally, or purified by art, it is precisely the same. All the differences found among the varieties of common salt, in its native state, proceed from impurity or admixture, which produces great variety even in common salt of the same origin; it being seldom or never perfectly pure, and often very foul. Rock-salt, for example, is commonly attended with a large intermixture of earthy matter, and has besides a bitterish taste, proceeding from a small proportion of other salt intimately blended with it. Salt of springs or fountains is liable also to admixtures of mud, and other salts. And in the sea, we find several other salts or saline compounds mixed with the common salt.

The great quantity of water too in which sea-salt and spring-salt are dissolved, must be considered, in a commercial view, as an extraneous matter, which it is necessary to separate from it. The proportion of this water to the salt is different, however, in different springs, and in different parts of the ocean. In general, the sea is less salt in cold climates, near the poles, and salter towards the equator. It is a common observation of naturalists, that such is the arrangement and regularity of nature, that since this salt seems mixed with the sea, in order to prevent its putrefaction, so it is mixed in the greatest quantities in those places where the heat is greatest, and where, for this reason, there is the greatest danger of putrefaction. The variety of saltness in the ocean is produced by greater or less evaporation, and more or less rain. The evaporation is much greater near the line, from the greater force of the sun; and the vapours, or the greatest part of them, generally move towards the poles, so as to descend in more frequent showers there than where they were elevated. And though the difference of saltness occasioned in this way is hindered from going a great length, by the agitation to which the ocean is subject, from various causes, still, as these operate slowly, the difference is always considerable. Thus, in the northern parts of the Baltic, a pound of sea water scarcely contains two drachms of salt. Farther south, from the mouth of the Elbe to Holland, and on the British coasts, it contains one ounce. In the Mediterranean it contains two ounces; and in the Atlantic, near the line, it contains more than three. Mr. Boyle has observed a phenomenon which he ascribes to this cause. Where the sea is very deep, the water is salter at the bottom than at the surface. Even in moderate depths near the land, this inequality of saltness obtains also. This, in all probability, is owing to the freshes from the land, which float a-top by their specific levity; and it is a long while before they are mixed by the agitation of the winds. Ovid has preceded Mr. Boyle in this observation; and describes it most accurately in some very beautiful lines in one of his elegies.

These are, therefore, the different states in which common salt is found in nature, and from which it is prepared and refined for use.

Where the rock-salt occurs in a state of considerable purity, it is used by many without preparation. In Poland, numbers of the inhabitants used their fossil salt in its natural state; but this is uncommon. The rock-salt is generally so impure that it cannot be used, without being first refined. And in general mankind almost universally use common salt that has been prepared or manufactured by extracting it from the waters of the sea, or of salt springs or wells, or by refining or purifying the common salt.

The methods which have been contrived, in different places, for extracting it from the waters of the sea and springs, with the least expence, are very numerous; and much ingenuity has been shewn in pursuit of this object. But I believe I can employ your time better than in describing all these contrivances. You will find a very good account of them in Dr. Brownrigg's book, entitled, "The Art of making Salt."

I shall only remark, that all the methods which have been in use may be distinguished into two varieties, and a mixture or combination of these two: 1*st*, In the one, the water is evaporated, and the salt made to crystallize by the heat of the sun and action of the air only, in shallow ponds. 2*d*, By the other, these operations are performed by the heat of fuel; and the salt is called boiled salt.

The first method is practicable in the hot climates only, where the great heat of the sun, and dryness of the weather in summer, occasion a copious and quick evaporation, without any expence. In those climates and situations where these circumstances are the most favourable, very little art is required, or scarcely any; for wherever the sea-water is received at spring-tides into shallow ponds or pools that are not overflowed at other times, the salt crystallizes between one spring-tide and another. But where the evaporation is not so quick, more art is employed, as in the salt ponds on the coast of France. The general contrivance is to this purpose:....On a flat beach, the sea is walled off, except at one entry, which is shut by a sluice: all within it is the salt pond. This is divided into a vast number of portions, in the manner of a labyrinth, all com-

municating with the main inlet; but by so many turnings, that any one trench, if stretched into a straight line, is very long, and all of them nearly of the same length. The different portions are made shallower as they advance inland. When the sea is admitted at high water, the whole is filled to a level, and the sluice is shut. The evaporation reduces the surface. At next high water, more is admitted: this pushes before it the water already in the pond, which has become a little salter than what is now admitted. Thus we see, that as the brine becomes richer in salt, it is pushed farther in, toward the last recesses of the labyrinth; and therefore the granulation will begin in those places, and the water will continue to deposit its salt chiefly there, where it is lifted out with proper instruments. These parts of the salt pond are, therefore, firmly constructed, and formed of stiff clay, well rammed; while the parts nearer the inlet are of common earth, or frequently of mere sand.

The second method of preparing salt, viz. by the heat of fuel, is practised in these colder and wetter climates, which do not admit of the first. In this country especially, the preparation of boiled salt is a considerable business, because we have fuel very plenty and cheap: and a part of it may be had for almost nothing, on account of its being unfit for household purposes.

In some places in England, they practise both methods in part; that is, they evaporate part of the water, first by the heat of the sun, and afterwards finish with fuel.

The salt made with the sun and air alone, is called bay-salt. Its crystals are much larger, and more solid than those of boiled salt, as it is commonly made, but not so white, by reason of light mud which remains suspended during the whole evaporation. But the bay-salt, though it has the appearance of being more impure, is much more effectual for preserving provisions; and when we make an inquiry into its constituent parts by experiments, and compare it with boiled salt, we discover the reason of this, which is, that it is in reality purer than the common boiled salt; that is, it is more free from the admixture of other salts, or saline compounds. For, as I remarked already, sea-water contains several salts, or saline com-

pounds, beside common salt, and these give it the bitterish taste. By the violent boiling, and hasty crystallization commonly practised in preparing boiled salt, these extraneous and useless salts are but very imperfectly separated. A great part of them remains, and depraves the quality of the salt for curing provisions; whereas the bay-salt being produced by a slow evaporation and crystallization, there is more time for the separation of the heterogeneous, and concretion of the homogeneous saline particles. That this is the cause of the difference, appears from Sunday's salt, which remains upon a slow fire that is not renewed during the whole of that day, and its crystals are much larger, more agreeable to the taste, and sell for a higher price. Bay-salt has a taste very sensibly sweetish, which is not to be found in any boiled salt whatever, and which it loses by two or three solutions and crystallizations. It is in all probability owing to the influence of the sun's light, the chemical effects of which on other subjects are analagous to this.

It is, however, very much to be wished, and an object of great consequence to trade and the fisheries, to prepare common salt as free as possible from all impurities: and many ingenious men have turned their attention to this subject. It is the main scope of Dr. Brownrigg's book, though he was perhaps under a mistake in his notion of the defect of common boiled salt.

The Earl of Dundonald has lately published the account of a cheap, though ingenious process, by which common boiled salt can be purified to a very considerable degree from the extraneous salts. The general principle of his process is this; the disagreeable salts contained in the common boiled salt, dissolve in much greater quantities in hot than in cold water. In order, therefore, to purify a parcel of common salt, it is put into a conical vessel, or basket having an aperture at its apex, stopped with a plug of straw. A saturated solution of common salt in boiling hot water, is poured upon it, boiling hot. This trickles down through the salt, and escapes through the straw. Being already saturated, it can carry off none of the pure sea-salt, but it washes it clear of the bitter brine with which

it was covered; and, being boiling hot, it dissolves the greatest part of the crystals of the bitter purging salt which had tainted the whole. His Lordship found, by accurate experiment, that a saturated solution of one pound of common salt, poured upon ten pounds of salt, takes away about four-fifths of all the bitter salts that it contains, by one operation.

My friend the late Dr. Roebuck also studied this subject, and practised a process, by which he refined boiled salt to a very high degree, and made it even superior to bay-salt. But his process was expensive, and cannot be made subservient to the fisheries, but only to supply the luxury of the rich. It depends entirely on repeated and slow crystallization.

It is much to be wished, that the preparation of common salt, and the commerce in it, were less shackled with limitations, monopolies, and heavy duties. It is not only a necessary of life to all ranks, but of the greatest consequence to the fisheries: and salt is capable of being employed in a number of manufactures, which are prevented from taking place by the price of this article, and by the trouble to which those who use it are subjected.

AMMONIACAL SALTS.

All the compound salts which contain the volatile alkali combined with the different acids, are called ammoniacal salts. This general denomination is taken from the compound with the muriatic acid, which is commonly used, and has been long known by the name of sal ammoniac. The name is derived by some from Ammonia, one of the Cyrenaic territories, in Egypt and Lybia, which was supposed to produce it. Pliny, in treating of common salt, says, that the Cyrenaic territories were remarkable for producing a species of it called Hammoniac, on account of its being found under the sand of the soil. And it is supposed that he meant this salt, which is very probable, both on account of the name, and of the description which he gives of it. But it is plain that he had only an imperfect knowledge of its nature, and had been misinformed concerning its origin. *Vide Plin. Hard. tom. II. p.* 559.

With respect to the general nature of these salts, they can always be distinguished from the compound salts, by the action of a fixed alkali on them. It immediately attaches itself to the acid, and detaches the volatile alkali, which is perceptible by its pungent odour. It is by the decomposition of one of these salts that we obtain a pure volatile alkali, or that which is the fittest for chemical experiments, or for the purposes of medicine. If equal quantities of sal ammoniac and salt of tartar be dissolved in an equal weight of water, we shall immediately perceive the pungent smell of the volatile alkali. If this mixed solution be put into a retort, and distilled to dryness, with a heat gradually increased, we shall find in the receiver a solution of volatile alkali, in its least acrid form. It is known by the name of *spirit of sal ammoniac* or *of harts-horn.*

Beside this effect of the fixed alkali on them, which distinguishes the ammoniacal salts, they are also more volatile than other compound salts,....both of the simple salts of which they are composed being very volatile. But their volatility is not so remarkable as we might be led to expect from our knowledge of the volatility of their ingredients in a separate state.

SPECIES VII.....VITRIOLIC AMMONIAC.

The first in the table is the *Vitriolic Ammoniac*, likewise called the Secret Ammoniac of Glauber, because that author, who was inventor of Glauber's salt, was likewise the first who took particular notice of this, and imagined that it possessed some remarkable powers over metals, and made a sort of secret of it for some time. But I do not know of any qualities which it possesses that deserve your attention.

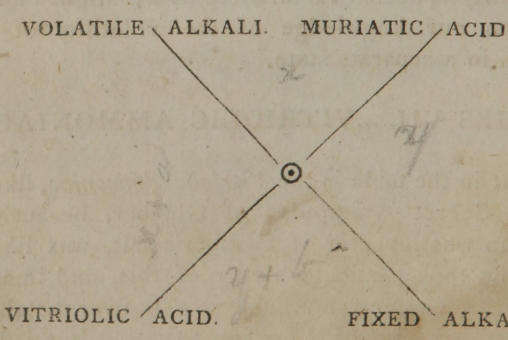
We may, however, before we dismiss this salt, take the opportunity to explain a double elective attraction in which it plays a part. The fact, as discovered by experiment, is this.....

If vitriolic ammoniac and common salt be both dissolved in water, and mixed together, and the mixture boiled for

some time, there is a double exchange, or double elective attraction. The vitriolic acid leaves the volatile alkali, and unites with the fixed alkali of the common salt, while, at the same time, the acid of the common salt unites with the volatile alkali that was in the vitriolic ammoniac; and then, by evaporating the saline mixture, we obtain first Glauber's salt, and afterwards common sal ammoniac*.

The reason of this must be, that there is a greater difference between the attractions of the fixed alkali for the two acids, than between the attractions of the volatile alkali for the same two acids, which may be shortly expressed by saying that the fixed alkali has a greater partiality for the vitriolic acid than the volatile alkali has. For, let us suppose that these differences are the same, and then consider what would be the consequences.

These four chemical substances, the two alkalis and two acids, when mixed together, may be represented, in some measure, by four bodies placed at the extremities of two moveable diameters of a circle, and each of them attracting the two that are next to it; thus,



Each of the acids is disposed to unite with either alkali, and each of the alkalis consequently with either acid. But they cannot unite with one without leaving the other:

* It is easy to perceive that the double exchange will happen without the condition required by Dr. Black, if the partiality of the vitriolic acid for the fixed alkali be greater than that of the muriatic acid for the same alkali. This operation must be considered in the more general manner expressed in note 24, p. 268.....EDITOR.

and in proportion as they are attracted by one, they are drawn away from the other; and while one of the acids unites with either alkali, it repels the other acid from it, and in the same manner either alkali repels the other. Now let us see what will be the play of these four substances, on different suppositions of the difference of their attractive forces. And first, let us suppose that the differences of the attracting forces of the two alkalis for the two acids are equal, or that each of the alkalis attracts the vitriolic acid more strongly than the muriatic, by an equal superiority of attracting force. In this case no exchange can happen: the attractions are exactly balanced.

For, let the attraction of the volatile alkali for the muriatic acid be represented by x, and its attraction for the vitriolic acid by x, and some other quantity a, or $x + a$. In like manner, let the attraction of the fixed alkali for these two acids be y, and $y + b$.

The forces which maintain things in their present state are $x + a$ and y, the sum of which is $x + y + a$.

The forces which tend to change the state of things are x, and $y + b$, the sum of which is $x + y + b$.

It is plain, that if a, the difference of the attractions of the volatile alkali for the two acids, be equal to b, the difference of the attractions of the fixed alkali for them, then $x + y + a$ is equal to $x + y + b$, and no change can happen.

But if b be greater than a, it is equally plain that $x + y + b$, the sum of the changing forces, is greater than $x + y + a$, the sum of the maintaining forces. We must, therefore, have a change of combinations, and must find in the solution sal ammoniac and Glauber's salt.

If heat be applied to this mixture, the difference of attracting forces will be still more increased; because this, by increasing the volatility of the volatile alkali, and the muriatic acid, will weaken their connection with their primitive and more fixed bases.

There are many other ways by which the vitriolic ammoniac can be decompounded by double elective attraction, but they will be more easily understood hereafter.

SPECIES VIII.

NITROUS AMMONIAC.

Nitrous Ammoniac, or *Nitrum Semivolatile*, or *Nitrum Flammans*, is fusible, volatile, and inflammable. The volatile alkali contains inflammable matter, as may be seen by trying all the ammoniacal salts with melted nitre. It cannot be distinctly observed in the alkaline crystals themselves, on account of their too great volatility, which makes a violent ebullition, and seems to keep the nitre from coming into contact with them. But in all cases where they can be made to mix in red heat, the inflammation is even brilliant: for example, if the vapour of melted nitre be made to pass through that of volatile alkali.

This salt dissolves readily in water; and, with the assistance of heat, very copiously. This seems to proceed from its fusibility, for it is not remarkably deliquescent. It is decomposed for the acid by vitriolic acid, and for the volatile alkali by either of the fixed alkalis.

It is said to be contained in the juices of some plants, and that it is often found in natural efflorescences; but when we have occasion for it, we always prepare it by art. It is necessary to observe the caution of evaporating the solution of it with extremely gentle heat; for, if we go on with a strong one, we may be deceived, and evaporate the whole salt before we are aware. (*See Note* 33. *at the end of the Volume.*)

SPECIES IX.

SAL AMMONIAC.

The last of these salts, the common *sal ammoniac*, or crude sal ammoniac, is the best known, and the most useful; and it is a considerable object of manufacture and commerce. When we examine by trial how it is affected by heat, we find it is one of those bodies which, under the ordinary pressure of the air,

are more easily changed into vapour than melted; and therefore, when heated, it totally evaporates in white smoke, before it be heated enough to make it melt. It has nearly the same attraction for water as common salt. It deliquiates in damp air, and dissolves in about three waters. In solution it produces 20 degrees of cold, by Fahrenheit's scale. It is easily decompounded, so as to give either the acid or the alkali pure. But we never take the trouble to separate the acid, which may be got from a much cheaper salt. It is only for the sake of the alkali that we decompound this salt; the alkali which it yields being the purest volatile alkali.

This decomposition may be effected by means of either of the fixed alkalis, in their ordinary mild state. A quantity of pearl ashes, salt of tartar, or soda, is mixed with about twice its weight of sal ammoniac; and the mixture is put into a wide-necked retort, and treated in the way of distillation.

It is usual to add water to facilitate the action of the salts, and the condensation of the volatile alkali, which is difficult to condense without water. As soon as the retort becomes warm, the alkali, and a part of the water, begin to distil over together. But the alkali comes in greatest quantity at first, on account of its being the most volatile; and the water, which comes with it at first, is not sufficient for dissolving it: A great part of it, therefore, condenses, in the form of a saline crust, on the internal surface of the receiver. But afterwards, a larger proportion of water comes over with the rest of the alkali; such a proportion as is sufficient for dissolving very nearly the whole of it. Thus, we have a saturated solution of volatile alkali in water, which, when prepared in this manner, is called *spirit of sal ammoniac.*

The London chemists prepare a dry volatile alkali for smelling bottles, which is much more volatile than the *sal ammoniaci volatile, cum creta.* They decompose the salt with fixed alkali, luting up the vessels very close, with a paste of flour and glue, and by taking all methods of cooling the receiver. In this way, they get half the weight of the sal ammoniac.

Origin.....This salt is not found native in such quantity as to serve any of the uses to which it is applied. A small ap-

pearance of it is sometimes met with in the neighbourhood of volcanoes, and upon stones thrown out of those mountains; also in clefts of the ground, or of rocks in the neighbourhood of coal-pits which had been accidentally set on fire, and have continued to burn for a long time: but such specimens are extremely rare and trifling. The great quantity of this commodity consumed in Europe was, for a long time, imported from Egypt, where it was known and manufactured; and sometimes quantities of it are brought from some parts of India. It was late, however, before any distinct accounts were published of the manner in which it is manufactured in Egypt. We were only told that soot was the principal article employed; until some French gentlemen, who were in Egypt, having given particular attention to it, communicated a detail on this subject to the Academy of Sciences. Their account was, that the fuel of the districts in which it is manufactured is the dung of cattle, dried in the sun; that the soot is collected, and without any addition, put into glass globular vessels. These they fix in the vault of a furnace, which has the form of a sort of oven, built in the open air, and apply fire cautiously, &c.

When this account was published, it was supposed that the production of sal ammoniac depended on the particular nature of the soot, or of the fuel from which that soot is produced. But it has been discovered that soot of other kinds of fuel, and pit-coal among the rest, can be made to afford it; and several manufactories of it are now established in Europe, which produce it of the best quality.

From its being observed also that the great laboratories of sal ammoniac also prepare Glauber's salt, employ much vitriolic acid, and do not purchase the muriatic acid, it is conjectured that the volatile alkali is first prepared from the soot, then made into vitriolic ammoniac, and this mixed with sea salt, and the mixture sublimed. In this process, a double exchange must take place: and we must obtain sal ammoniac in the receiver, and Glauber's salt must remain in the retort.

This salt is used in medicine, and in tinning iron or copper; and in some other manufactures.

The salts which contain the acetous acid are regenerated tartar and acetous ammoniac.

SPECIES X.

REGENERATED TARTAR.

REGENERATED tartar was so called, from its component salts, the one being the salt of tartar, or the vegetable fixed alkali, and the other, one of the vegetable acids. It was supposed that these, when joined together, should produce a salt like tartar, in its entire state, or a regenerated tartar. But we now know perfectly well, that the acetous acid which this salt contains, is quite different from the acid of tartar; and, accordingly, the compound salt is not a regenerated tartar, being very different from tartar. It was formerly called *sal diureticus*, in the London Pharmacopœia; lately they have changed this name to *kali acetatum*.

This salt is always made artificially, by joining pure vegetable alkali with the acetous acid in its purest state, or distilled vinegar. A large proportion is necessary to saturate the alkali, on account of its being an extremely weak or diluted acid. A phenomenon occurs in making this mixture, which Dr. Boerhaave mentions, and could not account for. When vinegar is first added to the alkali, it dissolves it without perceptible effervescence. But after more of the acid has been added, so that some part of the alkaline salt is saturated, further additions cause it to effervesce violently, as in other cases, when acids and alkalis are joined together. This phenomenon we shall soon have an opportunity to explain.

The process for making this salt is best conducted by putting a quantity of pure fixed alkali into an evaporating bowl, adding distilled vinegar, and evaporating the salt almost dry. Then more vinegar is to be added, and evaporated, until further additions of vinegar do not produce an effervescence: and it is better to add a little too much than too little. Every time the evaporation is performed, it is only the watery parts

that exhale; the acid remains combined with the alkali. When full saturation is obtained, we may evaporate to dryness, which must be done with a very mild heat. Thus we have a salt of a dark brown colour, and very unctuous and foul. A quantity of fæculent unctuous matter is extricated from the vinegar, when evaporated to dryness along with the alkali, though it appeared a limpid fluid before. This unctuous fæculency is separated from the salt by covering up the bowl, and gradually increasing the heat until the salt melt, which it does in such a degree of heat as is sufficient for evaporating the more volatile parts of the oily matter, and scorching or burning the rest, so as to convert it into a sort of charcoal. (N. B. This heat makes polished steel yellow, and might be measured). By this means the salt, which before was brown, becomes of an iron-grey colour; and if it be now dissolved in water, the burnt matter is rejected or left undissolved by the water, and forms a sediment which may be separated by filtration; and the clear limpid solution then affords, by gentle evaporation, a pure and white salt.

Many authors, in describing the manner of purifying this salt, advise to do it by dissolving in spirit of wine, which separates part of its foulness from it, and then the spirit is to be distilled off, and the salt redissolved in the same manner several times. But, if our only purpose is to make it white and pure, this will prove a tedious and imperfect method. The one I have described is much the best.

Dr. Boerhaave, who extols the virtues of this salt very highly, seems to think this purification of no great importance, or rather that the salt is a better medicine for retaining the oil. He had a prejudice in favour of every thing that contained salt and oil blended together; and called all such mixtures saponaceous, or soapy. But it is certain that this salt is greatly improved by the purification I have described. The unctuous matter thus separated from it, has a bitter taste and nauseous flavour, disagreeable to the stomach: and this is a bad quality in any medicine intended for the uses to which this salt is applied.

The properties of this salt, as thus prepared, are, that it melts with a very moderate heat, below red, into a transparent fluid like oil; and, upon being allowed to cool again, concretes into a mass composed of thin plates, or leaves, cohering together, like the plates of the earthy or stony substances hereafter to be described under the name of talc or mica; for which reason some of the elder chemists named it very improperly *terra foliata tartari*. When mixed with water, it shews a great degree of solubility, greatly exceeding every other compound salt. It is so deliquescent that it is not easy to keep it dry. It is also soluble in vinous spirits, and is thus purified from other salts. When it is to be separated from water, this is done by evaporation to dryness with a very gentle heat, stirring often in the end. The salt concretes in the form of a white scum or skin, which, being drawn to one side, is quickly renewed, until the whole water be thus evaporated. The salt is then a spongy mass, as white as snow, which, if the heat be increased, melts and forms the foliated mass which I described.

When we desire to decompound this salt, we may do it so as to have either the alkali or the acid pure.

If we would have the alkali, we need only to put the salt into a crucible, and heat it gradually till it becomes red hot. That degree of heat burns and totally destroys the acid; dissipates great part of its principles in the form of fœtid vapours, which are partly watery, partly oily, and partly aërial; and leaves only remaining with the alkali a quantity of black carbonaceous and other matter, which can be separated without difficulty.

If we desire the acid, we can detach it by any of the fossil acids, of which the vitriolic, however, answers best, and is employed sometimes for this purpose, when an acetous acid of extraordinary strength is desired. But this purpose is better accomplished by means of the next salt in the column, namely,

SPECIES XI.

THE ALKALI FOSSILE ACETATUM.

This consists of the acetous acid united to the fossil alkali. Its properties greatly resemble those of the salt now described, only it melts more readily. It congeals in plates, and is destructible by a great heat like the other. It dissolves copiously in water, and is easily separated from the water by crystallization, forming very fair crystals; whereas the other is crystallized with difficulty. This salt is better suited to the purpose of obtaining a strong acid by decomposition, because it is easily kept in the form of a dry powder, not being disposed to deliquiate, except in very damp air. It is therefore much prepared in Germany for this purpose, by the name of *sal vegeto-minerale*. It is not, however, by the simple mixture of its component salts that it is manufactured; as I am informed by a person who long conducted the process; but by double elective attractions, employing Glauber's salt, and a salt consisting of lead combined with the acetous acid. When the salt thus prepared is decompounded by vitriolic acid, the acetous acid is detached in a most concentrated and active form, equal in acidity to the mineral acids, though weaker in its elective attractions, and possessing all its native valuable qualities.

SPECIES XII.

ACETOUS AMMONIAC.

Acetous ammoniac, or *vegetable ammoniac*, or *spiritus Mindereri*, when in a liquid form, so called from the author's name, is a composition always produced by art. It is very volatile, being little inferior to water in volatility, and at the same time of great solubility. It cannot be evaporated dry. A great part of the water, however, can be separated by slow distillation or evaporation: and we thus obtain a saline fluid of a

thickish consistence, like oil or sirup, and of a brown colour, which, if the heat be continued, evaporates entirely away without yielding any dry part. It is of a penetrating quality. If we desire to have a vegetable ammoniac in a dry form, we may have it by a double elective attraction. The sal vegeto-minerale and common sal ammoniac, for example, will give it; the muriatic acid uniting with the fixed alkali, while the more volatile acetous acid unites with the volatile alkali. For similar reasons, we may employ a mixture of vitriolic ammoniac, and the salt, which I mentioned lately, consisting of lead combined with the acetous acid. This last will more certainly insure the dry form of the salt obtained; but it will differ, I believe, from the salt obtained by the other process, containing less of the distinguishing property of the acetous acid; containing it in a state which may be called the acetic, while the other is called the acetous.

The different ways by which it may be decompounded are obvious: but we never have occasion to decompound it. The only point that deserves attention with regard to it, is the compounding it properly, or uniting its two ingredients, so as to produce it in perfection. This is done by choosing good distilled vinegar, which has been distilled carefully, to avoid a burnt taste and flavour, and a pure volatile alkali, prepared from sal ammoniac. That which is prepared from animal substances is unfit. And further, these materials must be mixed so as to be exactly neutralized, the one by the other. Thus, it will be best fitted for the purposes of medicine, for which it is intended.

Having described the salts in use which contain the acetous acid, we proceed to those which contain the acid of tartar.

The compound salts, commonly known and in use, which contain the acid of tartar, are, 1*st*, soluble tartar; 2*dly*, common tartar; in both of which this acid is combined with the vegetable alkali in different proportions; and 3*dly*, the Rochelle salt, sal Rupellensis, or sal polychrestus Rupellensis, in which this acid is combined in part with fossil alkali.

SPECIES XIII.....TARTAR.

You, no doubt, remember the appearance and properties of the acid of tartar. It differs from the fossil acids, and from the acetous, by being capable of evaporation to dryness, and a sort of crystallization; which evaporation, however, must be performed with a very gentle heat. The dry acid thus obtained, resembles in appearance brown sugar, or sometimes is whiter. And, when we expose it to a burning heat, or heat of ignition, it is burnt and destroyed in the same manner as sugar, or other vegetable substances. It is dissolved easily, and in large quantity, by water, forming a solution which has the appearance of a sirup, but is exceedingly sour.

The nature of this acid, and of the compounds which it forms with alkalis, was not explained fully and clearly until the ingenious Dr. Scheele of Sweden gave a set of decisive experiments upon this subject. It was he who first exhibited this acid in its separate state, and who shewed how easily it is destroyed by fire, without needing to be joined to a fixed alkali, as the acetous acid does. Dr. Scheele has also shewn, that it differs from all the other acids, by a disposition to form with each of the alkalis two different compound salts, in consequence of its being capable of uniting with each of them firmly in two different proportions.

When to the solution of an alkali in its ordinary state we add a certain quantity of pure acid of tartar, we have effervescence; and we form the compound salt, named in the table *Tartarus solubilis*, similar in nature to other neutral salts, in which neither acid nor alkali can be perceived to predominate. But, after having done this, if we add more of the acid, although there is no more effervescence, a certain quantity of this superfluous acid joins itself to the neutral salt we had formed at first, and adheres to it strongly, constituting with it another compound salt, composed of the same acid and alkali, but in which the acid predominates. It is no longer a neutral salt, but shews the qualities of an acid, in mixture with other substances. It is this acidulous compound of the tartarous acid with the vegetable alkali that is best known

and most useful; it is called simply *tartar*. It is much used in medicine, and in some of the arts, and is certainly a very valuable article of the materia medica, on account of its deobstruent and cooling powers. It is, therefore, worth while to attend to its history and chemical qualities.

Tartar is not an artificial substance, but is produced by nature in the juices of some vegetables, from which we acquire it. The juices of many vegetable fruits contain compounds of this kind, which resemble tartar more or less. But he species of this saline substance that is in common use in medicine and the arts, is obtained from the juice of the grape, fermented to a wine. The sharper wines contain the most of it, the Rhenish especially; and, when long kept, deposit the tartar, which concretes by crystallization to the internal surface of the cask, in the form of a coarse and fæculent saline crust, called WINE-STONE or ARGAL. The wine itself is considerably improved by this separation, &c. becoming more smooth and palatable, and being therefore more valued.

At the same time that tartar thus crystallizes, some of the colouring matter of the wine separates along with it. Hence we have red tartar and white tartar. Neither of them is employed in medicine, or much in the arts, in their native impure state. They are commonly made to undergo a refinement, by which the colouring matter of the wine is separated, and the tartar is also made purer in other respects. This is done by solution in boiling water, clarifying the solution and crystallizing. Thus are produced white crystals, or crystallized masses, called crystals of tartar. I must refer you for a particular account of this very considerable manufacture in the wine countries, to *Macquer's dictionary*, *Rozier's Journal de Physique*, *tom.* i. 67; and to the dissertation of Mr. Fizes, the inventor of the most approved French process, as practised near Montpellier, published in the Mem. Acad. des Sciences, 1725.

This refined or crystallized tartar is beaten to powder by the apothecaries, and kept in that form for use; and in that state is often called for and prescribed under the name of cream of tartar. The reason of this denomination is, that it was long

procured by evaporation to a pellicle, which was skimmed off like cream, and is renewed almost as fast as it is removed.

Let us now examine the chemical qualities of this substance.

When exposed to a burning heat, the acid, as you might expect, is consumed and destroyed; and we find the alkali, with which it was combined, in the coal or cinder that remains.

We had occasion to remark formerly, that the alkali of tartar is remarkably pure. The burning of this salt is therefore an operation frequently performed to obtain it; and the alkali thus obtained was formerly called salt of tartar. The preparation of it is prescribed in all the pharmacopœias.

It is a very simple process, and may be performed either by burning the tartar in a crucible or an iron pot, or by laying it among burning coals in a moderate fire. A strong fire would be unfit for this purpose, as being capable of melting or even evaporating the alkali. It is usual to take the crude tartar, and to wrap it up in wet paper before it be put into the fire; it then singes and coheres like feathers or hair, and forms a spongy cinder or coal, which must be left in the fire until it ceases to give smoke and flame; after which we shall find it easy to extract the alkali from the earthy and coaly matter of the cinder by water.

When we next examine the nature of tartar, by mixing it with other substances, we find, first, that it has but little solubility in water, especially if the water be cold. It then not only dissolves slowly and with difficulty, but requires a very great quantity of water. To make the tartar dissolve more readily, we must apply the water boiling hot, or boil them together. Even of boiling water, eighteen or twenty times its weight are required: and when the solution becomes cold again, the tartar separates by crystallization almost entirely.

In mixture with other things, tartar shews the qualities of an acid, in consequence of the predominant or superfluous acid which it contains. It reddens the vegetable colours, and it effervesces with alkalis. The alkali unites with the superfluous part of the acid, and changes the tartar into a perfect neutral salt. With the vegetable alkali it forms *soluble tartar*, or *tartarized tartar*. With the fossil alkali it forms Rochelle

salt, sal Rupellensis, also called sel polychreste of Seignette, a mixed neutral, containing two alkalis. With the volatile alkali it forms another mixed neutral, which has not been applied to any use.

All these neutralized tartars are much more soluble in water than tartar itself; and hence the name of soluble tartar which they had in common. They can be decompounded again, so as to restore the tartar to its former state, by adding any fossil acid, or even the acetous. The added acid joins with the *neutralizing* part of the alkali, and thus restores the tartar to its former condition. This has been known to happen in prescriptions, by the acid of tamarinds. But it is remarkable, that, after the other acids have thus separated the neutralizing part of the alkali, they have little power over the rest, and act on it but slowly and imperfectly. The abundance of the acid of tartar defends it from their action; a case which occurs not unfrequently in chemical combinations.

You now understand what sort of neutral compounds are formed, when we saturate with the different alkalis the superfluous acid contained in tartar or cremor tartari, and in what manner this acidulous compound salt may be decompounded.

In the first place, if we desire the alkali, the common way, as I observed before, is to destroy and consume the acid by fire. The alkali remains unchanged.

The manner of obtaining the pure acid part of tartar is not so obvious; because, as I have just now observed, the acids which may be employed for disengaging it, after having combined with what may be called the neutralizing part of the alkali, act but feebly on the rest, and detach it still united with part of the tartarous acid: and we obtain an acidulous salt which resembles the cream of tartar so much, that it was concluded to be the same, and chemists inquired no further about it. The decomposition of the tartarine neutrals seemed as good as that of nitre or common salt.

But Dr. Scheele was induced, by many reasons, to think that this decomposition was very imperfect.

When chalk, or some other earthy substances of the same nature, which we shall soon describe, is thrown into a hot so-

lution of tartar, it produces an effervescence, which is renewed by more chalk, until a certain quantity has been added, after which no more effervescence can be produced. The liquor being then allowed to cool and settle, deposits a plentiful white sediment.

Dr. Scheele, examining the clear fluid from which this sediment had subsided, found that it contained a tartarus solubilis, or neutralized tartar. He therefore concluded that the chalk had deprived the tartar of a *superfluous* acid which it contained, and had left no more combined with the alkali than what was necessary to constitute a salt perfectly neutral.

This idea induced him to examine the sediment: and in it he actually found a part of the acid of the tartar, combined with the chalk. They form together a compound, which has very little, or scarcely any solubility in water. The moment it is formed, therefore, it concretes into a quantity of small crystals or concretions, like fine sand, much exceeding the chalk employed. And as by this want of solubility it resembles a compound of chalk and vitriolic acid, to which the chemists and natural historians formerly gave the name of *selenites*, he called the new compound which he had discovered, *selenites tartareus*.

He next discovered that the acid of tartar may be extracted from this compound, by the action of the vitriolic acid, which has a stronger attraction for the chalk than the acid of tartar has.

When I say this, some of you may perhaps imagine that it may be extracted by an operation similar to that by which the nitrous and muriatic acid are obtained from nitre and common salt; I mean by adding the vitriolic acid, and then distilling the mixture, that the acid of tartar may rise in distillation. But if any person imagines such a process could succeed, he has forgot the nature of the acid of tartar. The acid of tartar cannot be distilled. It cannot rise with water in distillation, but remains behind, while the water is distilled or evaporated from it. And when we attempt to convert it into vapour after this, it is destroyed by the heat, in the same manner as wood or sugar, or the like vegetable substances.

But distillation in this case is not necessary. The separation is practicable, in consequence of the difference of solubility. The acid of tartar is exceedingly soluble in water. The vitriolic selenite, from which it is to be separated, has very little solubility. To obtain the acid of tartar by itself, we must therefore proceed in this manner: First, wash away all the neutral salt from the *selenites tartareus*; and, secondly, add a proper quantity of vitriolic acid, diluted with four times its bulk of water. This acid immediately unites with the chalk, and separates from it the acid of tartar. The vitriolic acid, in uniting with the chalk, forms with it a compound that is almost insoluble in cold water, and forms a white sediment in this process. The acid of tartar, being, in its separate state, exceedingly soluble, is found dissolved in the clear part of the fluid, after the sediment has subsided, and can be poured off; or it may be filtrated; and then we can evaporate it with a gentle heat to dryness; or it may be crystallized. As first obtained, however, it is not perfectly pure; a small portion of the vitriolic selenite adheres to it. But it can be purified by dissolving it again in a small quantity of water, which will leave the selenite undissolved.

We have now, therefore, a clear view of the nature of tartar, and of the acid which it contains; which is truly singular in many respects: for, besides being capable of uniting firmly with alkalis, so as to form either neutral or acidulous compound salts, it adheres to the alkali, with different degrees of force, according to the quantity of it. The other acids, the fossil for example, or the acetous, when applied to a neutral or soluble tartar, very readily unite with, and separate from it part of the alkali; and thus reduce it to the state of tartar again, or *cremor tartari*. But, after they have done this, they have much less power over the remaining alkali which it contains. The abundance of acid of tartar with which it is combined, defends it, or adheres to it more stongly; and probably repels the particles of the other acid. It does not, however, prevent entirely the action of the fossil acids: for if these are applied in large quantity to the *cremor tartari*, they certainly produce a decomposition of it, by uniting with the alkali.

But the difficulty or impracticability of decompounding it, by moderate quantities of other acids, concealed the nature of this compound salt for a long time.

It is also remarkable, that, although the vitriolic acid detaches the acid of tartar from the alkali, the pure acid of tartar will partly decompose the vitriolated tartar, nitre, and digestive salt.

To finish this subject, I shall only further notice, that as soon as I learned this process of Scheele's, I discovered that the acid of tartar may be extracted more completely by a little variation of Dr. Scheele's process, viz. by using quicklime in place of chalk. But of this more hereafter.

I must also observe, before quitting this subject of tartar, that, besides this agreeable acid obtained from the fermented juice of the grape, there is a variety of acidulous salts obtainable from other vegetables, in their native state, which seem to be of the same kind, or at least very analogous to the tartar already described. I am convinced, from repeated experiments made by myself, from the very beginning of my chemical studies, that all the native vegetable acids, whether those which are unfolded during the maturation of their fruits, or those contained in the native juices of the plants, as we find it in the whole tribes of rumices and acetosæ, resemble the tartar of wine in this chief circumstance, that they contain a fixed alkali in their composition, super-saturated with an acid. All these dry salts, and sour juices, give the same alkali by incineration. Their differences seem to proceed entirely from small variations in the acid, consisting either in a different proportion of the parts truly saline, or more generally from mucilaginous or resinous matter. These varieties are the characteristics of the different kinds, the chief distinctions of which are the degrees of solubility of the compound salts, formed by their union with the alkali. All of them are equally destructible by fire, and incapable of being volatilized. I am therefore disposed to think that the real acid is the same in all, and that their distinctions arise from ingredients not saline. One of these forms is the tartar of wine. I would say that another forms the tartar of sorrel, &c. In short, I would call them all

tartars, were it not that it is a barbarous appellation. I am further of opinion that they are all ultimately resolvable into acetous acid. I think that their denominations have been multiplied without reason: Malic, citric, oxalic, &c. answer no purpose.

SPECIES XIV.

BORAX.

We come now to the last compound salt in the table, Borax. This salt was long known and employed in the arts, before the nature and composition of it was understood. The chemists found that it possessed some alkaline qualities, as taste, and changing vegetable colours to green. They were, therefore, inclined to consider it as a particular species of alkali. But this idea of it was not readily adopted, on account of its not effervescing in the least with acids. At last, however, its nature was thoroughly explained by the experiments of some of the French academicians, which shewed it to be a compounded salt, containing that peculiar acid, the sedative salt, joined with the fossil alkali. And hence the alkaline qualities of it appear now to be a consequence of the weakness of the acid with which the alkali is combined in this salt.

All the Borax used in Europe has hitherto come from the East Indies, in the form of crystals, which cohere together by means of unctuous matter; and the whole is called *Tincal*, or *Tincal paste*. This Borax is refined in Europe by a process which is still kept secret; and was for a long time practised only in Holland, though surely there can be no great mystery in it. The refined borax is sold to goldsmiths, and other artists, who make use of it in the form of large crystals, somewhat resembling alum.

The effects of heat shew that there is much water in the composition of these crystals. They readily undergo the watery fusion, and then swell up into a very spongy blistered mass. When the water is at last dissipated, they become a clear glassy salt, having all the tough ductility of glass when

hot, and, when cold, splitting and breaking precisely like a piece of glass. But it is still a perfect salt, dissolving completely in a large portion of water, and crystallizing as before.

The compound nature of this salt is easily demonstrated, and the two ingredients of it separated from one another. The easiest and shortest method to separate the sedative salt is to dissolve the borax in a small quantity of hot water, and to add a proper quantity of any of the fossil acids, which immediately unites with the alkali, and then allow the solution to cool. The sedative salt separates by crystallization. This is the only example of the decomposition of a salt in this particular manner. I may add, that the alkali is obtained in its purest state, when we employ the nitrous acid for the decomposition, and then deflagrate the cubic nitre.

From the process, it is plain that fossil acids have a much stronger attraction for the alkali than the sedative salt has. There is, however, a fact which, when I mention it, will at first appear inconsistent with this superiority of attraction. The fact I mean is this, viz. the decomposition of nitre and common salt by sedative salt. It is not, however, inconsistent with what happens in the process, but is an example of an elective attraction in consequence of heat. The volatility of the nitric or muriatic acid, when the compound is urged by a great heat, diminish its attraction for the alkali, while the attraction of the sedative salt suffers little or no diminution. The sedative salt has not, however, the power to separate the vitriolic acid in the same manner. If we mix some crystallized sedative salt with Glauber's salt, or vitriolated tartar, and expose the mixture to heat, nothing happens but the sublimation of a small part of the sedative salt. Hence the process for sedative salt by sublimation. (Vide Experiments on the Sedative Salt by Bourdelin, Mem. de l'Acad. 1753 and 1755.)

Borax is used in melting gold, silver, and some other metals, and in soldering them, and in the composition of very fine glasses, or pastes as they are called. It is also exceedingly useful in making experiments with the blow-pipe.

With respect to the origin of this salt, I said already that hitherto all that we have had in Europe has been imported from the East Indies, under the name of *tincal*, or *tincal paste*. The account given of its origin in that part of the world is, that it is produced from the waters of certain mineral springs, which, being evaporated by the heat of the sun, afford this salt. (See several particulars relative to the production of borax, in a letter from Mr. Blane at Lucknow, Phil. Trans. vol. 77. Part 2d.) Nothing like it, however, had been observed in any of the mineral waters of Europe, until a few years past, when, in Tuscany, the Duke's apothecary having examined certain hot springs in a volcanic part of his Highness's dominions, found various salts and other mineral substances, which had been deposited by the waters; and, among these saline substances, he found considerable quantities of sedative salt, from which we are told borax has since been manufactured. This I had occasion to mention when speaking of the sedative salt.

Borax and tartar, or *cremor tartari*, afford a rare example of two compound salts uniting together, and acting somehow on one another without the decomposition of either. This appears when we mix sixteen ounces of cremor tartari with two ounces of borax. We should expect something like this; for tartar is sensibly acid, and borax is sensibly alkaline. These salts enter into some sort of union, in consequence of which the cremor tartari becomes very soluble in water, although it still retains its acidity as before. No part of its acid appears to be taken from it by the borax, nor is the borax itself decompounded; for no part of the sedative salt separates by crystallization. This may, therefore, be considered as a case in which chemical attraction has sufficient power to produce one effect, viz. a diminution of cohesive attraction, but not enough of power to produce the full effect, which is produced in the most of such cases, I mean exchange or decomposition. The German physicians, I am informed, make use of this power of borax to increase the solubility of cremor tartari in pharmacy and prescription.

SYNONYMOUS DENOMINATIONS OF THE SALTS.

Many of these salts, which I have described as resulting from the combinations of the alkalis and the acids, were substances never seen, or never observed before, and therefore were things without a name. Yet they must be denominated. Their names were given in consequence of some circumstance accompanying their formation. Sometimes the ingredients from the admixture of which they resulted ; such as *vitriolated tartar*, *tartarized tartar*....sometimes expressing what was thought to be their nature, *regenerated tartar*....sometimes from their medical effects, real or supposed, *digestive salts*.... sometimes from their discoverer, or the place of their first appearance, *Glauber's salt*, *Epsom salt*....sometimes from mere whim, *sal de duobus*, *arcanum duplicatum*, &c.

Moreover, as what occurred to one person in the course of his chemical operations may as readily occur to another, and, particularly, as the same ultimate composition may result from very different processes, it must have often happened, that a substance denominated in one way by one discoverer, received a different denomination in the hands of another chemist. And it may often be some time before these two names are found to belong to one and the same substance ; and it may even require a good deal of examination to prove the identity.

From such causes as these, it has happened that almost every salt that I have mentioned has been known by several different names. Not only the accidental circumstances now noticed, but also the languages of different nations and of different classes of people, have augmented this list of synonymes. Novel objects imported from other countries, will retain, in a different language, the name which they had at home. Men of science will sometimes allow a thing to retain the name which it got among the workmen in whose daily occupations it first occurred. Such names, having no other significancy, will be considered as pure appellations, *or proper names*.

In reading the writings of the chemists, we shall be in a continual puzzle, and may often be obliged to go back through a

train of discussion, before we are certain what substance it is whose effects and properties are engaging our attention.

Therefore, I thought that it would be useful to collect, under each of the denominations that we have been considering, all the synonymous appellations by which you will find them mentioned in the chemical writings. This will appear a disagreeable farrago at first sight, and many names will appear ridiculous or barbarous; but our future disquisitions will frequently shew some reasonable account for their acquiring such names.

For a long series of years, while chemistry was only a collection of processes in the various chemical arts, these denominations being accidental, and in the language of persons of no general cultivation, were altogether anomalous, and frequently suggested very false notions of the objects. As chemistry began to assume a scientific form, and its professors were persons of more extensive knowledge, these improprieties were observed, and great inconvenience was frequently found in employing them. Attempts were therefore made by some chemists to reform the nomenclature, by reducing it to some rule, founded on a principle pervading the whole, and equally applicable to any new discoveries which may be made from time to time.

The first of these attempts, of any note, was made by the late Professor Bergmann of Sweden, whose essays and treatises on different subjects in chemistry contain a rich fund of accurate experiments and useful facts. His plan was this.....

In the first place, he named the alkalis and acids as they are named in the table before you. And the compound salts were expressed by the name of the alkali which they contained, with an adjective formed from the name of the acid; thus,

Vitriolated Tartar	is	Alkali vegetabile vitriolatum.
Glauber's Salt		Alkali fossile vitriolatum.
Vitriolic Ammoniac		Alkali volatile vitriolatum.
Nitre		Alkali vegetabile nitratum.
Cubic Nitre		Alkali fossile nitratum.

Nitrous Ammoniac	is	Alkali volatile nitratum.
Digestive Salt		Alkali vegetabile salitum.
Common Salt		Alkali fossile salitum.
Common Sal Ammoniac		Alkali volatile salitum.
Regenerated Tartar or Sal Diureticus	}	Alkali vegetabile acetatum.
— — —		Alkali fossile acetatum.
Vegetable Ammoniac		Alkali volatile acetatum.
Soluble Tartar		Alkali vegetabile tartarisatum.
Rochelle Salt		Alkali fossile tartarisatum.
— — —		Alkali volatile tartarisatum.
Borax		Alkali fossile boraxatum.

The plan of this nomenclature was suggested by some of the old names, in which something like this was attempted, though in a bungling and partial manner; and it has the advantage of being applicable to a multitude of other compounds, which contain acids combined with earthy or metallic bodies. It was therefore, well received, and many of these new names were adopted in the last editions of the Edinburgh Pharmacopœia, and in many others abroad.

It has, however, been objected that these names are too long; and, as it is necessary in expressing the particular state of some of these salts, to add another adjective, the name becomes, by its length, cumbersome and disagreeable.

Notwithstanding this objection, the advantages of a regular and decent nomenclature were so sensible, that this method became very prevalent; and would, in all probability, have soon obtained the acquiescence of all the philosophical chemists, had not the science itself experienced, at this very time, a great and almost total revolution.

A number of most important discoveries were made, about this time, by the chemists of Britain, France, and Sweden, relating to the constituent parts or principles of natural substances. New objects were discovered, which required new names: and some of the substances already known, which had formerly been considered as simple, and perhaps elementary, were now found to be compounded; while others, formerly held as compounds, were now found

to be more simple than the substances of which they had been thought to be compounded. This being the case, it is plain that, while the *method* proposed by Burgmann is still advantageous, the *construction* of the nomenclature must necessarily be changed, that it may be consistent with the knowledge we have acquired.

By a most sagacious and careful consideration of those discoveries, Mr. Lavoisier formed an opinion concerning the composition of bodies, and the principles by which this composition was effected, which comprehended the whole of chemistry, in such a way as to point out a series of compositions in many degrees of subordination. This must evidently regulate the construction of a nomenclature, on Mr. Bergmann's plan. This philosopher, therefore, associated several other eminent chemists in his labours, and the study soon acquired, in their hands, very great improvements. Assembled in Paris in 1787, and, confident of the superiority of what they called *French Chemistry* over all former doctrines and theories, they adopted a plan by which they hoped to give it universal currency and authority. They hoped to effect this by means of a nomenclature, so adapted to their system, that the very denominations of the different objects should imply the doctrines of their theories; so that, by using this language, it should scarcely be possible to think on chemical subjects, in a way different from their theories. They framed the language so that the composition of the most complex substance should be expressed by two or three words, modified by proper terminations, and so that the precise place and degree of subordination should be clearly and compendiously indicated.

With this view Messrs. Lavoisier, De Morveau, Berthollet, and Fourcroy, published the *Method of Chemical Nomenclature*, to which they annexed a corresponding system of chemical characters, composed (I believe) by Messrs. Adet and Hassenfratz. This was published at Paris in 1787, and is adopted by Mr. Lavoisier in his Elements of Chemistry, as also by Fourcroy and Chaptal, and, indeed, by almost all the French chemists.

I cannot here explain to you the whole of this new nomenclature. Many of the facts on which it is founded

have not yet been made known to you. But when we shall have advanced further in this course, you will easily understand it, by consulting the books I just now mentioned. In Mr. Lavoisier's Elements, the new system and new language are stated with the greatest precision and clearness imaginable. (Dr. Pearson of London has lately published a treatise to recommend the new language). At present we can only give our attention to the names proposed for the salts in that system. This will be fully sufficient for enabling you to see and understand the general rules, by which the denominations and the whole phraseology are offered and conducted.

One of the general rules which they thought it proper to observe in contriving their new nomenclature was, to give names ending with *similar* sounds, to all the things that are analogous in the *mode* of composition, and names ending with *different* sounds to things which differ in this respect: For example,

First, the acids, when they are in their most perfect, or most powerful, or most acid state, are,

Acide sulphurique,...*acidum sulphuricum*,...sulphuric acid.
Acide nitrique,...*acidum nitricum*,...nitric acid.
Acide muriatique,...*acidum muriaticum*,...muriatic acid.
Acidum aceticum,...*acide acetique*,...acetic acid.
Acide tartarique,...*acidum tartaricum*,...tartaric acid.
Acide boracique,...*acidum boracicum*,..boracic acid.

But some of these acids appear on some occasions in a less perfect, or less acid, or less powerful state, by reason of a redundancy of their distinguishing ingredients. For example, the vitriolic acid, when it is in its volatile and suffocating form, is so weak an acid in that state, that although it can be joined to alkalis, and form compound salts, such salts can be decomposed by the weakest acids, such as vinegar, or the acid of tamarinds, or the acid of tartar.

The nitrous acid is another example. In its most volatile and deep-coloured state, it has but a weak attraction for alkalis and for water, and other substances.

To distinguish this state of the acid, the French chemists, instead of the termination *-ique*, derived from the

Latin *-icus -a -um*, which is the form of a generic epithet, employ the termination *-eux*, derived from the Latin *-osus -a -um*, which is the form of an epithet expressing a redundancy of the subject or quality. Thus,

Acide sulphureux,..*acidum sulphurosum*,...sulphurous acid.
Acide nitreux,....*acidum nitrosum*,....nitrous acid.

Their names of the alkalis are,

FOR THE VEGETABLE ALKALI,

Potasse,....*potassa*,....potash.

FOR THE FOSSIL ALKALI,

Soude,....*soda*,....soda.

FOR THE VOLATILE ALKALI,

Ammoniaque,....*ammoniacum*,.....ammoniac.

In naming the compound salts, they use two words, the first suggesting the acid, and the second the alkali; or, in general, the *acidifiable base*.

All the compound salts, and other compounds that contain the sulphuric acid in its more perfect state, are called *Sulphats; Sulphas* in Latin.

All those that contain the nitric acid in its most perfect or powerful state, are called *Nitrats; Nitras*.

All those that contain the mutriatic acid are called *Muriats; Murias*.

All those that contain the acetous in its most perfect or powerful state, are called *Acetats; acetas*.

In conformity to this rule, we have the

Sulphat of potash,....of soda,....of ammoniac.
Nitrate of potash,....of soda,....of ammoniac.
Muriate of potash, &c.

These compounds are distinguished from those in which the acids are redundant in their distinguishing ingredient, by giving to the latter the termination *-ite*, from the Latin *-is*, or *-itis*; thus,

Sulphite,....*Sulphis*, or *Sulphites*, of potash, &c.
Nitrite,....*Nitris*, or *Nitrites* of potash, &c.
Acetite,....*Acetis* or *Acetites** of potash, &c.

* We shall see afterwards that muriates are not properly named....EDITOR.

The acid of tartar is also considered as an imperfect acid; and therefore they call the compounds formed by it *Tartrites*; *Tartris* in Latin.

The compounds that contain the sedative salt are called *Borats*; *Boras*.

These names have evidently been contrived to suit the genius of the French language, in the first place, and then have been transferred into the Latin words; or the words which were meant to be used in the Latin language have been coined from the French ones. When changes are thus made in the names of things which are familiar to us, I believe most people find them disgusting at the first, on account of the shock and derangement which they give to the habits they had formed before. These latinised French words appeared to me at first very harsh and disagreeable. This, it must be confessed, cannot be avoided, in making an attempt of this kind, and must therefore be overlooked.

When this rage for reformation and innovation was going round, it was natural for every person to think a little on the subject, and consider of what he would propose, were it required of him to give his opinion: And, if you will give me leave, I shall state to you what has occurred to myself.

When I give my plan for naming the salts, you will think perhaps that I have as little mercy for languages as other people; but I remarked before, that an attempt to coin new names, especially in our science, cannot be made without transgressions of this kind.

The following small table of the neutral salts will give you a sufficient notion of my plan:

DR. BLACK'S TABLE OF NEUTRAL SALTS.

	Acidum Sulphuricum.	Acidum Nitricum.	Acidum Muriaticum.	Acetum.	Acidum OEnolithicum.	Acidum Boracicum
Lixiva.	Lixiva Sulphurica.	Lixiva Nitrata, or Nitrica sive Nitrum.	Lixiva Muriatica.	Lixiva Acetosa.	Lixiva OEnolithica, et OEnolithus, sive Lix. OEn. Acidula.	Lixiva Boracica.
Trona.	Trona Sulphurica.	Trona Nitrata, or Nitrica.	Trona Muriatica sive Muria.	Trona Acetosa.	Trona OEnolithica. Trona OEn. Acidula. Oenolithus Tronatus.	Trona Boracica, sive Borax.
Ammonia.	Ammonia Sulphurica.	Ammonia Nitrata, or Nitrica.	Ammonia Muriatica sive Sal Ammoniacus.	Ammonia Acetosa.	Ammonia OEnolithica Am. OEn. Acidula. OEn. Ammoniatus.	Ammonia Boracica.

The volatile vitriolic acid will be acidum sulphureum; and the compounds of it with alkalis, sulphurea. And sulphur itself, when combined with alkalis, may be sulphur lixiviatum, sulphur tronatum, sulphur ammoniatum or ammoniacum. Or lixiva sulphurata, trona sulphurata ammonia sulphurata; which is perhaps better, on account of the more extensive application of the epithet; thus argentum sulphuratum, calx sulphurata, ferrum sulphuratum, &c.

To express the compound salts formed by the other acids, I may proceed as follows:...lixiva succinata, lixiva formicata, fluorata, citrata, phosphorata, &c. &c. *(See Note 34. at the end of the Volume.)*

The many different names which have been given to the same salt by its occasional discoverers, are a great inconvenience, and cause much obscurity in reading their writings. To remove this in some measure, I have collected the most usual synonymes, and arranged them under the leading names which I have just now been explaining to you. With very little trouble you may arrange them, either according to Bergmann's or the French method. You will find the list very useful.

SALIUM ALKALINORUM SYNONIMA.

1. Lixiva.
2. Alkali fixum vegetabile.
3. Kali. Pharm. Lond.
4. Potassa Gallis.
5. Sal Tartari.
6. Sal Absynthii.
7. Cineres clavellati. Nitrum fixatum.
8. Oleum Tartari.
9. Lixivium Tartari.
10. Aqua Kali. Lond.

1. Trona.
2. Alkali fixum fossile.
3. Soda. Pharm. Edin.
4. Natron. Lond.
5. Soda. Gallis.

1 Ammonia.
2. Alkali volatile. Edin.
3. Ammonia. Lond.
4. Ammoniaca. Gallis.
5. Sal volatile ammoniaci.
6. Sal cornu cervi.
7. Sal Urinæ.

Aqua dilutum.

8. Spiritus salis ammoniaci
9. Aqua ammoniæ.
10. Spiritus cornu cervi.
11. Spiritus Urinæ.

SALIUM ACIDORUM SYNONIMA.

1. Acidum Sulphuricum. Sulphurosum.
2. Acidum vitriolicum. Pharm. Lond. et Edin.
3. Oleum vitrioli, vel acidum, vel spiritus vitrioli.
4. Acidum vel spiritus sulphuris per campanam.
5. Spiritus aluminis.
6. Acidum chalcanthis.
7. ——— primigenium.
8. ——— catholicum.
9. ——— universale.
10. ——— aëreum.
11. ——— vagum fossile.

1. Acidum Nitricum. Nitrosum.
2. Acidum nitrosum. Pharm. Lond. et Edin.
3. Spiritus nitri.
4. Spiritus nitri Glauberi.
5. Aquafortis.

1. Acidum Muriaticum.
2. Spiritus salis marini.
3. Spiritus salis Glauberi.
—Acidum muriaticum oxygenatum.

1. Acetum.
2. Acedum acetosum.
3. Acetum destillatum.
4. Spiritus aceti.
—Acidum aceticum.

1. Acidum OEnolithicum.
2. Acidum tartari vel tartarosum.

1. Acidum Boracicum. Boracinum.
2. Sal sedativus.
3. Sal sedativus vel narcoticus Hombergii.

SALIUM COMPOSITORUM SYNONIMA.

1. Lixiva Sulphurica.
2. Alkali vegetabile fixum vitriolatum. Edin.
3. Kali vitriolatum. Lond.
4. Sulphas Potassæ.
5. Sal polychrestus.
6. Nitrum vitriolatum.
7. Sal enixum.
8. Sal e duobus.

1. Lixiva Nitrata. Nitrosa.
2. Nitrum.
3. Nitras potassæ. Gallis.
4. Sal petræ.

1. Lixiva Muriatica. Muriata. Lixiva muriata oxygenata.
2. Murias potassæ. Gallis.
3. Sal digestivus vel febrifugus Sylvii.
4. Sal marinus regeneratus.
5. Spiritus salis marini coagulatus.

1. Lixiva Acetata.
2. Alkali fixum vegetabile acetatum.
3. Kali acetatum.
4. Acetas potasse....Acetis. Gallis.
5. Tartarus regeneratus.
6. Sal diureticus.
7. Terra foliata tartari.

1. Lixiva OEnolithica.
2. Alkali fixum vegetabile tartarisatum.
3. Kali tartarisatum.
4. Tartris potassæ. Gallis.
5. Sal vegetabile.

6. Tartarus solubilis.
7. Tartarus tartarisatus.

1. OEnolithus.
2. Tartarus. Ed. & Lond.
3. Tartarus acidula potassæ. Gallis.

1. Trona Sulphurica.
2. Soda vitriolata. Ed.
3. Natrum vitriolatum. Lond.
4. Alkali fixum fossile vitriolatum.
5. Sal Glauberi.
6. Sal mirabile Glauberi.
7. Sulphas sodæ. Gallis.

1. Trona Nitrata.
2. Nitras sodæ. Gallis.
3. Nitrum cubicum.
4. Nitrum quadrangulare.

1. Trona Muriata.....Muriatica.
2. Muria. Ed.
3. Sal marinus. Ed.
4. Sal muriaticus.
5. Natrum muriatum. Lond.
6. Murias sodæ. Gallis.
7. Sal communis.
8. Sal gemmæ.

1. Trona Acetosa.
2. Acetis sodæ. Gallis.
3. Sel vegeto-mineral.

1. Trona OEnolithica.
2. Tartris sodæ. Gallis.

1. OEnolithus Tronatus.
2. Soda tartarisata. Ed.
3. Natron tartarisatum. Lond.
4. Sal rupellensis.
5. Sal polychrestus rupellensis.

1. Trona Boracinata.....Boracica.
2. Borax.
3. Boras sodæ. Gallis.

1. Ammonia Sulphurica.
2. Sal ammoniacus vitriolicus.
3. Sulphas ammoniacalis. Gallis.
4. Ammoniacus secretus Glauberi.

1. Ammonia Nitrata.
2. Nitras ammoniaci. Gallis.
3. Nitrum semivolatile.
4. Nitrum flammans.

1. Ammonia Muriata. Muriatica.
2. Sal ammoniacus. Ed.
3. Ammonia muriata. Lond.
4. Murias ammoniacalis. Gallis.

1. Ammonia Acetosa.
2. Spiritus Mindhereri. Edin.
3. Aqua ammoniæ acetata. Lond.
4. Acetis ammoniacalis. Gallis.

1. Ammonia OEnolithica.
2. Tartris ammoniacalis. Gallis.

*** Unless the chemical reader makes this list very familiar to his mind, he must remain incapable of reading with intelligence the writings of all the chemists of Europe previous to the publication of Mr. Lavoisier's system. Yet those writings contain a vast body of solid chemical knowledge, all of which has a chance of being forgotten, if it have not an immediate and palpable dependence on the new doctrines. He will remain equally ignorant of the writings of the most eminent natural historians and mineralogists, who employed no other language in all their discussions.....EDITOR.

CHEMICAL HISTORY.

CLASS II.

EARTHS.

THE nature of the salts in general, and that of the principal varieties of them, have been already explained to you. It was proper to present that class of natural substances to your consideration the first of all, because the salts are the most active of the objects of chemistry. They shew an attraction, or a dissolving and active power, in mixture with a great multitude of other substances. We cannot therefore describe conveniently the nature of any of the other objects of chemistry, without taking in the relation of such objects to the different salts, or to some of the principal species of them.

Next after the salts, I have found it most convenient to describe the earthy bodies: and I have two reasons for choosing this arrangement. The first is, that some of the earths resemble the salts so much by their chemical relations, that the transition from the one to the other is perfectly easy, and the knowledge of the salts must therefore facilitate the apprehension of what is to be said of the earths. The second reason is, that we must have some knowledge of the earths, before we can proceed conveniently to the study of the other objects of chemistry which have not yet been considered.

That I may prepare you for understanding some terms and expressions, which I shall have occasion to use, in

speaking of the different states and conditions in which we find the different earthy and stony substances, I am under the necessity of stating or describing a number of facts or appearances, which, to be clearly apprehended, require a more than usual exertion of the attention. I trust, therefore, that you will favour me with your attention, which, at any rate, will be well employed, as in thus preparing you, I must make known to you many of the most important and instructive phenomena that are connected with the natural history of this globe.

The common definition of earthy and stony substances is, that they are bodies not soluble in water, not inflammable, and whose density or specific gravity, compared with that of water, does not exceed the proportion of four to one. These characters are chosen to distinguish them from salts, and from ice, by the want of solubility in water; from inflammables by the want of inflammability; and from the metallic substances by inferior weight.

This definition, however, as well as that commonly given of the salts, is not unexceptionable. The distinction taken from the want of solubility may be objected to, as not applicable to some of the earths, which are perfectly and totally soluble in water. Such is calcareous earth, and barytes, and strontian spar. And it must be confessed, that some of these earths, or natural substances, which appear to belong more properly to the class of earths than to any other, are truly of an intermediate nature between salts and earths, partaking of the properties of each, in such a manner, that it is difficult to say which of the two classes they resemble the most. Mr. Fourcroy, thinking that they resemble the salts more than the earths, has removed them from the class of earths, and described them as salts. But it is of little importance under what name a thing is described, provided it be well described, and the nature of it thoroughly made known.

There is, in every part of nature, a transition from one set of her productions to another; so gradual, that we cannot find a precise limit between the classes or assemblages of them which we choose to make.

Beside those qualities of the earths which are commonly given, to distinguish them as a class from other bodies, they have one which, though not taken into the definition, does, I believe, always make a part of the general idea of an earthy substance in the mind of a chemist. This quality is the great degree of fixedness in the fire, by which the earthy and stony bodies, in general, excel all the other classes of the objects of chemistry.

The substances which belong to this class are well known to exceed greatly in quantity all the other objects of our science. They compose almost the whole of the solid materials of this globe which we inhabit. It is, therefore, proper to take some notice here of the situation and arrangement of the earthy bodies in the interior part of the globe, so far at least as we have yet been able to penetrate into it, which we must confess is only to a very small depth. This step is necessary, that we may have an opportunity to explain some terms which are in general use, in describing the different states and conditions in which the principal species of earths are found in nature. But my observations on this subject have a more important aim. The description to be given of the natural situation and condition of the earthy substances, and of those which they inclose and contain, give the most evident marks of a gradual change, both in the situations, forms, and even properties, of those substances. As all these are the effects of heat and mixture, operating by means of chemical forces, it is plain that the changes exhibit a series of instructive observations, and must furnish us with informations which nothing but the length of time, and the enormous pressures competent to these situations, could procure. This is a valuable addition to all the momentary labours of our little laboratories and experiments. And, on the other hand, our chemical knowledge enables us to understand many of those changes which must otherwise have been mysterious and unaccountable. Thus will chemistry and natural history derive mutual aid and improvement.

We have acquired some knowledge of the state of the interior parts of the earth, by observing the excavations

formed accidentally by torrents of water, and by digging deep pits in many different places for the purposes of mining, or, on some occasions, for procuring water.

Whenever we have had opportunities, in these different ways, for observing the construction of the interior parts of the globe, it has been perceived that the matter of which it is composed is arranged, for the most part, in extensive beds, layers, or strata, composed of different materials, and very various in their thickness, but generally parallel to one another, and in which we see many parallel divisions, like the leaves of a book. Where the matter of the earth is arranged in this manner, it is called STRATIFIED MATTER, or STRATA.

This arrangement, however, is perceived in few places only, at the surface of the ground. The surface is covered almost every where, to different depths, with a confused rubbish and loose earth, composed mostly of the materials which lie more solid and regular below; a part of these having mouldered down into this rubbish and earth, and, in most cases, having been removed by the action of water to a considerable distance from the place to which they originally belonged.

Before we can see the appearances of the stratified matter, we must therefore penetrate through this rubbish, or find places where it has been broken through, or swept away, for a depth of some feet or fathoms, or, in many cases, for a much greater depth; and then we seldom fail to perceive them.

The parallel position with respect to one another, and the great extent and equal thickness of these strata, have been most distinctly seen in mining countries, where frequent pits have been dug, to reach the objects of the miner; also in digging of wells in populous countries.

Derbyshire is an example of a mining country, in which a very great number of pits have been dug, on account of numerous metallic veins of lead ore which it contains: and Mr. Whitehurst has given an account of the general experience and knowledge that has been acquired by the frequent perforations of the earth in that country.

The country around Newcastle is another example, where, on account of the abundance and numerous strata of coal which are found there, the interior parts of the earth have been diligently examined by numerous pits, and by other means, as boring, &c.

From the insight that has been got on all such occasions, it has appeared that the strata lie in very different positions with respect to the horizon in different places; that in some districts they are level or horizontal; that in others, and these the greater number, they decline from the horizontal position, or have what is called a DIP; that in others, they are somewhat waved, or alternately rise and sink in an irregular manner: and in others, are thrown into *disorder* by interruptions, sudden bendings, and fractures, and by very steep declinations from the plane of the horizon. There are even examples of two sets of strata in different positions, the one over the other; the undermost set commonly erected, more or less, and the hardest; the uppermost less erected, or horizontal, and softer. This is seen in the banks of the river Jedd, near Jedburgh.

Such are the different states of the stratified matter which is found in almost every place where we have opportunities to examine the interior parts of the earth.

But I must farther remark, that in many places, and especially in those countries in which we find the strata the most disordered, we generally also find large quantities of stony matter, in which we cannot perceive that stratified arrangement of parts, but which constitutes enormous masses, irregular in their form and size, sometimes spread out or interposed between the strata, but never of such an equal thickness, or disposed in such a regular manner; and often split into numerous pieces.

The stony matter which has this appearance, may be distinguished from stratified matter by the name of rock, or rocky matter.

An example of the difference between the rocky and the stratified matter, is to be seen in Salisbury Craig, which is an extended mass of rocky matter, with stratified matter below it, and above some parts of it: and Arthur's

Seat is a mass of rocky matter, but has stratified matter under it.

These masses of rocky matter, in which we cannot perceive any stratified arrangement, compose in some countries very high mountains. In other places, the ridges, or chains of mountains, are formed more or less by stratified matter that is uncommonly hard, and the strata of which are much declined from the horizontal position; in consequence of which, their edges project above the general surface of the globe, to form those mountainous ridges. Frequently, however, the very high mountains are formed by an intermixture of *rock* with these hard and erected strata, which, along with it, have sustained the injuries of time and of the weather, better than the softer matter which surrounded them; and therefore part of them now remains, and forms those projections, after the softer matter has been demolished around, and washed away to a great depth.

That the surface of the globe has everywhere undergone great changes in this way, by demolition, and removal of the materials to very great distances, will be clearly seen by any person who surveys it with a discerning eye. When we ascend very high mountains, the rocky tops of them are all shattered and ruinous, and their sides are covered in many places to a great depth with the rubbish which has fallen from the upper parts of them. In this rubbish, we find deep scars and ravins, formed in heavy rains and storms, by torrents of water, which, by their repeated effects, gradually wash down that rubbish into the lower grounds. During the great length of time required for its complete descent, it undergoes further demolition and decay, into gravel, sand, and earth; and, under these forms, is at last spread out by the brooks and rivers, to form the plains and the sands found on the shores of the sea. For, as the rivers, in consequence of the unequal resistance of the different soils through which they run, have in general a serpentine course, and are gradually undermining their banks, and shifting their channel in different places; they have the natural effect to undermine, and bring to a level, the eminences and accumulations of

soil and rubbish which have been formed in particular places. And, for this reason, all great rivers are in general surrounded, in their course toward the sea, with immensely extensive plains, which have been formed by themselves.

Any person who wishes to be satisfied of what I have now said, of the demolition that is going on in the elevated parts of the earth's surface, must visit very high, mountainous, and Alpine countries, or read the accounts of those who have visited them. Common mountains and hills do not shew it so evidently, for although these too are suffering a gradual demolition and waste, it is so slow, on account of their being less exposed to the violence of the elements, that it is not obvious. They become covered with rubbish, and soil, and vegetables,....all which defend them in some measure from the less violent impression of the storms ; while the tops of very high mountains are so much exposed to their fury, that soil or rubbish cannot remain on them, but is swept away as fast as it is produced. There is a fine example of this in the mountains of Arran, in the west, which are among the highest in these islands. The summits of those mountains are all ruinous. They present, in some places, lofty precipices, which terrify the beholder by their awful heights, and by the mountainous blocks of stone which are prominent from them, and seem ready to fall and crush every thing below them. They are accessible only to eagles and other birds of high flight, who choose them for their habitation. The foot of these precipices terminates in a steep slope of great extent, forming a great part of the side of the mountain. This slope is composed entirely of blocks of stone and of rubbish, which, in the lapse of time, have fallen from the top of the precipice.

For more examples of similar appearances, I refer you to the description of the higher parts of the Alps of Savoy, as given by Mr. Saussure of Geneva, in his account of different excursions and journeys he made among them, and in some of which he was exposed to great danger. His accuracy in observing, and fidelity in relating what he saw, may be entirely relied on : and he presents his reader

with a number of the most sublime objects and instructive facts in natural history.

You will also find proofs of the decay and demolition of mountains of granite, described by Mr. Hassenfratz, in the eleventh volume of the Annales de Chimie. He saw them on the road from St. Flour to Montpellier; and they are a very striking phenomenon.

But I have wandered I may say into a digression. I was led into it by endeavouring to illustrate the remark I made on the nature of many mountains and chains of mountains; that they are composed of hard stratified or rocky matter, or of a mixture of both, which now is eminent above the surface of the globe around them, in consequence of the gradual demolition, and removal to a great distance, of the softer matter which formerly surrounded these harder materials, which are even themselves liable to a more slow demolition and waste.

To proceed,....It is necessary further to be understood, that both the stratified and rocky matter are found split or divided, in innumerable places, by fissures nearly perpendicular, or across the strata; and that the parts, thus broken asunder, are often considerably displaced with respect to one another: the materials on the one side of the fracture being frequently sunk below the level of those on the other, or removed to some distance from them, so as to produce in the stratified matter *discontinuities* of various wideness. These rents and intervals of the fractured strata, or rock, are in general filled with a matter different from that of the rock or stratum in which the rents are found. And rents of a certain width, thus filled up with extraneous matter, are called *veins*, or, in Cornwall, *lodes*. These veins are subject to all the variations of width, and irregularity of direction, which you can easily imagine in fractures and rents of hard strata and rock; and they go down to a depth far below any to which we can reach. The matter which fills them is generally a whitish stony matter, named *spar*. It is more pure and more simple in its composition than most other stones; but there are several kinds of it: and intermixed with it, we often find also different metallic and mineral substances. It is indeed in those veins chiefly that the ores of metals are found.

And wherever there are vacuities left in the vein, by its being imperfectly filled, there we are sure to meet with crystallized matter of the several stony and mineral substances which the vein contains.

In a great many examples, however, the rents and discontinuities I have described, are of greater width than what are commonly called veins. The width of veins is from an inch, or a fraction of an inch, to several feet or even yards, in some cases. But we have examples of rents, the width of which is equal to many fathoms; and in this case, rock or rubbish, or other extraneous matter, fills up the interval. When this occurs, the interval and materials which it contains is not called a vein. Our miners give it the name of a *dyke*, or *partition*. The extent to which these dykes, as well as the veins, are continued downwards into the bowels of the earth, is hitherto unknown. Their depth is plainly much greater that what human art and labour can reach.

These rents and dislocations of the strata, with the intervals thus formed, and great quantities of rock or rubbish which sometimes fill up these intervals, are well known to our colliers, who meet with them often in cutting out the coal; and they call them in general *troubles;* because there they meet with an interruption in the coal, in consequence of a division and shift of the strata, which they call a *hitch*. The coal is continued beyond this break or hitch, but upon a different level, which the miners must find out, sometimes at great expence. And often they find interposed, between the edges of the interrupted strata, a thick partition of rocky or other matter, called a *dyke*.

You will see numerous examples of small veins in Salisbury rock; and examples of small dykes in the bed of Leith water or river; between Canon-mills and the mills above them.

I have only one general fact more to relate, which belongs to this subject: It is the discovery of sea-shells, corals, and coraline bodies; and of the bones and skeletons of fish, and other relics of marine productions, which are found in most places intermixed with the stratified matter. These have appeared on innumerable occasions, and in all parts of the world in which stratified matter, especially

some kinds of it, have been examined;....on the sides of the highest mountains, as well as at the greatest depths to which we have gone in digging the earth. Sea-shells have been found at Amsterdam 100 feet deep, under the surface of the earth; at Marly-la-Ville, six leagues from Paris, at 75 feet deep: sometimes in mines under a cover of 50, 100, 200, 1000 feet: as in the Alps and Pyrenees. They have also been found in mountainous countries, at a very great height above the level of the sea; as in the mountains of Spain, the Pyrenees, the mountains of France and of England, the marble quarries of Flanders, the mountains of Gueldres, and in the heights round Paris; also in the Alps, particularly Mount Cenis. And M. Saussure, in his instructive journeys among the Alps, describes oyster-shells which he found in a part of the Alps to the south-east of Geneva, at the height of 1172 fathoms above the sea; that is, 7032 feet. *(Saussure Voyages dans les Alpes*, p. 393.*)* They have been seen also in the Appenines, and in most of the stone and marble quarries of Italy. *(Vide Buffon, tom.* 1. p. 408.*)*

We have evidence also of their having been found in the highest mountains of the world, the Andes of South America. Don Antonio de Ulloa found petrified shells upon the *Cordeliers des Andes dans le gouvernment de Wanca-Vellica*, in 13 or 14 degrees south latitude. These shells were found at such a height, that the barometer stood there at 17 inches $1\frac{1}{4}$ line French measure; that is, at $2200\frac{1}{3}$ fathoms above the level of the sea, or 13,202 feet. *(Mem. de l' Acad.* 1771.*)*

And, in all these different examples, it is in the stratified matter, only that they are found.

We also find frequently, in some kinds of stratified matter, impressions of the leaves and other parts of vegetables, and pieces of wood, penetrated with stony matter of different kinds.

From the whole of these phenomena, it is evident, that the materials of this globe have been affected, in many places, with violent concussions and derangement, and have also undergone very great changes in their position with respect to one another; that what was once covered by the sea is now land or mountains, and what was once

at the surface, or covered only with water, is now under cover of solid matter to very great depths; and that these changes of situation have even been often repeated; although the successions of the one to the other must certainly have been extremely slow, and must have required a length of time, the limits of which cannot be assigned from the phenomena themselves.

Such are therefore, in general, the appearances which present themselves, when we examine the state of the solid materials of which this globe is composed, and which mostly belong to the class of earths, which we are now to consider. Various conjectures and hypotheses have occurred to the human imagination, to account for the manner in which all this has happened.

To give a short account of the attempts to explain these phenomena, I shall first remark, that all these attempts agree in supposing the materials of the strata to have been arranged by water, depositing or arranging them one over the other, in succession. This is inferred not only from their general appearance, similar to that we perceive in lakes, pools, and other small collections of water; at the bottom of which, when they dry up, we find the sand, mud, and other matters deposited, or arranged in parallel layers; but also from the appearance of shells and other marine productions, which abound in the composition of a great number of strata. These shells are in many places found so entire, that they are perfectly well known. The different species of them are very numerous: and in some places they are collected together in immense quantities; in quantities so great, that we cannot suppose any other origin for them, but that the place where they lie was once the bottom of the sea. The strata are supposed to have been originally in an horizontal, or nearly horizontal position. The slope or declination from the horizon, which many of them now have, and the apparent disorder in other respects, by rents, changes of level, and interruptions, have been imputed to different causes by different theorists. Some have imagined that a general

convulsion must have shaken the whole of the globe. Others have supposed that partial ones have gradually affected the different parts of its surface in succession.

The general convulsions which have been supposed sufficient to produce these great effects are, first, the catastrophe of the deluge, described in the scripture, and by the poets. And Dr. Burnet, in his Theory of the Earth, by giving full liberty to his imagination, has shewn some ingenuity in the contrivance, I may say, of a deluge equal to these effects.

The great Dr. Halley, whose mind was more occupied with celestial objects than with any other, proposed a supposition, that this globe had perhaps more than once received a shock from a comet, which, impinging on it obliquely, gave it its diurnal rotation; and, by the sudden communication of such a violent motion, shattered and deranged all the materials of it that were near its surface.

But the greater number of philosophers appear now inclined to believe that the convulsions which have deranged the strata have been partial or local only, but with such a succession as gradually to affect every part, or almost every part of the earth's surface; and that they have been produced by subterranean fires.

That volcanic and subterranean fires must have been a very common cause of the inequalities of the earth's surface, and disorder of its materials, is plain from the natural history of this globe. We know that in some cases they have produced sudden and violent elevations of some parts of it, and as sudden sinkings and depressions of others. We know that some of the highest mountains are composed chiefly of materials thrown out of the craters of volcanoes; and that the most convincing proofs are visible, in innumerable places, of formerly existing volcanoes, and craters, the eruptions of which have ceased long since, while others have succeeded to them, and are at present in different states of activity.

We know farther, that the action of those subterranean fires is not confined to the derangement of the dry land. The agitations which they produce are in many cases felt

with great violence even at sea: and they are so very extensive, that it is plain they must act at an immense depth below the surface; and therefore far below the bottom of the ocean: a consequence of which is, that they elevate that bottom in many places so as to make it rise above the surface of the waters, where it remains in that elevated state. A great number of islands in different parts of the globe shew the most undeniable proofs that they have had this origin. Such are the islands of the Archipelago in the Mediterranean; the Azores, Teneriffe, and the islands of the West Indies. In all these we find lavas, and other signs of the action of subterranean fire, and in some of them springs of hot water, and sulphureous vapours, breaking out at the surface, shew that the internal fires, although smothered, are not completely extinguished.

We find the same symptoms of internal fire in almost all the great ridges of mountains in the world; and many of the greatest and most active volcanoes are found in those ridges. Such are the Appenines in Italy; the mountains of Sicily; those of France in Auvergne and Dauphigny; the Pyrenean ridge between France and Spain; the immense ridge of South America named the Andes, or Cordilleras; the Russian peninsula of Kamtchatka; the mountains of Iceland. In all these we find either existing volcanoes, or indubitable proofs of their former existence in places where their fires and vapours are not now seen. Even in this country, there are some signs of the former action of subterranean fire. Many gentlemen who have visited volcanic regions, and who have given particular attention to the effects and productions of subterranean fire, find so much resemblance between our whinstone and some of the lavas of existing volcanoes, that they are persuaded our whinstone has been a sort of lava. And, even setting aside that resemblance, there are many other reasons for believing that our whinstone has been a matter melted by subterranean heat *. This, however, does not infer actual volcanoes.

* In digging the cellars and common sewers of the New Town of Edinburgh, freestone strata are found to commence a few feet under the surface, and occupy the whole ridge on which the buildings are erected. A fissure,

Subterranean fires, therefore, and the internal convulsions, the eruptions and explosions which they have produced, have evidently shaken and deranged the materials of the globe in such a very great number of the parts of its surface, that there is very great reason to think all the derangement we find in other places has been produced in this way; and this is now the most general opinion.

The author, however, who has been the most celebrated for his attempt to give a natural history of the globe, I mean the late M. Buffon, formed for himself a different system, which is the most fully displayed in his *Epoques de la Nature*, and in his *Histoire Naturelle*. He admits that considerable changes have been produced by subterranean fires; but is of opinion that the principal phenomena are to be accounted for in another way.

He undertook by his system to point out the very origin of this globe, as well as that of the other planets which revolve along with it around the sun. In this opinion, there was a time when the sun stood alone, without any planet, and was visited only now and then by the comets. One of these, coming too near, was drawn, by the attraction of gravitation, into the body of the sun, and falling obliquely, and with immense velocity, against his surface, dashed off great masses of the melted and burning matter, of which Mr. Buffon supposed the external parts of the sun are composed. These masses were thrown off with different velocities, and flew to different distances, before the progressive motion was overcome by the attraction of the sun. At last, however, the velocities which these masses had received were so much diminished by this attraction, that it became an equal antagonist to them; and these masses thus became planets, and revolved in the orbits in which they still continue to move.

or rent, was found crossing all these strata, to an unknown depth. This fissure is completely filled with whinstone: and in some places, the whinstone spreads out a little above, on each side of the fissure, in the same manner as mortar will spread out over the joint between two bricks when they are pressed together. It appears to have been in a fluid, or at least muddy state, and to have been forced through from below.....EDITOR.

The same powerful impulse by which they were driven off from the surface of the sun, gave each of them also a rotatory motion round its own centre or axis; and being at first liquid or melted matter, the attraction of their parts for one another gave them a spheroidal form, which, at the same time, became a little oblate, by the greater centrifugal tendency from their own centre of some parts of them than of others, in consequence of the rotatory motion they had acquired.

Mr. Buffon further supposed that, in flying off from the sun, they carried with them a part of his atmosphere, which he imagined to be loaded with a vast quantity of vapours, produced from every sort of matter which can be converted into vapour by intense heat, but especially a very great quantity of watery vapours.

The planets continued for some time to revolve round the sun, each of them surrounded with its vaporous atmosphere; for their heat at first was too great to admit of any condensation of these vapours on their surface. But they cooled by degrees, and the first effect of this cooling was, that the external parts of them became solid or congealed. The solid surface, which was formed in this manner, he supposed to have had all the roughness and inequality which is commonly seen on the surface of earthy, stony, and mineral substances, which have been all melted together and congealed. There were eminences in some places, and depressions in others; the matter in some parts of it was cavernous and spongy, and more solid in others: and, by the contraction of the cooling matter, a multitude of rents, and chasms, and vast caverns were formed.

Such, he supposes, was the surface of our globe before the water descended from the atmosphere. This did not happen until the heat was so much abated, that the vapours, which were contained in such great quantity in the atmosphere, began to condense there, and to fall in rain. His lively imagination paints here a dreadful scene, by presenting the immense quantity and violence of those original rains which were destined to fill the whole bed of the ocean. They were attended also with violent explosions, and other effects which

the water produced when it penetrated into the crevices and caverns of the new earth, the heat of which was still so great as to convert very quickly into vapours again the water which first fell on its surface.

This period of violence and convulsion at the surface of the earth, and in the atmosphere, had a certain duration. But the heat continuing constantly to decrease, the watery vapours were at last more completely condensed, and the fluid element gained possession of the surface, and lodged itself in the depressions and cavities which had been formed either originally, during the change of the globe from a fluid to a solid state, or afterwards, in consequence of the convulsions I have just now mentioned. Still, however, the waters on the surface of the globe were for a long time excessively hot, and in some places even boiling. This was necessarily attended with great evaporation, excessive rains, and violent commotions of the atmosphere. And during this period, and the one which immediately preceded it, a great part of the solid and hard materials, at the surface of the earth, were penetrated by the hot water and vapours, and by more active substances, which had condensed along with the water: and thus these hard materials were mouldered down into rubbish and mud, which formed the first soil on which vegetables and animals were to be nourished.

Thus Mr. Buffon thought he had accounted for many of the appearances which are observable in examining this globe.

In order to explain the rest, and, particularly, the formation of the strata, and the abundance of shells and other relics of marine productions which abound in the compositions of many of them, he supposed that the globe afterwards underwent more slow and gradual changes.

His opinion was, that the sea is making a constant, but very slow progress, over the surface of the globe from the east to the west: that this is the consequence of the action of the trade-winds, and of the general direction of the tides in the ocean, which is from east to west. While the trade-winds brush the surface of the sea, they affect the water; and in fact produce a current westward in the Atlantic, which, by its in-

cessant action on the coast of America, has formed, as Mr. Buffon supposed, the great Gulf of Mexico. The water, which in consequence of this, would be accumulated there, had it not found an outlet, is well known to turn back again in a north-easterly direction, and to run in that direction along the coast of North America, where it forms what is called the gulph stream, which is distinguished by its being warmer than the rest of the ocean in that latitude. A current westward, similar to that I just now described, is known to exist also in the Pacific Ocean, and in a part of the Indian Ocean, except where it meets with the coast and mountains of Africa, which reverberate it, and give it a turn the other way. By this continual impression of the sea on the eastern coasts of the continents and islands, Mr. Buffon imagined that the shores are worn away; the sea encroaches upon them, and by degrees takes possession of their place; the materials of them being deposited at the bottom, either in a horizontal position, or formed by the currents and tides into risings and depressions, or long submarine ridges and extensive valleys, (if they may be so called). And thus he imagined the whole face of the globe has been modelled some time or other by the action of the water, and retains every where the relics of the productions of the sea, from which it received its form.

This splendid system has in some parts of it an air of sublimity and grandeur, especially as it is embellished by the eloquence of Mr. Buffon. But it certainly shews a degree of presumption and temerity in the author of it, which excite in the mind very different emotions from those that arise when the phenomena of nature are explained in a satisfactory manner, and with strict attention to principles of reasoning that are well founded and just.

The very first supposition in this grand system is totally inadmissible,.... I mean the supposition that the planets received the projectile motion by means of which they revolve in their orbits, in consequence of their being dashed off from the surface of the sun. According to this supposition, they could have made no more than one very eccentric revolution. As soon as by the constant action of gravitation, they were made

to bend their course again towards the sun, they could not do otherwise than to complete the ellipse, the one half of which they had described in flying off to their greatest distance; and in completing this elliptic orbit, they must necessarily have fallen again into the surface of the sun.

Nor is the other part of his system, by which he endeavours to account for the relics of sea-productions, which occur in every part of the globe, at all satisfactory. We cannot understand by it how the sea should have carried those relics to such a very great height above its present level, as 10,000 feet or more. And had the distribution of land and sea depended on this principle, there would have been no land under the line: All the land there would have been worn away and deposited.

Other attempts have been made more lately to explain this subject, such as Mr. Whitehurst's, in his *Inquiry into the Original State and Formation of the Earth.* Another by Mr. De Luc, of Geneva, in his *Letters to the Queen.* But I cannot enter into all these systems: it would take up too much of our time. They are all conjectures, and liable to great objections. A system has lately been communicated to the public in this country by Dr. James Hutton, which appears to me much more comprehensive and satisfactory than those. But I think I have done enough when I have prepared you for understanding and judging of such attempts, by describing the general facts or appearances to which they refer; while, at the same time, I had an opportunity of explaining some terms which I shall have occasion to use, in mentioning the different states and conditions under which the principal species of earths are found in nature.

And being thus prepared for a survey of the variety that occurs among the earthy and stony substances, we shall next proceed to the examination of them.

When we begin to do this, however, we find the variety of them to be so immensely great, that to give a full account of every particular would take up a great deal too much of your time; and would be otherwise improper here, as being the province of a separate institution,....NATURAL HISTORY. I

shall not therefore attempt a particular description of all the varieties of earthy bodies, but refer you to the authors who have published systems on this branch of knowledge. The most eminent are, Wallerius, Cronstedt, and the late celebrated Professor Bergmann, who made great improvements in our knowledge of many earthy and stony substances, by his accurate and skilful analysis of them. His work on fossils is translated into our language by Dr. Withering. Mr. Kirwan of Dublin has also published a mineralogy, or systematic arrangement and description of fossils, in which he takes advantage of the lights which have been thrown on this subject by Bergmann and others; and has added much from his own experiments, so as to give in his book the most complete enumeration and description of fossils that has yet appeared.

These authors, and my colleague, the Professor of Natural History, will give you information of all the particulars. In this course we have not time to follow the subject so far, but must confine our attention to the most remarkable and distinguished chemical varieties which occur in nature.

These, I think, may be referred to five orders; the denominations and characters of which I shall now give you:

The *first* of these I shall call the order of the ALKALINE EARTHS. They have been commonly called ABSORBENT EARTHS. The state in which these are found in nature, and that under which they are commonly called absorbent earths, is not a state of purity, but of combination with a particular substance with which I shall soon make you acquainted. But as there is hardly any example of their being found in a pure state, and as the state just now mentioned is the state of them to which we are most familiarised, I shall consider and describe them, first, as appearing in this state, and afterwards shew how we render them pure, and what properties they have in their state.

The characteristic of them in their natural state is to effervesce with acids. They appear under many different modes of concretion; from that of loose earth to the hardness of stone; but are never so hard as to scratch glass, or give fire with steel.

On the contrary, a knife can be made to scratch them, or make an impression on them.

The *second* order I call the PLASTIC EARTHS. They are commonly called the ARGILLACEOUS, or CLAYEY.

These, when mixed and kneaded with a moderate quantity of water, become a tough and ductile paste, which is easily modelled into any form, and which, if it be afterwards well dried, and then burned with a strong fire, contracts in its dimensions, and becomes compact and hard.

The *third* order I call the HARD earths or stones. They are commonly called the SILICEOUS, or FLINTY.

They are, in general, stony masses of a larger or smaller size, the most eminent quality of which is hardness. Their hardness is such that they scratch or cut glass, and give fire with steel. And when a knife or file is applied to them, it does not make the least impression. It is also a general quality of them to resist the most violent heat of common fires and furnaces without being melted.

The *fourth* order I name the FUSIBLE.

These are commonly stony concretions which have considerable hardness. Some are so hard as to scratch glass, and give fire with steel; but they are not quite so hard as the hard stones. Their most remarkable quality is *fusibility*, or a disposition to be melted in a strong fire.

The *fifth* order I name the FLEXIBLE.

They are concretions of a scaly, a plated, or a fibrous structure, easily divisible into parts which are *flexible*, and often *elastic*. They are so soft as to be easily scraped with a knife; and do not suffer much change of their appearance and qualities when exposed to a moderately red heat.

We shall now, therefore, proceed to describe the earthy and stony bodies which come under these several divisions; and begin with the first, the alkaline earths, or, as they are commonly called, the absorbent.

GENUS I.

ALKALINE EARTHS.

OF the alkaline earths and stones there are several kinds, which, in their natural state, are mild insipid substances: And it is difficult to perceive in them, by experiments, any sensible degree of solubility in water.

Their characteristic in that state is, that they effervesce with acids, and are dissolved by those salts: and such is their nature with regard to acids, that they produce similar effects in mixture with them to what the alkalis produce: Upon which account I call them ALKALINE EARTHS. Thus, we find that in general they unite with acids in one certain proportion only. If there is too much of the earth, it is not all dissolved; if too little, it is united with a part of the acid only, the rest of the acid remaining free. There is, therefore, the same mutual saturation here as with alkaline salts. The compound produced is likewise analogous to a neutral or compound salt, and in most cases dissolves easily in water. The acid is rendered less volatile by its cohesion with the earth: its acrimony is greatly diminished, and its acid taste is not perceivable. And further, these earths attract different acids with different degrees of force, and this in much the same order as that in which they are attracted by alkalis: so that a compound earthy salt, which contains the nitric acid, can be decomposed by the vitriolic acid; one that contains the muriatic acid, by vitriolic acid or nitric acid; and one that contains the acetous acid, by any fossil acid, &c.

They, therefore, resemble the alkalis, both in their attraction for acids, and by many particulars in the nature or manner of this attraction. But, on the whole, its force is less

than that of the alkalis. Most compounds of acids with the alkaline earths may be decomposed by the alkalis, and especially by the fixed alkalis. These unite themselves to the acid with more force, and cause the earths to separate and fall down in the form of white powder.

Such is the general nature of these earths. Let us now attend to the different kinds of them.

SPECIES I.

CALCAREOUS EARTHS.

The principal species, which occurs the most abundantly in nature, and is at the same time the most useful, is called the Calcareous Earth. It is distinguished from other alkaline earths by the effects of a moderately strong heat, which changes it into common Quicklime.

It is found in a variety of forms or conditions,

1*mo*, Very numerous and extensive strata are composed entirely, or principally, of this kind of earth. Such are the Marbles, Limestone, and Chalk, which differ from one another only by the degree of purity in which they contain this earth, or by the manner in which it is concreted together. Both chalk and marble are often burnt to make lime, and afford it of excellent quality. Marbles and limestones are found in all parts of the world; and form numerous and extensive strata,....and so does chalk, in some countries.

2*do*, This earth is often found in veins, or filling up rents and crevices in rocky mountains, and hard strata. In this state, this earth is called Spar, Spathum, or, more particularly, Calcareous Spar, to distinguish it from some other stony substances called spars, on account of a resemblance of form, and of their native situation, but which are of a different nature. Its appearance in this state is that of a whitish stone, more or less transparent, and which, when broken in pieces by the strokes of a hammer, is shivered into fragments of a rhomboidal figure. In some veins it is perfectly transparent, and is then called Iceland Crystal. This has caught the

attention of opticians, in consequence of its refracting light in a particular manner, so as to make objects appear double. In veins that contain calcareous spar, wherever a vacuity remains not filled, the inner surface is beset with crystals of the same matter, which are columnar or pyramidal; and sometimes composed of two pyramids joined together, and forming one crystal.

3*tio*, It is commonly this earth which forms the stony masses called STALACTITES. These are stony concretions, formed chiefly in the roofs of subterranean caves, and cavities of some extent. They are produced by waters which contain a small quantity of this earth dissolved in them, and which, penetrating into such caves, drip from their roofs, or ooze out from their sides and floors, and deposit this earth. While it separates slowly from the water, it concretes, and forms gradually large pendulous cones and columns, and a variety of fantastic figures; which are found hanging from the roofs, or projecting from the sides and floors of such caverns, and somewhat resemble the icicles more quickly formed from dropping water in frosty weather. The famous cave at the Peak, in Derbyshire, is a well-known example of this. There are similar examples near Slains Castle, north of Aberdeen, and in many other parts of the world.

The waters which produce this effect are called PETRIFYING WATERS, on account of their forming these stony concretions, and sometimes penetrating and encrusting vegetable and animal substances with the same stony matter, so as to convert them, as it were, into stone. Such is the spring called the Dropping-well, at Knaresborough in Yorkshire, which has formed a sort of quarry of stone, by petrifying the moss and other vegetables which its water passes over. There is a similar spring in the Duke of Hamilton's deer park, and at Matlock in Derbyshire.

Waters of this kind are very common in Italy, in consequence of the great quantities of limestones and marbles with which that country abounds. There is a marsh not far from Rome, the water of which incrusts the reeds which grow in it.

And by means of these waters they have made very pretty medallions.

The formation of these calcareous petrifactions and stalactites, shews plainly that this earth is in some degree soluble in water: and we have many other proofs of this fact. Calcareous stalactites and incrustations, and the petrifying waters which produce them, are in general found in countries which abound with limestone or marble, or other forms of the calcareous earth. Wherever any parts of the calcareous strata are exposed to the rain, they shew most evident signs of their being subject to a slow dissolution and waste. (A calcareous mass at Lord Elgin's quarry is dissolved at top, and incrusted at the bottom). And when more water gains admittance into rents and chasms of such strata, it gradually enlarges the passages through which it runs, and forms at last extensive caverns, in which it is common to find abundance of stalactites. The quantity of this earth, however, which pure water can dissolve, is exceedingly small, as I have learned by experiment. But water sometimes contains other things combined with it, which increase its power as a solvent of this earth.

4*to*, The stony shells of all crustaceous animals, among fish and reptiles, from the coarsest to the pearl, are made up of this earth, and a small quantity of animal glue. And of the same materials are egg-shells formed, as also those marine bodies, which, on account of their resemblance to the external form of plants, with the hardness of stone, were formerly called LITHOPHYTA, or stony plants,....as coral, and a variety of other bodies of the coral kind, or allied to it, which later naturalists suppose to be the work of animals, or to be produced in the same manner as shells. And a late author, Pallas, who has written particularly upon this kind of productions, represents them in a still more curious light. Hence they are called ZOOPHYTA, or animated plants. Whatever may be their nature, and in whatever manner they may be formed, they are composed, like the shells, principally of calcareous earth: and there is a very great variety of them in respect of form and appearance. Some are spread like a crust upon stones and other solid bodies, and full of microscopic pores,

inhabited by animals,....Millepora. Others are protuberant masses; others an assemblage of pipes,....Madripoda. Others are branched,....Corals. These are full of animals.

Under these four forms now described, the calcareous earth has generally a great degree of purity; and in some of them, perhaps, is perfectly pure,....that is, unmixed with any other earth. But there are also some fossil earths, which, though they be not composed entirely of calcareous earth, but, on the contrary, contain sometimes but a moderate portion of it, deserve, however, to be mentioned here, on account of their usefulness and importance. These are the earths called Marles, which have been long successfully employed as manure to improve soil. Every substance to which the name of marle is properly applied, and which proves of general usefulness as a manure, contains more or less calcareous earth; and is useful and valuable in proportion to the quantity it contains.

Marles are commonly divided into three kinds,....Shell Marle, Clay Marle, and Stone Marle.

1*st*, Shell marle is composed of the shells of shell-fish, or other crustaceous aquatic animals, lying together in immense quantities. Many are entire, but in general they are decayed, and mostly mouldered down to dust, and intermixed with more or less sand, or other earthy substances. When we examine this matter, as occurring in different places, it may be distinguished into two kinds,....fresh water marle, or bog marle, and sea-shell marle. We have an example of bog marle in the Meadow, composed of the shells of the small fresh water wilk or snail, which multiply greatly in lakes or ponds, or brooks of fresh water, and of other shells, which are gradually deposited in great collections by the water. The other kind of shell marle, the sea-shell marle, constitutes much greater collections, which are found in many places, though at present far removed from the sea. One of the most noted examples has been described by Mr. Reaumur, in the Memoirs of the Academy*.

* Of the Fahlun or marle of Touraine. This district, of 80 square miles, is more than 36 leagues distant from the sea, and is every where filled with

2*dly*, Clay marles consist of earths of different colours, which more or less resemble, and actually contain clay. But with it some calcareous earth is mixed, in fine powder like chalk.

3*dly*, Stone marles are of very great variety in colour and appearance. They are harder and more stony than clay marles; and that is the only distinction between them. But they differ from masses properly stony in this, that by being only a few weeks or months exposed to the air, they split into pieces, and crumble down into earth, or a matter like clay. Some, however, take a long time to break down in this manner: and there is all the variety possible in this respect between them and the clay marles. This disposition to moulder down by the weather, depends on the admixture of clay, which they contain. A consequence of the gradual, though very slow dissolution of this earth by water, has been observed in the strata of hard marles. It has been found by experience, that such strata do not contain any calcareous earth where they crop out, on the surface of the ground, nor even at the depth of a few feet below this. Many gentlemen who were in possession of a stratum, which they knew, from the neighbourhood, to be a rich stone marle, have, without fear, expended great sums of money, and covered much of their land with this crop marle. They not only lost their money, but, in many cases, spoiled their land, by filling it with a hard baking clay. This effect upon beds of marle is without exception: and it is even found that the upper plates of single strata of limestone are deteriorated in the same way. This fact also explains, by the way, the wearing out of lime used as a manure upon land.

marle. It is found about eight or nine feet from the surface, and they dig it to the depth of 20 feet. The marle is still deeper, but it is too expensive to follow it. One gentleman, from curiosity, penetrated 18 feet, and did not know how much farther it might extend. Suppose it is of no greater depth, it would contain above 130 millions of cubic fathoms. It is totally composed of shells, some of which are entire, but they are generally decayed, or broken into fragments, and mixed with other marine productions, such as coralines, millepores, madrepores, &c.

When we now examine with attention many of these natural collections of this sort of earth, we are led to a conclusion which may appear surprising at the first hearing of it; but which is founded on a multitude of the most authentic facts.

The inference I mean is, that all the large collections of calcareous earth have derived their origin from shells and lithophyta, or that they were once in that form. The proofs of this are so numerous and striking, that they cannot be resisted.

1. Beds of sea-shells, or other calcareous productions of the sea, are found in many parts of the world, of great extent, and in all the different states of decay.

2. We find abundance of shells, or fragments of shells, and of zoophytes, in the greatest number of the calcareous strata of marbles, limestones, and chalk; which are the greatest collections of calcareous earth.

We do not find shells in calcareous spar, nor in stalactites; but it is evident that these forms of the calcareous earth have been completely fluid, so that all the organic structure of the original matter is necessarily lost.

There are also many marbles and limestones, in which we do not find any of the appearances I speak of. But this too can be explained, by examining their structure or aggregation, which shews that the matter of them has been dissolved or liquefied by other operations of nature*. Another cause of the non-appearance of shells and lithophyta in some collections of calcareous earth is, that the shells have been broken and worn down into fragments like sand, or even reduced to powder, by agitation and attrition, upon the coasts, or by other causes. This seems to be the case of chalk. There is another example of this kind in England, in the Bath stone and Portland stone, which are calcareous: and similar stones occur in many parts of the world. There are some few entire shells found in these stones; but the greater part of it does not exhibit any.

The abundance and great extent of the strata of calcareous earth are, therefore, a proof of the great antiquity of this globe, and of the great changes which have happened in its surface.

* The rapidity with which the coral rocks in the Pacific Ocean are formed, by the little animals, is altogether astonishing; and it is evident to the sight.

In some few places the bones of land-animals have also been found, in very considerable quantities, mixed with calcareous matter; as in Dalmatia, and some islands of the Adriatic; at Gibraltar, in Spain, and in France *.

In whatever condition the calcareous earth is found, it is easily distinguished from other earthy substances, by effervescing with acids; and, when it is not very impure, by becoming common quicklime, when exposed for some time to the action of a strong fire.

In making the trial with acids, however, it is necessary that the person who makes it should understand it well; as I have known many who never had seen or attended to real effervescences, imposed upon by the appearance of it. I have often had earths sent me by farmers, or country gentlemen, as calcareous marles, which they assured me effervesced, or fermented with vinegar, and dissolved in it too; but which, when I tried them, shewed not the smallest effervescence. Upon desiring them, therefore, to shew me the fermentation and dissolution they spoke of, I found that they had thrown the earth dry into the vinegar; and that what was taken for effervescence, was the expulsion of a small quantity of common air which was contained in the pores and vacuities of the dry earth, and which arose slowly in little bubbles, when the fluid was sucked into these pores; and the supposed dissolution was the diffusion of the earth. Remember, therefore, always to soak and moisten with water before the acid be applied.

In describing the properties of the objects of chemistry, I begin commonly with the effects of heat. But, as this earth, in consequence of the state in which it is found in nature, undergoes a very great change in all its chemical relations by the action of a strong fire, I shall first notice its properties with regard to mixture, in its ordinary or native state.

* *Memoires sur les ossemens fossils qui ont appartenus à des grands animaux: Observations de Physique, Mai* 1781. The author is of opinion that they are not the bones of elephants, but of some large aquatic animals which have inhabited the lakes and great rivers, or rather the sea. His observations render this very probable. The memoir is curious, and deserves a careful perusal.

I have already remarked that the action of acids on it is very similar to their action on alkaline salts. Let us, therefore, attend to the manner in which it unites with each of the different acids.

The first of these, therefore, the sulphuric acid, attaches itself to this earth with great rapidity, and violent effervescence. Thus, when we throw powdered chalk into diluted sulphuric acid, violent effervescence is produced: but the chalk, however, is not dissolved. It renders the liquor thick and muddy; and, if allowed to rest, falls to the bottom in the form of a sediment much more bulky than the chalk alone. The reason of this is, that the compound produced by the union of the sulphuric acid with calcareous earth has very little solubility in water. It requires a very large quantity of water to dissolve it, 500 times its weight at least. Hence, not finding water enough in the mixture, the greatest part remains undissolved, and is more bulky than the chalk, because it consists of that chalk and the salt which it has formed with the sulphuric acid. This compound was formerly called GYPSUM OR SELENITES, or the Selenitic Salt. The name now given to it, by the French chemists, is SULPHAT OF CALCAREOUS EARTH, or SULPHAT OF LIME. It is formed naturally in considerable quantities in the bowels of the earth, and is valued on account of several useful properties which belong to it. These we shall mention more fully afterwards.

Although this compound is difficult to dissolve, and requires much water to its dissolution, it can, however, be completely dissolved, when enough of water is applied to it, viz. one ounce for each grain. And when the water is evaporated, the compound concretes into numerous slender and small crystals, as fine as hairs, which subside and form a white sediment. A small portion of this salt is the general impurity of those spring waters which are called hard waters.

Such is the action of the sulphuric acid upon this earth, in the form of powder. But it does not operate upon it so readily in its solid and compact form, because the surface is neutralized, and protects the interior parts from the corrosion of the acid.

None of the other acids, hitherto described, form insoluble or difficultly soluble compounds with this earth, except the tar-

tarous acid, which forms with it the compound called by Dr. Scheele *selenites tartareus*, now named the tartrite of lime *.

The other acids, viz. the nitric, muriatic, and acetous acids, form with it very soluble compounds; and all of these acids too, as I before observed, are attracted by the earth in the same order as they are attracted by the alkali: and therefore, if the sulphuric acid be added to the solutions or compounds formed by any other acid, it immediately disengages the other acid, and unites itself to the earth, in consequence of its stronger attraction, forming with it the sulphat of lime already described, which therefore precipitates or falls to the bottom.

The calcareous earth not only has a stronger attraction for the sulphuric than for other acid, but, further, some experiments shew that it has a greater partiality (so to call it) for this acid above others, than the alkalis have. This I think appears from what happens when we mix any compound salt containing the sulphuric acid, with a compound or solution of the calcareous earth in any other acid than the sulphuric. Thus, if we mix a solution of Glauber's salt, or sulphat of soda, in hot water, with some of the solution of calcareous earth in nitric acid greatly diluted, the mixture will become muddy, and deposit a sediment. There is therefore a double elective attraction. *(See Bergmann.)*

There are only two of the acids already described, which, as I learned by some experiments made on purpose, have not power to act on the calcareous earth in its natural state. These two acids are the sedative salt or boracic acid, and the sulphurous acid *(acidum sulphurosum)*, or acid of sulphur in its volatile suffocating state. And to these we may add sulphur itself, which was spoken of in treating of the sulphuric acid. These three chemical bodies, the boracic acid, the sulphurous acid, and sulphur itself, are but weakly attracted by alkaline substances in general.

With regard to the other class of simpler salts, the alkalis shew as little disposition to act on calcareous earth as on one another. The only observation that belongs to this head is, that

* It forms insoluble compounds also with the phosphoric, malic, and some other acids.—EDITOR.

they have a stronger attraction for acids ; and when mixed with solutions of the calcareous earth, immediately precipitate it,.... uniting themselves to the acid in its place. And the effect is the same, whether we use a fixed or a volatile alkali in their ordinary state. It should also be remarked, that when an alkali is employed to dislodge calcareous earth from an acid, *we have no effervescence.*

Such is the relation of the calcareous earth to the acids and alkalis.

Of the compound salts, none are affected by it except tartar, and the ammoniacal salts. Tartar, when boiled with it, is neutralized, or, to express it more properly, it is deprived of its superfluous acid. And the ammoniacal salts can be decompounded by it, but only when it is assisted by heat.

If, for example, we mix chalk with common sal ammoniac, ...the muriat of ammoniac ; either taking this salt as dissolved in water, or in the form of very fine powder, we cannot perceive any change or effect produced, however long they remain simply mixed together. But if they be mixed in the form of fine powders, and we then apply heat to this mixture, as soon as the heat increases to a certain degree, the ammoniacal salt begins to be decompounded. The acid of it is joined to the calcareous earth ; and the volatile alkali arises into the receiver in large quantity, and forms a very solid saline crust on its internal surface. The process is as easy as the distilling of water. The vessels are to be luted with chalk made into a thin paste, with mucilage or gum-water. The heat may be slowly raised till the sublimation begins to dim the vessels, and then kept in that state ; and the operation stopped whenever a dimness appears in the top or neck of the retort. This indicates a commencing sublimation of the sal ammoniac, if too little chalk has been employed.

This process for decompounding sal ammoniac by the action of chalk and a strong heat, is often performed in England, to obtain a volatile alkali for the purposes of medicine. The alkali thus obtained is remarkably solid and dry, and in larger quantity than that which is procured from the same quantity of sal ammoniac, when it is decompounded by a fixed alkali.

These are the properties of the calcareous earth with regard to mixture in its natural state.

But it suffers a remarkable change by the action of fire on it, which is next to be described.

If it be exposed to the action of a strong red heat for some time, it becomes what is well known by the name of QUICKLIME. For this purpose, the marble, limestone, or chalk, is broken into pieces of small size, and piled up in a kiln built in the form of an inverted frustum of a cone, mixed with a proper quantity of fuel, taking care to have a sufficient quantity of fuel at the bottom, to raise a heat in the beginning; and also taking care that the whole may be so piled up, with spiracles properly conducted through it, by laying the materials open in those places, that the heated air may have a current pretty equably distributed through the whole mass. This soon kindles the interspersed fuel all over the kiln. And it would soon become so hot as to risk the melting of impure limestone, were it not checked by contracting the apertures by which the air enters in below, or (if it be a simple clamp kiln) by covering the whole at top with earth. The proper degree of heat must be learned by trials; it being different according to the nature of the limestone and also of the fuel. Some pit-coals have a great tendency to vitrify even the purest limestone. And limestone containing iron in any state is very much disposed to vitrification. It is only experience which can teach how much fuel is required for raising the due heat, and for continuing it till all shall be calcined. If it be a clamp kiln, the fire is allowed to burn out: and the quicklime is taken out when the kiln is sufficiently cooled. But limekilns are more artificially constructed, so that the work is never stopped. The calcined lime is taken out at an opening properly contrived below, by which the whole subsides: and the limestone is continually added above, mixed with baskets of fuel. The fuel is entirely consumed in the lower and narrower part of the cone. And the great heat of the glowing blocks of quicklime maintains the current of fresh air through the interstices, and causes it to arrive at the unconsumed fuel above, in a state fit for continuing the combustion. The consumption of the fuel is vastly slower than would happen were it interspersed in the same manner

among lumps of free-stone or pebbles, for reasons which you will soon understand.

When we want to prepare a small quantity for experiments, we just mix it with abundance of fuel, in any ordinary furnace, and urge it with the greatest heat, which will not vitrify it when impure. Pure limestone, marble, or chalk, may even be calcined in a crucible, without touching the fuel: but this requires a very great heat, long continued.

Quicklime has a number of qualities different from those of the natural calcareous earth. If it have been hard before, it becomes more friable and porous, especially the purest kinds. It also loses a very great part of its weight, 40 per cent. in the purest kind. This great loss is well known to those who have occasion to bring lime from a distance; and it is the best mark of complete calcination. Further, from being a mild, insipid, and inert earth, we find it now an active and acrid substance, like the alkaline salts. It shews a very considerable degree of activity in mixture with a variety of other bodies. Applied to the tongue, it is extremely acrid, giving a taste very much like an alkaline salt. If left any time upon a moist succulent part of animal or vegetable substance, it either corrodes and dissolves it to a pulp, or weakens the cohesion of it to a great degree: and it has the same effect on the most solid and firm parts, if it be made into a soft paste with water before it is applied. This shews that it has a strong chemical attraction for the matter of those substances. We discover in it also a strong attraction for water. This attraction is one of the most remarkable qualities by which it differs from calcareous earth in its native state. Thus, when we pour water upon the lime, a quantity of it is quickly sucked up into the pores of the stone: and, after a short time, the masses of quicklime which we have moistened begin to grow warm, and to smoke. They swell, split, and crumble down into pieces: and these are affected in the same manner, until the whole, in a few minutes, is converted into a subtile white powder, greatly more bulky, and which, if too much water have not been used, is perfectly dry and dusty. While this is going on, it becomes so hot, that a part of the water is evaporated in boiling hot steams: and if the quantity of lime so wetted at

once is much greater than this, the heat increases to a degree capable of inflaming combustible bodies. If a stick, for example, be thrust into a large heap of it, the extremity will be burnt to a black coal. Leaky ships have sometimes been unfortunately set on fire at sea by a cargo of quicklime. This is so well known, that when they venture to load with it, they take every precaution to prevent such a misfortune.

As soon as the lime has been thus reduced to a subtile powder, by a sufficient quantity of water, no more heat is produced. It cools and does not produce heat again if mixed with water. It is called SLAKED LIME,...CALX EXTINCTA. If we weigh it, we find it considerably heavier than before the water was added to it. This addition of weight is from a part of the water now closely united with it; every particle of the lime having its due proportion. The water thus united with the lime is retained by it with a strong attraction; and cannot be separated again without a red heat. Being in a solid form, the emersion of the latent heat, which occasioned its fluidity, is the source of that great heat which is produced during the slaking of the lime, and affords one of the most remarkable instances of this emersion. But if such a heat be applied to the slaked lime in a retort and receiver, we recover the water in its former state. The lime from which it is separated becomes quicklime again, and is disposed to produce the same effects with water as before. These effects, therefore, evidently depend on a strong attraction which the lime and water have for one another. And slaked lime is lime saturated with water, or combined with as much water as can unite with it, so as still to form a dry compound. The consequences of this union with water, however, are not such as to take away the attraction of the lime for other substances. It has the same acrid taste as before, and the same, or even a greater corrosive and dissolving power, with respect to a variety of different substances. Nor is its attraction for water saturated by this solid combination. It still manifests a solubility in that fluid, perfectly resembling, in this respect, the relation of crystallizable salts to water. They, after having combined with a certain quantity, are dissolved in a larger quantity. This solution is perceived when we mix slaked

lime with a much larger quantity of water, or dilute it largely in water. If we examine this water, we shall find that it has either dissolved a part of the lime, or extracted something from it, so as to form a clear solution like that of the alkaline salts, and resembling them much in taste.

This is the fluid called LIME-WATER, the nature and best preparation of which was, some time since, a subject of much disputation in this place. The general opinion was, that the production of the lime-water depended on an active and subtile principle, extracted by the water from the lime, which was imagined to contain only a small portion of it; and that the lime could therefore make only a moderate quantity of good lime-water, such as 10 or 12, or at most 20 times its weight.

It is known now that a much greater quantity of good lime water can be made of lime,....that is, of a good quality; perhaps 300 or 400 times its weight. And the process for making good lime-water is so simple, that it was thought unnecessary to insert it in the former editions of the Edinburgh Pharmacopœia. But a process was given for it in the last edition, viz. 1*mo*, Slake the lime with a small quantity of water, about one-fourth or one-third of its weight, and let this be done in a vessel of earthen ware or glass, keeping it covered while the lime is slaking: 2*do*, Pour on it 30 or 40 times its weight of more water, and after agitating to diffuse the lime through the water, cover up the vessel again. The agitation being repeated afterwards 10 or 12 times to promote the dissolution, we may then allow the remaining lime to subside, and filtrate the lime-water, to have it clear. Thus lime-water is made as strong as possible. But, in its strongest state it contains but a small proportion of the lime, or limy matter. I made experiments to ascertain this point; and found, that the strongest lime-water we can make, does not contain a larger proportion of lime than one part in 500 parts of the water. It has, however, a pungent, acrid, disagreeable taste, resembling that of the alkaline salts; and has also the power to change the vegetable colours like those salts. A moderate quantity produces first a sea-green; a little more, a grass green; and more still, a yellow, or fillemot, attended with muddiness; the colouring matter being

corroded and destroyed. It is the most transparent fluid known.

Such are the effects of water mixed with lime in different ways.

When we next try the effects of acids, we find that lime is still more disposed to unite with these, than the calcareous earth was when in its natural state. It unites much more quickly with the vegetable acids. Distilled vinegar, which dissolves the calcareous earth but slowly, dissolves lime readily and quickly. And when we boil lime with a solution of tartar in hot water, the lime takes to itself the whole acid of the tartar, not the superfluous acid alone, which only is separated from the tartar by the calcareous earth in its natural state.

Further, lime can be joined with the boracic and sulphurous acids, so as to form a borat and a sulphite of lime; neither of which can be produced from the natural calcareous earth. And when we mix lime with the muriat of ammonia, it shews such a strong propensity to unite with the muriatic acid, that it decompounds the muriat the moment they are mixed together, not requiring the assistance of a strong heat, which is required by the natural calcareous earth.

Beside the quickness and facility with which lime decompounds the ammoniacal salts, the volatile alkali, which we obtain from the mixture by distillation, is in an uncommon and very remarkable state. When heat is applied, this alkali arises in vapours which are in the highest degree elastic, pungent, and penetrating. They cannot be condensed without the aid of some water to repress their volatility by its attraction. Were we to neglect the proper application of water to this mixture, for the purpose of condensation, this alkali would continue in the state of an incondensible elastic fluid or gas. This is what Dr. Priestley called alkaline air, and made the subject of many experiments. One of them is very pretty and amusing. If some of this vapour be mixed with that of the muriatic acid, we have immediately a precipitation of sal ammoniac. If this experiment be made in the modern pneumatic apparatus, a disagreeable accident sometimes happens. The vapour of either being suddenly mixed with the other, in the upper part of a jar, standing in

water or mercury, the whole collapses in an instant, and the water or mercury dashes against the top of the jar with such force, as to beat it up to a considerable height, and with risk to the operator.

When we do employ water, though in no greater quantity than what is absolutely necessary, no part of the alkali is ever condensed into a solid form. It always constitutes, with the water, an highly pungent, acrid, volatile, alkaline fluid.

A volatile alkali is ordered to be prepared in this state, in both the London and Edinburgh Pharmacopœias. It was formerly named *Spiritus Salis Ammoniaci cum calce vivâ*. Now it is named *Aqua Ammoniæ puræ*, for a reason which you will soon understand.

Various processes have been recommended, by different authors, for preparing it in the best and most convenient manner. Some have advised to put the quicklime into the retort unslaked, and then pour on it the sal ammoniac dissolved in water. But this mode is inconvenient, causing sudden and violent heat, which makes the volatile alkali rise so impetuously, and in such incoercible vapours, that the greater part of it is lost. In distilling it, a very gentle heat is absolutely necessary, that time may be allowed for its condensation, by means of its union with the water that is to assist in condensing it. It requires much caution and patience to accomplish this; because the alkali rises in vapour more readily than the water, and does not carry off with it a very considerable portion. And, should we attempt to promote the condensation by putting water into the receiver, we shall still be disappointed; because the alkali, combined with the water merely sufficient for its condensation, forms a fluid considerably lighter than water, which will, therefore, float on the surface of that in the receiver, and this, being already saturated with alkaline vapour, will condense no more. I mention this particularly, because similar things frequently occur in distillations; and must be carefully attended to, to avoid accidents. Mr. Woulfe's method obviates this difficulty: but is best adapted to the distillation of large quantities.

After having tried different methods, I now practise one which does not require this complicated apparatus, and serves very well for preparing a small quantity of this alkali. Having put the sal ammoniac, in lumps, into the retort, pour on it a mixture of an equal quantity of lime, and thrice its weight of water, stirred till uniformly mixed, and kept till cold. The volatile alkali begins immediately to be separated in pungent vapour: but, as there is enough of water present to repress and moderate its volatility, the vapours are not troublesome. Now apply the receiver, which has first been well warmed, to rarefy the air, and thus expel a part of it; and immediately close up the joining of the two vessels, so as to make that joining perfectly air-tight. This is done by first applying common putty, made of chalk and lintseed oil. But as this paste, though impenetrable to air, is in some degree soft, and would be forced open by the pressure of the elastic vapour from within, we may secure it from this accident by putting over it another luting, which will soon grow quite firm and hard, and will bind the putty strongly in its place. This other luting is a mixture of chalk and gum-arabic,.... nine parts of the chalk to one of the gum. It must be made into a fluid paste with water, and spread on slips of paper, and these put on the joint. Being then brought into close contact with every part of it by a ligature or bandage, it makes the joint so close and strong, that the vessels would be burst open in any other part of them sooner than in this. The joining being thus made perfectly air-tight, it is evident that we must be very cautious in applying the heat to perform the distillation. Too much heat would certainly burst the vessels, by giving too much elasticity to the air and vapours: and it would also bring over too much of the water, supposing the vessels were strong enough to withstand it. We, therefore, apply a very gentle heat, and apply it so long only as may be necessary for obtaining the product in proper quantity. Thus the alkali, and a portion of the water, will distil over together, slowly and imperceptibly, until we have enough of it; which will be the case when the heat shall have continued 24 hours. *(See note 35, at the end of the volume.)*

Beside this action of quicklime on muriat of ammoniac, and other qualities of it which we mentioned, a further

particular, which shews that its powers, as an alkaline substance, are increased, is its effect on sulphur. It is capable of uniting with it in the dry way, by mixing it in powder with the sulphur, and applying such a heat as converts the sulphur into vapour, or melts it.

But a more convenient way is to join them in the way of solution, or *viâ humidâ*. Equal weights of sulphur and quicklime must be mixed in a flask, and a quantity of water added boiling hot. The mixture must be boiled for some time, and then more boiling water added, and the boiling repeated. After standing a proper time for subsidence, the clear liquor must be decanted into a phial, which must be carefully stopped. This gives a perfect compound of sulphur and lime.

The compound we thus obtain is called the sulphuret of lime,....*sulphuratum calcis*. It is incomparably more soluble in water than the lime alone : and it has the same yellow colour and disagreeable odour, that is so strong in the compounds of sulphur with alkaline salts. The union of the two ingredients of this compound is similar to that of the alkaline sulphuret. It is decompounded by exposition to the air : and in its place we obtain gypsum or selenite, composed of the sulphuric acid and calcareous earth. Moreover, this decomposition is accompanied by the absorption of oxygenous gas, leaving only the mephitic air of Scheele, or the phlogisticated air of Priestley. Indeed, it was with this sulphuret that Scheele made his first experiment. Like the alkaline liver of sulphur, too, it is decompounded by any acid. The nitrous acid does not disengage from it the hepatic or stinking gas, without some particular attentions, which shall be mentioned afterwards.

All these facts and experiments shew that lime has a stronger tendency to unite with other bodies than the calcareous earth has when in its natural state.

The most remarkable property of lime appears in the change which it sustains by mixture with the alkaline salts, and the change which it induces on them. This constitutes the chief difference between quicklime and the natural or crude calcareous earth. If we mix it properly with an alkaline salt, the lime immediately loses its activity and

corrosive nature, and becomes quite mild, insipid, and no longer soluble in water. To illustrate this, we may notice the effects of an alkali upon lime-water. This fluid, as I observed before, contains but a small proportion of limy matter dissolved in the water, about one grain to the ounce. Yet, upon dropping into it a small quantity of dissolved alkaline salt, it instantly becomes muddy, and deposits the lime in the form of mild insipid calcareous earth. And the effect is similar when we use, instead of lime-water, a muddy mixture of lime and water, or a quantity of water with more lime in it than it can dissolve into lime-water. Provided we add to such a mixture a sufficient quantity of the alkaline salt, both the dissolved part of the lime, and that which, for want of a sufficient quantity of water, is not dissolved, will be immediately rendered mild, inactive, and incapable of being dissolved by pure water.

Here is, therefore, a sudden restitution of the lime to its original state of a mild, inactive, insoluble earth; for when we collect and dry the mild earth thus obtained, we find it has every property of the calcareous earth, in its natural or ordinary state, and may again become lime by calcination.

But, further, when this change is produced in the lime, the alkali suffers one which is as remarkable. This is perceived when we separate the alkaline liquor again from the lime, and examine this liquor, or by evaporation obtain the alkali again in a dry state.

We find it incomparably more fusible than before. It is melted long before the heat of it is raised to the degree of ignition.

Moreover, it becomes more susceptible of vaporisation. A very sensible quantity is carried off by hasty boiling the solution of it in water: and if long continued in a red heat, with spongy matters to prevent its melting, it evaporates very fast, and is lost.

We find also that its acrimony, or activity to dissolve different substances, is very greatly increased. In the treatment just now mentioned,....the melting of it by heat,....it often happens, that by raising it to a red heat, it dissolves the earthen vessel in which it is melted.

Alkali, rendered more active in this manner by lime, is much employed in some of the arts; and, being also used for some purposes in medicine, is ordered to be prepared in both our pharmacopœias.

Three parts of alkaline salt, and four parts of perfect quicklime, are to be suddenly mixed in twice their weight of water. This will produce great heat and ebullition. The vessel must be covered, and the mixture agitated repeatedly. It must then be poured into a filtrating funnel, which is set into a phial, or other vessel, proper for holding the lixivium. After it has ceased running through the filtre, water must be poured on above, and allowed also to run through the filtre, till the whole lixivium is about thrice the weight of the salt and lime. It will be without colour or smell, if these have been pure, and must be kept in bottles closely stopped. The water may be expelled by heat. When the boiling has ceased a little while, the purely saline part remains fluid like sluggish oil; and the vessel is, at this time almost red hot. When poured out on an iron plate, it quickly congeals; and may be divided, while very hot, into pieces fit to go into the mouth of a phial, where it may be kept shut up from the air. This is the *alkali causticum acerrimum* of the dispensatory. The *causticum mitius* is made by pouring the melting salt on quicklime, and mixing before it cools.

The advantages of this process are, *1st*, The lime, being slacked with unusual violence, is the more subtilely divided. *2d*, The heat promotes the action of the lime and alkali. *3d*, The small quantity of water used also promotes their action; the lime not having room to subside.

Here I must mention a circumstance which I am not yet able to explain: namely, that this caustic ley has a singular effect on the earthen-ware vessels in which it is kept. I always used vessels of that kind of pottery called in this country stone-ware, which is a species of porcelain, far superior to the soft bibulous pottery. I have very often observed that, after two or three months keeping in such vessels, they split all over, with a loud crack. The same observation has been made by other persons of my acquaintance. Nor is this confined to this particular material. It happens also to glass bottles, though not so frequently. The only conjecture

that I can form on the subject is, that the alkalis, acting on the inner surface of a vessel not well annealed (and it is scarcely possible that any can be *perfectly* annealed) corrodes the stratum which serve to support the whole in its state of unequable contraction. Yet I could not see any such corrosion.

I have also observed, and my observation was confirmed by Dr. Irwin, that caustic ley, very long kept, loses its acrimony; and that its alkaline properties are really impaired, as if the salt had evaporated from it, or that it was neutralized by some other substance. You will notice that I suppose it all the while to have no communication with the air.

Dr. Alston made an observation on caustic leys, which is curious, and of which I do not see any explanation. The specific gravity of an alkaline ley is considerably diminished by adding lime to it. This effect is very remarkable in the solution of volatile alkali.

The activity of the allkali, to dissolve animal and vegetable substances, is now increased to a surprising degree; some of the firmest parts of animals being soon dissolved by it into a pulp. Hence it is often used externally in surgery, for opening abscesses, destroying fungous flesh, or making issues in the skin, when the patient is afraid of the knife. It acts with burning pain: Hence it is called the POTENTIAL CAUTERY, or the CAUSTIC ALKALI. Notwithstanding this high degree of acrimony, it has been used of late internally. But it must be greatly diluted and obtunded, by which means the fossil acids themselves may be taken internally with safety.

Such is the activity of the caustic alkali with respect to animal substances. Of the vegetable there are many which it will penetrate and dissolve as readily. But the dry or pure woody fibres of vegetables sustain its action for some time. Of this woody or fibrous matter, cotton, bleached linen, paper, and the like substances, are composed. Even these, however, though they are not dissolved, are corroded, or made tender by it, and their cohesion much diminished, as has often happened to linen cloth in bleaching. The two fixed alkalis acquire just the same activity from lime, and have the same effect upon lime. The volatile alkali likewise

produces the same effect upon the lime, in restoring it to its mild state; and is affected itself much in the same way as the fixed alkalis are, if allowance be made for its different nature. Its volatility is prodigiously increased, as I have already observed: and it is now incomparably more acid and pungent, so that it must be smelt to with great caution, otherwise it will excoriate and destroy the nostrils. Like the caustic fixed alkalis, it dissolves animal and vegetable substances into a pulp; and acts on oils and fats in the same manner, making them miscible with water; in short, rendering them soaps. It becomes precisely the same with the *spiritus salis ammoniaci cum calce vivâ*. As in that preparation the vapours are incondensible without water, so, when as little as possible is used, they are inseparable by distillation. Mr. Du Hamel imagined that the volatile alkali was destroyed by repeated additions of lime: but this is a mistake, owing to the escape of part of it at each addition, by the sudden eruption of incoercible vapours, in consequence of the heat produced by the addition of the lime.

I have now described the more remarkable properties of quicklime in the way of mixture. I must now observe, that when it is exposed to the air, it begins, after some time, to swell, split, and crumble down, until it is slowly reduced to as fine a powder as when it is slaked with water. This happens to it plainly in consequence of its gradually attracting humidity from the air, until it has received enough to saturate it, or to convert it into slaked lime. But the lime slaked in this manner is not so acrid and active as that which is slaked immediately with water, and without being much exposed to the air. The air, at the same time that it supplies humidity to it, is also found to weaken its force by degrees, and continues to weaken it more after it has been completely slaked, until, in a certain length of time, it deprives it of the qualities of quicklime altogether, and reduces it to the state of insipid calcareous earth.

The lime does not undergo this change when it is preserved in close vessels. It suffers it only when we expose it to the free air, or when we keep it in vessels that are left open. And we further find, that the more wide and loosely it is spread out to the air, it becomes inert so much the sooner.

It loses its activity faster, in proportion to the more extensive contact or communication of the free air with it.

But, if the lime be made into a paste with water, and this paste be collected and compacted together in the form of a round mass, it then retains its activity, and the other qualities of lime, much longer than when it is exposed to the state of a dry powder, and spread out to the air. And the reason is plain: when it is in the state of a paste, the water, filling up the interstices between the particles, excludes the air from among them; and only those that are at the outside of the wet mass can be affected by it.

Lime-water is also liable to a similar change by exposition. It may be preserved in the same manner for a long time in close vessels, without alteration of its qualities. But if it be left in an open vessel, we may see, in a few minutes, a thin film produced upon its upper surface, where it is in contact with the air. This film continues to increase in thickness, until, after a number of hours, or perhaps a few days, it will form a thin stony crust. In proportion as this crust is formed on the top, the water below loses its taste and the other qualities of lime-water, and at last becomes a mere insipid water. The crusty matter itself, on examination, proves a mild calcareous earth, like the calcareous earth in its natural state. These several particulars occasioned lime-water to be considered as a surprising unaccountable fluid. When fresh drawn from the lime, it has a pungent, acrid, alkaline taste, and several other qualities, as if it contained an alkaline salt. And it retains these qualities if it be shut up in close vessels. But if exposed to the air, it becomes quite insipid. And yet we can observe no cause of this change, but the separation or rejection of an earthy matter from it, which is also perfectly insipid, and which cannot again be dissolved.

There remains to be mentioned one other property only of lime, and it is one of its most useful properties; I mean that of making good MORTAR, when it is skilfully mixed with sand and water. The qualities of *good mortar* are, to adhere readily to stones or other solid bodies; to cement them together; and to acquire, by time, a stony hardness. These qualities, in such a mixture, have been thought the

more surprising, for these reasons, that lime and water without sand has not all the qualities of good mortar, and that nothing is so little disposed to cohere as sand by itself.

After all, however, the effect of the sand, in giving cohesion and hardness to the lime and water, has been exaggerated. And Mr. Macquer errs a little from the truth, when he says that lime and water without sand do not concrete in the least.

If we give to a paste of lime and water the form of a small ball, and allow it time enough, that it may dry slowly, it will contract its size, and become very hard,...harder, I believe, than if sand had been added. But that is not the way in which lime-mortar is used. It is not made into balls or other masses that are to dry and harden without being connected with other matter. It is employed for cementing stones or bricks together, and for plastering walls and other such parts of buildings. And, if it were made up so as to be liable to contract much in drying, the consequence would be, that it must necessarily separate from those bodies to which it is applied, and which cannot contract along with it; or, if continued adhering to them, it must split and divide itself into innumerable small parts, and so become quite shattered and useless. The reason why lime alone, when made into a paste with water, contracts so much, is the great quantity of water which such a paste contains; for a good quantity of water is required to make slaked lime into a soft paste. But this contraction and its consequences are prevented almost entirely by the addition of sand to the lime.

Some skill, however, is required to add the sand in the most proper manner. If too much be added, the mortar will not be very hard and firm when it dries. The sand will give it an openness of texture, which diminishes the cohesion of its parts, admits water too readily into its pores, and exposes it to the effects of frost.

Some time ago, a French engineer, Loriot, proposed a contrivance, which he asserted to be a great improvement in the composition of lime-mortar for many purposes, and by the use of which less sand was necessary to prevent its contraction. He made common mortar with the usual proportion of sand, but with a little more water than ordinary,

so as to be almost fluid; and just before using it, he added to it one-fourth or one-third of quick-lime, not slaked, but reduced to powder mechanically. When quicklime is thus mixed with a good deal of cold water, it does not slake so suddenly as when no more water is used than is necessary to slake it. The quicklime put in does not swell and slake until the mortar is used, and put in its place. The powder of the quicklime, then slaking throughout the whole of the mortar, absorbs and consolidates a part of the water which it contains: and the mortar becomes hard and dry remarkably soon, and without contracting. And when the rest of the humidity is evaporated, it acquires a degree of hardness and compactness far superior to that of ordinary mortar. It is impenetrable by water. Vases of it filled with water do not imbibe a sensible quantity. The hardness and strength of this mortar, is undoubtedly owing to its density and more perfect setting. Mr. Loriot was of opinion that the Romans made their mortar in some such manner. Lime mortar sets in time, if left at rest. This setting is somewhat analogous to the concretion of salt and water in the act of crystallization. Mortar will set again and again, after kneading or beating up, but more weakly than before. Loriot's mortar, therefore, must set the most strongly of all, because it is not afterwards disturbed.

Since Loriot, Dr. Higgins of London published a little tract on this subject, containing a description of a great number of experiments, made to discover the best compositions for making mortar or lime cements of different kinds. His experiments agree in shewing that the hardness and strength, which mortar or lime cements acquire, depend very much on the freshness and activity of the lime employed. And, in his receipt for the best composition, he insists particularly on a method of using the whole lime in its most active possible state, so as it may be exposed to the air as little as possible, after being burnt and slaked. And he also found that much advantage was gained by using sands of different sizes mixed together, and even a small addition of some other ingredients still finer than the finest sand. The particulars of all this are in his pamphlet, which I think judicious.

There is a way of making a lime-mortar or cement, the concretion and induration of which does not depend on its being dried. It is found to concrete and become hard and very durable, even under water, and is therefore used in buildings or works that stand in water, or are very much exposed to be washed by it; and such mortar is named water-mortar. Mr. Smeaton having had occasion to use this mortar in building a most useful and important light-house, which stands on a low narrow rock in the mouth of the Channel, where it is often exposed to the utmost fury of the waves, exerted all his ingenuity to make the building durable; and among many other points, made a number of experiments to ascertain the best composition for water-mortar. And he was so accurate and industrious in his investigation of it, that he is the best author to be consulted on this subject. The detail of his experiments is given in the account he published of the building of that light-house, which was a most arduous work.

I have now proceeded so far in the history of the calcareous earth, as to have related the principal facts upon which were founded the first attempts to explain this subject, and to account for the difference between the earth in its natural state, and in the state of quicklime.

In general, those who attempted to give an explication applicable to the whole, or to the greater part of this subject, entertained a notion, or rather formed a supposition, that the calcareous earth, when burnt to quicklime, receives some subtile and active principle, communicated to it by the fire or heat; that from this principle it derives its acrimony, activity, and solubility in water. They imagined that lime-water is produced by dissolving such a part of the lime as has the largest proportion of this principle combined with it; and that this principle evaporates from the lime or lime-water exposed to the air. Further, some supposed that this principle is attracted from the lime by alkaline salts, and that thus are produced the caustic alkalis. The greater number, however, seem rather to have considered these as compounds of the alkali and the quicklime in substance, or the more acrid part of the quicklime. But neither has the existence of this active principle even been demonstrated; nor is the

supposition of its combining with lime consistent with many capital facts which are known to all. Indeed it is inconsistent with our general experience in chemistry. When limestone is burnt to quicklime in the fire, instead of receiving any addition, it suffers, on the contrary, a very considerable loss. And the alkali is also diminished in weight when rendered active by the quicklime. Moreover, we generally find, that the combination purely chemical, of the most active substances, generally diminishes their activity. It is thus that neutral salts are less active than their ingredients.

Other theories have been attempted, as I said, chiefly to explain some parts of the subject. Such was Dr. Stahl's opinion. He was one of those who believed salts to be compounds of earth and water. And he supposed slaked lime to be a sort of salt hastily and imperfectly formed; and therefore liable to be easily decompounded again into its constituent parts,....calcareous earth and water.

Mr. Macquer again, in order to explain some particular phenomena, supposed that the calcareous earth acquires a small quantity of some acid principle in the fire, just enough to give it solubility in water, but in too small quantity to saturate it; and therefore lime is still alkaline. By this supposition he endeavours to explain the action of lime and tartar on one another, but at the time when he wrote, the nature of tartar was but imperfectly known, and ill understood. And neither his theory nor Dr. Stahl's are at all satisfactory when closely examined. You may see an account and examination of those theories, in the second edition of the English translation of Macquer's Dictionary, under the article *Causticity*.

Upon the whole, the chemists had been, at that time, but little attentive to the variety of earthy bodies, and had but an indistinct knowledge of any alkaline earth, except the calcareous.

They only knew that there were two or three earths beside the calcareous: and they knew some saline compounds which held earths combined with acids. But they had not turned their attention to them, so as to examine by experiments how they were distinguished from one another. They supposed them to be all more or less similar to the calcareous, or to

have a great deal of affinity with it, if they were not the same thing.

Dr. Hoffmann was the first who gave distinct notice of an alkaline earth, which he shewed to be different from the calcareous. It was called *Magnesia*. When I first began to make chemical experiments, I had the curiosity to examine more carefully this earth indicated by Hoffmann. I made a number of experiments to learn its properties, and how it was distinguished from the calcareous and some other earths. The result of these experiments suggested to me, some time after, an explication of the nature of lime, and of its effects on the alkaline salts, and engaged me in an inquiry, by which a clear light was thrown on this subject, and on many other important parts of the science of chemistry.

I propose, therefore, to give an account of that inquiry. It is a long story. But when I began to give these lectures, and for a long time after, I was in some measure under the necessity of following this method, giving, at full length, the investigation of the subject of quicklime, and the foundation of the opinion and system which I formed upon that subject; for this reason, that it was not generally understood and approved of by the chemists abroad. Some chose to doubt, or explain in a different way, the proofs which I had adduced: and they adhered to their old opinions. Others set up, or supported and extolled another new system, which was directly contrary to mine. So long as the opinion of a number of reputable chemists was unfavourable to my views of the subject, I thought it became me to shew the grounds of my opinions; and to leave those to whom I addressed myself at liberty to judge for themselves. Of late, however, most foreign chemists and philosophers agree on this subject with me.

But I think it is still worth your while to hear a history of the investigation. The same facts and doctrines, when delivered in a dogmatic or didactic manner, do not make such an impression as when made the subjects of historical narration. The mind is then led through the most natural chain of ideas; it being that which took place in the mind of the person who followed out the investigation.

I said just now, that a dissertation or essay of Dr. Hoffmann's, on an earth called magnesia, occasioned the beginning of the inquiry, the history of which I am going to give you. But I was peculiarly excited to it by the then recent discoveries of the power of lime-water to give relief in cases of the stone and gravel, in which it was supposed to act by dissolving those concretions, and expelling them out of the body. Dr. Whytt and Dr. Alston, professors in this university, were then engaged in a dispute on this subject, They both believed that it had efficacy. But Dr. Whytt imagined that he had discovered that the lime-water of oyster-shell lime had more power as a solvent, than the lime-water of common stone-lime. I therefore conceived hopes that, by trying a greater variety of the alkaline earths, some kinds might be found still more different by their qualities from the common kind; and perhaps yielding a lime-water still more powerful than that of oyster-shell lime.

I therefore began by examining the alkaline earth which Hoffmann had mentioned or described; and for the preparation of which there was a process given in our pharmacopœia.

SPECIES II.....MAGNESIA.

We learn from Dr. Hoffmann, that it was a white earthy powder, which had gained reputation as a secret remedy, under the name of the Powder of Count Palma, or Magnesia Alba. The Doctor having learned the manner of preparing it, which he describes, made several trials to assure himself of its medical virtues, and to acquire some knowledge of its nature in other respects. And he reports that it is an alkaline or absorbent earth, which effervesces with all the acids, and neutralizes them; that it is, therefore, proper for neutralizing acids in the stomach, with this additional good quality, by which it is distinguished from the calcareous earth commonly employed at that time by physicians, that the magnesia has purgative or laxative powers, and therefore clears the bowels from the undigested matter which had produced the acid. And he supposed that the purgative power was a quality of the compound of the

magnesia and acid after they were united together in the stomach.

The subjects from which Dr. Hoffmann prepared this earth, were some saline compounds, in which it is combined with acids: and these saline compounds are obtained in preparing nitre and common salt. He first made use of that which is procured in preparing nitre, or in extracting the nitre from nitrous earths and composts. It is called the MOTHER LEY OF NITRE*.

But, afterwards, having learned, that, in preparing common salt from the waters that contain it, a similar liquor is obtained, he made use of this also in some of his processes for preparing magnesia. This bitter saline liquor, produced in manufacturing common salt, is well known to our salt boilers who prepare salt from sea-water: And they call it *Bittern* in England,....in Scotland commonly *Oil of Salt*.

Dr. Hoffmann described two ways of obtaining this earth from these saline liquors. The first was by evaporating the saline liquor to dryness, and then exposing the dry matter to a red heat in a crucible; by which heat some acid vapours were expelled, and the earth remained in the crucible. The second was by adding to the saline liquor a solution of an alkaline salt, which immediately precipitated the earth, by uniting with the acid with which this earth was combined. And he prefers this process to the other.

In this country, (Scotland) as we cannot procure any of the nitrous liquor, we have always prepared our magnesia from the *bittern* of common salt, or of sea water. Or, which is the same, we prepare it from the saline compound which is procured from the bittern by crystallization.

The saline compound has been long used in the practice of medicine, under the name of *Sal catharticus amarus*, the bitter purging salt. It was first obtained from the waters of some purging mineral springs at Epsom, in Surrey, and sold at a high price, on account of the small quantity of it which those

* *Moder* is the German word for scum, mud, or dregs, which separates from vinegar, ale, or other liquids, by careless keeping. This term is still in use in the northern parts of these islands, and the liquor is said to *mother*. The French translate it ignorantly *eau mere*.....EDITOR.

waters contained. But afterwards, the manufacturers of common salt, finding they could produce it in plenty from the bittern of sea water, and very cheap, prepared large quantities of it, at Lymington especially, and exported it to the continent, where great quantities were sold.

The appearance of it, as commonly prepared from the bittern is that of small prismatic or columnar crystals. It is rather more purgative than Glauber's salt, or sulphat of soda, and of a bitterish, and vastly more disagreeable taste. These crystals contain about one half of their weight of water, and therefore readily undergo the watery fusion when suddenly heated. The rest of their substance is a compound of the sulphuric acid and an alkaline earth, which becomes evident by the action of an alkali on this salt. The alkaline earth, which is the magnesia, is precipitated: And, by the same experiment, we learn that the acid with which it was combined is the sulphuric. It forms, with the vegetable alkali added, a sulphat of potash. The Epsom salt is, therefore, a sulphat of magnesia.

This saline compound, being crystallized with a little more care than is commonly employed in manufacturing it, concretes into much larger crystals, which, as they resemble and even excel Glauber's salt by their purgative quality, have also considerable resemblance to it in their appearance. This became known to the manufacturers, who soon crystallized large quantities of it in this manner, and sold it for Glauber's salt for some time. But the fraud was detected: and Glauber's salt has been sold so cheap since that time, that it is not worth while to attempt such a fraud, especially since the method of distinguishing the one of these salts from the other is generally known. We need only to dissolve a little of the salt in water, and add an alkali. The solution of the sulphat of soda remains transparent. The other becomes turbid and thick by the precipitation of the magnesia.

By not having knowledge of this distinction, Mr. Pott, of the Berlin Academy, maintained a dispute with Mons. Du Hamel, of the Royal Academy of Sciences, about the Alkaline basis of common salt. Mr. Pott asserted that common salt contained an earth for its basis. Mr. Du Hamel demonstrated by experiments, that it contains an alkaline salt. Pott had drawn

his conclusions from experiments made with the sulphat of magnesia, which was sold at that time in Germany as Glauber's salt: and he did not suspect that it was any thing else. But, as genuine Glauber's salt is prepared from common salt and sulphuric acid, it must necessarily have the same alkaline basis as common salt. And finding that the salt, which passed for Glauber's salt in Germany, had an earth for its basis, he concluded that common salt must contain the same earth.

The process I used for preparing magnesia for my experiments, was what we have now in the Edinburgh Pharmacopœia, or much the same. I dissolved in water separately equal quantities of Epsom salt, (sulphat of magnesia) and of potash, such as is commonly sold under the name of pearl-ash. The Epsom salt must be dissolved in twice its weight of the purest water and an equal quantity of dry pearl-ashes must be dissolved in four or five times its weight of pure water. Each of these solutions must be carefully purified from all admixture or foulness. The alkali may be purified by subsidence and decantation. It is adviseable to clarify the solution of Epsom salt with the white of egg, violently agitated with it when just hot enough to coagulate the egg. This produces a fine net-work, which will entangle every thing that is not chemically dissolved: and the clear saline solution will then drain slowly through a linen cloth.

Equal quantities of the two salts having been thus dissolved, the clarified solutions must be mixed together by violent agitation, in order that the salts may act quickly on each other, and the decomposition be as perfect as possible. This must be further promoted by making the mixture just boil over a brisk fire.

Now, add to the mixture four times its bulk of boiling hot water, and again agitate it briskly. Let it now stand to settle. The magnesia is scattered over the whole liquor in a most impalpable powder, and will subside with extreme slowness. When settled, decant off the clear liquor, and again pour on it the same quantity of cold water, and, when it has completely settled, again decant the clear liquor. This edulcoration must be repeated ten or twelve times before the magnesia can be cleared of the vitriolated tartar, formed by the alkali and the sulphuric acid of

the Epsom salt, which, you know, requires a prodigious quantity of water for its solution, especially when cold;....and in these ablutions it is found that hot water occasions a much longer suspension of the magnesia. But these repeated effusions will effectually clear it of all saline admixture, leaving the magnesia pure, and in a fit state for philosophical examination. Having decanted off the tasteless water for the last time, strain the sediment through a linen cloth, using gentle compression at last,....for very little of the powder will come through. N. B. We shall never succeed by using the finer filtering papers. For, although magnesia is a fine hard powder, yet, while wet, it has more the appearance, the feel, and even the transparency, of a jelly*.

There are several niceties in this process, which seem somewhat capricious, but are abundantly plain when we attend to the properties of the substances employed. The vitriolated tartar, being of difficult solution, impedes by its very formation the progress of the decomposition; therefore boiling briskly is absolutely necessary. Also, the magnesia has a tendency to a peculiar mode of crystallization in little round grains formed like zeolyte, of spiculæ diverging from a centre. They are hard, and would be very inconvenient for medical preparations. When a very minute quantity of the two salts is dissolved in a great deal of water, and allowed to rest without disturbance, the particles have room and time to assume this arrangement very regularly. Therefore, we must prevent this by making our first liquors pretty rich in the salts, and this, with the agitation and boiling, immediately destroys this regular formation of crystals, and causes the whole to become a fine impalpable powder. I find that a quart of water to a pound of Epsom salt, and three quarts to a pound of dry pearl-ashes, are a very good degree of strength for the first solutions. The gelatinous appearance,

* This transparency is unfortunate for the painters; for magnesia would otherwise give a most dazzling white, superior to any they possess, and which would not change its colour, as the preparations of white lead do. But when ground with oil, it has hardly any colour, forming an almost transparent varnish. It will do perfectly well, however, in water colours; because it regains its brilliancy when perfectly dry.....EDITOR.

when wet, arises from a spongy adhesion of a great quantity of the water: and when this is evaporated to dryness, the mass is an exceedingly light and spongy substance,....and this extreme lightness is one of the best marks of its goodness. Mr. Henry of Manchester thinks that in this process too little water is used, saying that these gritty particles require a vast deal of water to dissolve them. But this is a mistake. No quantity whatever of pure water will dissolve them: and if the first liquors are not too much diluted, and the mixture be well agitated at the first, these gritty particles will not be formed.

My prescription of equal quantities of the two salts, as proper for decompounding the Epsom salt, is founded on an experiment by which I discovered that it requires 100 grains of dry alkali to saturate the acid saturated by 30 grains of calcined magnesia.

Having thus procured a magnesia, of the purity of which I was certain, I was anxious to examine it as a medicine. I made a salt by dissolving it in vinegar, thinking this acid the most nearly analogous to that which is formed by vegetable matter, imperfectly digested in weak stomachs. Two drachms of this powder proved a good purge for an adult, and half an ounce a very brisk purge: but both operated gently and without any spasm or sensible inconvenience. The taste was in a moderate degree nauseous.

Let us now attend to the chemical relations of this new substance; and, first, with regard to the acids.

1*st*, It effervesces with all the acids, and neutralizes them and forms with them compounds remarkably different from those formed by the calcareous earth. With the sulphuric acid, for example, it forms a compound easily soluble in water;....with the nitric acid a compound soluble and crystallizable;....with the muriatic acid a deliquescent compound, but which differs from the calcareous compound with this acid, by being subject to decomposition, or separation of its acid, or of the greater part, by the action of heat alone. Its compound with the acetous acid has been already described.

2*dly*, Magnesia, prepared in the way now described, separates the calcareous earth from acids. When a little uncalcined magnesia is put into a solution of the muriat of lime, and the mix-

ture promoted by agitation, and allowed to settle, we have a powder lying at the bottom, which is not distinguishable at first from the magnesia that we put in. But when it is dried and edulcorated, we find it to be a calcareous earth; for it burns to a true quicklime, wholly soluble in water. If we have added enough of magnesia, and not too much, we shall find that, after having separated the powder now spoken of, if we then pour a little sulphuric acid into this solution, we shall observe no precipitation. Now we know that the sulphuric acid, when added to the muriat of lime, forms a selenite hardly soluble in water. Again, if, instead of the sulphuric acid we put a solution of Glauber's salt into the saline liquor we are now considering, we shall obtain an Epsom salt and common salt.

3dly, It produces a very remarkable effect on lime or lime-water. In the first experiments by which this was discovered, I added some magnesia to a muddy mixture of lime and water. The lime was rendered insoluble. In a second experiment I added the magnesia to lime already dissolved; that is, to lime-water. After long digestion and frequent agitation, the water was rendered perfectly tasteless, and the powder at the bottom was a mixture of magnesia and crude calcareous earth.

I was induced to try these experiments with lime and lime-water by the event of the preceding experiment, which made me imagine it was allied to the alkalis.

4thly, When exposed to the action of fire, it does not become a quicklime. Some magnesia, which had been exposed to a strong heat, was tried with water, to learn whether it would slake like lime, or form a lime-water. I also laid a little of it on my tongue, to learn whether it had acquired any degree of acrimony. But in none of these trials did it shew the qualities of lime. It neither slaked or shewed any attraction for water like quicklime, nor formed a lime-water; nor was it sensibly acrid when laid on the tongue. I learned, however, that in some of its qualities it is considerably affected and changed by the fire; and I called it calcined or burnt magnesia. The changes induced on it by the action of the fire, when a good red heat has been applied to it for some hours in a crucible, are these:

1*st*, We find that it is much diminished in bulk.

2*dly*, We also find that its weight is very considerably diminished, viz. by more than $\frac{1}{2}$;....or, by $\frac{7}{12}$ths ; 12 parts being reduced to 5.

3*dly*, When we try how the magnesia, in this diminished state, dissolves in acids, we find it can be dissolved without the least effervescence. When lime is thrown into strong and brown sulphuric acid, there is sometimes a violent heat produced (even flashes of flame) which makes the water boil. But this happens only when the acid is applied too strong ; and it is quite different from the effervescence which appears in dissolving magnesia in its ordinary state. And if we dilute the acid properly before we apply it to the calcined magnesia, there is no ebullition whatever, but only a moderate degree of heat produced.

This suggested an improvement of magnesia as a medicine for some cases and constitutions. Hoffmann remarks that some of his patients complained of the magnesia, saying that it raised wind in their bowels ; and this he imputes to its effervescing quality. But by thus calcining it, we deprive it of this quality, although it unites with acids as effectually as before ; for by dissolving the calcined magnesia in the different acids, I learned that it neutralizes the acids, and produces compounds entirely similar to those produced by the magnesia before it has been calcined. The use of calcined magnesia in medicine requires, however, some caution and attention: For magnesia, in the shops, is not always perfectly pure. Some of it contains a portion of calcareous earth ; and if such magnesia is calcined, we shall have a portion of quicklime in it ; which is not safe for internal use. The calcareous earth which is often found in common magnesia, proceeds either from a sulphat of lime, which is often contained, in small quantity, in the Epsom salt, or from a sulphat and a muriat of lime contained in the water with which the magnesia was washed, if this was a hard or a bad water. It very rarely happens that any troublesome degree of flatulence is produced by common magnesia ; and if there should, the addition of some aromatic will be a sufficient antidote.

4thly, A fourth peculiarity of the calcined magnesia was, that it did not separate the calcareous earth from acids. And a

5th, That it did not precipitate the lime from the lime-water.

The result of these trials prompted me to make further experiments, to learn in what manner the fire produced these changes in the magnesia, and what was the nature of that matter which was separated from it by heat in such great quantity, and by the loss of which it was so much reduced in its bulk and weight.

I therefore put a quantity of magnesia into a glass retort, and joined a receiver to the retort with common lute made of sand and clay. I then placed the retort in a sand-pot, which was very gradually heated until the bottom of the pot began to be ignited. The receiver was kept cool, to promote the condensation of any volatile matter that might arise from the magnesia. But I obtained only a very small quantity of watery fluid, which contained a small portion, scarcely perceptible, of volatile alkaline matter. The magnesia, which remained in the retort, had lost a great deal of its weight, (though not so much as when heated to a good red heat in a crucible); yet the loss it had suffered was equal to more than six or seven times the weight of the small portion of water condensed in the receiver. This appeared at first an unaccountable fact; but it made me recollect some of Dr. Hales's experiments, described in the essay to which he gave the title of Analysis of the Air, and in other parts of his works.

Mr. Boyle had before made experiments, in which he extracted air from different substances by the use of the air-pump, and by other means. But Dr. Hales pushed such experiments a great deal farther. He expelled, by the action of heat, from a variety of different substances, large quantities of elastic incondensible fluids, which he considered as different kinds of air, or as air in different states, which had been concealed in these bodies, united with their other ingredients in a dense and solid form. Chemists have distinguished this class of elastic fluids from atmospherical air, by the term GAS, a German word used to express the eruption from fermentations (*gährung*) of every kind. (*See Note 36. at the end of the Volume.*)

The apparatus he used in many of these experiments was very simple, consisting of a gun-barrel closed up at the breech, and bent into a swan neck. The substance from which the gas is to be expelled by fire, is put into the barrel, and this end is put into the fire. The other end is dipped in a tub of water, and a jar filled with water is inverted over the mouth of the barrel. The pressure of the atmosphere supports the water in the jar. The gas expelled from the gun-barrel rises through this water, displaces some of it from the jar, and occupies the upper part of it *.

By such experiments, and by others, Dr. Hales procured great quantities of air, or permanently elastic fluids, from a great number of vegetable, animal, and fossil substances. And this explained to the chemists some facts which often occurred in their distillations, and which they had not been able before to understand, viz. the loss of weight, and the bursting of their distilling apparatus, in spite of all attempts to promote condensation. Obtaining a vast deal of air in the same apparatus without red heat, from pease, and other fermentable substances, gave some knowledge of what happens in fermentation.

As what had happened in the last experiment with magnesia appeared to be very similar, I began to suspect that the loss of weight which it suffered in the fire was occasioned, in the same manner, by the loss of a quantity of elastic aërial matter, or air, which had escaped through the lute. And this supposition appeared the more probable, as it was very consistent with one of the qualities of burnt magnesia; I mean its uniting with acids without effervescence. For I began to suspect that the effervescence of the common magnesia proceeded from air which it contained, and which was expelled by the superior attraction of the acid; and that the reason why burnt magnesia did not effervesce was, that it did not contain this air, the air having been expelled from it by the action of heat.

Another fact which supported the same opinion, was the success of an experiment, in which I contrived to restore this air again, if possible, to the calcined magnesia.

* The same apparatus was employed by Mayhow in 1674....EDITOR.

The contrivance or plan of this experiment was suggested by considering in what manner the magnesia had obtained this air at the first. It could not have it while it was joined with the sulphuric acid in Epsom salt. The effervescence of magnesia with acids, shews that it cannot be joined with an acid and this air at the same time. It must therefore have received it from the alkali which was employed to precipitate it from the acid. This appeared the more probable, from recollecting that Dr. Hales had long before extracted much air from alkaline salts. By heating some alkali of tartar in his iron retort or gun-barrel, he extracted from it 224 times its bulk of air. In other experiments, he procured great quantities of air, by adding different acids to solutions of alkalis.

I therefore supposed that magnesia receives air from the alkali employed to precipitate it at first; that we can expel this air from it by the action of fire; but that it might perhaps be restored by dissolving the burnt magnesia in an acid, and precipitating again by the addition of an alkaline salt.

To make trial of this, I took 120 grains of common magnesia. I burnt it in a crucible with a sufficient heat, by which it lost 70 grains of its weight. This magnesia, thus calcined, was dissolved in a sufficient quantity of diluted sulphuric acid, in which it dissolved without effervescence: and it was again precipitated by adding a clear and warm solution of a common fixed alkali, which was boiled with it a little in the usual way; and the precipitate was washed in the usual manner. After being carefully dried with a gentle heat, it was found to have regained the whole weight which it had lost in the fire, except a mere trifle. It also effervesced with acids as violently as common magnesia. It separated the calcareous earth from acids, and it made the lime separate from lime-water. Thus it was restored to the state of common magnesia in every respect. It was just the same as if it never had been calcined.

The event of this experiment, therefore, confirmed me in the persuasion, that magnesia receives a quantity of air from the alkali employed in preparing it; and that the precipitation of magnesia from Epsom salt is not a case of single, but of double elective attraction.

This became still more evident, by considering attentively what happens in precipitating magnesia; for the alkali, in precipitating it, forms with the acid a compound salt, which is precisely the same in quantity and quality, as if the same alkali had been saturated with a pure acid. When an alkali is saturated with a pure acid, we see plainly that the air of the alkali is expelled. The effervescence shews this, as do Dr. Hales's experiments. And the compound salt produced is a compound of the acid with the alkali deprived of its air. But as the compound salt produced in precipitating magnesia is precisely similar, in quantity and quality, to a compound salt produced from the same quantity of alkali and a pure acid, the alkali of it cannot have retained its air. This air must have been expelled by the acid: and yet this expulsion of the air is not apparent by any effervescence. But as the air is actually found in the magnesia, this accounts for the non-appearance of effervescence, and shews that in the precipitation of magnesia there is a double elective attraction or double exchange. The alkali unites with the acid, separating the magnesia, which in the same instant unites with the air as it quits the alkali. We must therefore conclude, that the sum of the forces which tend to unite the alkali with the acid, and the magnesia with the air, is greater than the sum of the forces that tend to unite the magnesia with the acid and the alkali with the air.

Thus, I found reason to set aside the common opinion then entertained of the nature of the effervescence of acids with alkalis and alkaline substances. It was generally supposed to be a consequence or effect of the violent shock of the acid and alkaline particles,....but it now appeared to be a separation of a quantity of air which is present in alkalis, but which is expelled by the superior attraction which the acid has for the alkali.

When I now reflected on the great loss of weight which magnesia suffered in being calcined, it occurred that the quantity of air which it contains must be very considerable; and that it and the other alkaline substances, must lose a proportional part of their weight during their effervescence with acids,....since we have reason to conclude that this effervescence is nothing else but a separation and discharge of this air.

This idea led me to examine what loss of weight magnesia, or the common fixed alkali, would suffer by their effervescence with a pure acid, for which purpose I made the following experiments:

Into a diluted acid contained in a flask or phial, put a little alkaline salt, or chalk, or magnesia, and immediately stop the mouth with a cork, through which there passes a tube bent into a swan-neck. The other end of the tube is introduced (in Dr. Hales's manner) into an inverted glass jar filled with water, and standing in a tub of water. You will observe the effervescence, and the elastic bubbles rising copiously through the water to the top, where they collect, driving the water out of the jar.

Thus it is manifest, that it is not a temporary vapour, but a permanently elastic fluid, which escapes in the effervescence, not condensible by cold.

Mr. Homberg, therefore, was led into an error in the experiments which he made and published in the memoirs of the Academy, to determine the strength of the different acids, and the proportion of the acid to the alkali in the compound salts. He saturated equal quantities of an alkali with each, and concluded that the weight gained by the alkali, when perfectly dried, was the quantity of solid salt contained in that part of the acid which had completed the saturation. But we now see that he ought to have added the weight of all the air that is lost by the alkali.

We can also now perceive the reason why common and burnt magnesia, which differ by several properties, agree in forming the same salts with the different acids; for, since the different qualities of the magnesia in these two states proceed from the presence or absence of the air, it must happen that when magnesia, in its ordinary state, is dissolved in an acid, the air is expelled,....the compound produced must therefore be the same as if we had dissolved burnt magnesia, or magnesia previously deprived of its air by fire.

The only other experiments which I first published in my inaugural dissertation on magnesia, were a few more on the earth of alum, and on the ashes of animal bones, which were

at that time employed in medicine as an alkaline earth. I satisfied myself that neither of them acquired the qualities of quicklime in a strong fire; and that was one principal object of my inquiry. More light has been thrown upon both these earthy substances since that time by eminent chemists in Germany and Sweden: but of this we shall give further notice soon.

Such were the experiments which I then made to investigate the nature of magnesia. And from these you will perceive that this alkaline earth is very distinct from the calcareous. I need not add any thing further with regard to it at present; but shall take some notice of the different states in which we find it in nature.

It is produced by nature in great quantity. The sulphat of magnesia is contained in considerable quantity in the waters of the sea; and occurs also in many spring waters, in which it has been often mistaken for Glauber's salt. And sometimes waters that contain it, when they happen to be exposed in circumstances proper for evaporation, leave this salt behind in a concreted or crystallized form. Such is this specimen which I was told came from a coal-pit in England. And I am persuaded, that the salt called Glauber's salt, which is said to be found solid in Siberia in such great quantities as to supply the consumption of the whole empire of Russia, is not in truth a Glauber's salt, or sulphat of soda, but a sulphat of magnesia. My reason for this opinion is, that in Russia they do not know the distinction between this saline compound and sulphat of soda. Mr. Model, the Empress's apothecary, in one of his essays, mentions, as a well known property of Glauber's salt, that when we dissolve it in water, and add a solution of the fixed alkali, there is a plentiful precipitation of earth, which certainly happens with Epsom salt only but not with Glauber's salt. And there are other passages in his essays, which shew plainly, that what they called Glaubers's salt in Russia, was no other than this salt.

We may further remark with respect to the natural waters which contain some of this salt, that they also often contain a small quantity of a muriat of magnesia. There is always a quantity of it contained in sea water.

But these are not the only states in which magnesia is found. Mr. Margraaf of Berlin made great additions to the natural history of this earth, by discovering that it exists also separate from any acid, and sometimes pretty pure. There is a set of earthy or stony substances, concerning the classing of which, fossilists were a long time undecided and disagreed. Most ranked them among the clays, and Cronstedt with the rest. They have been known by the names steatites, lapis surpentinus, lapis nephriticus, and lapis ollaris. In the purest, the texture is close and semitransparent. In some species, it is somewhat plated or scaly. In general they are soft like soap or suet; so soft as to be cut or turned. They harden in the fire without melting. Hence some species are turned into vessels. This is the lapis ollaris. Inverary House is built of an impure species of it. Mr. Margraaf first shewed that all these contain more or less of magnesia, closely combined with some other earthy substances, and often with much iron, by which they are tinged with the green colour, more or less deep, that appears in many of them.

Mr. Margraaf also found that magnesia is an ingredient in the composition of the flexible stony substances, which we shall hereafter describe. And Mr. Lewis got some of it from the ashes of vegetables, and of the softer animal substances.

It is a considerable time since Mr. Margraaf published these discoveries. I can add further, that more recently, Mons. Monnet, in France, has repeated and confirmed the experiments of Margraaf, and has added many new ones, which are entirely his own, and which shew that this earth is produced by nature in much greater quantity still than was imagined. In making experiments with clays, and marles, and slate, he found that many of these contain a quantity of magnesia, mixed with the other earths, which compose the pripcipal part of them. There is an extract of his discoveries on this subject in the *Observations de Physique* for June 1774, which well deserves your perusal, as a specimen of well conducted investigation, and as it contains much new information.

There is also a lime-stone, very abundant in the neighbourhood of Doncaster, and I believe, in other parts of Eng-

land, which, when burnt, and laid on land as manure, is found greatly to injure its fertility. This has been examined lately by an intelligent chemist, and found to contain a very considerabe proportion of magnesia.

When I reflected on the experiments already described, they appeared to me to lead to an explication of the nature of lime, which easily accounted for the most remarkable properties which we find in it, and for many phenomena relating to it and to other alkaline substances.

By these experiments it was made evident that magnesia and the vegetable alkali, in their ordinary state, contain a large quantity of air, in an elastic, solid, or fixed state, which makes up a considerable part of their bulk and weight; and that their effervescence with acids is a discharge or separation of this air from the alkaline part of these substances, ...the acid acting here in the same manner as the sulphuric acid does when it expels the less powerful acids from the compound salts which contain them.

I therefore concluded, with respect to the other alkalis and alkaline earths, that their effervescence with acids depended on the same cause; that they all contain a large quantity of fixed air, which is expelled when they unite with acids; and that this air adheres to them with considerable force; since, notwithstanding that it is such a volatile substance, a full red heat is necessary to separate it from magnesia; and the same red heat is not sufficient to expel it entirely from the alkalis, or to deprive them entirely of their power of effervescing with acid salts.

I further was induced to think that the relation of alkaline substances to fixed air resembled, in some particulars, their relation to acids; that, as the alkaline salts and earths attract acids strongly, and, when saturated with them, become mild neutral salts, they, in the same manner, have an attraction for their fixed air, and, in their ordinary state, are in some measure *neutralized* by it, appearing on this account milder, or less active bodies, than when we have an opportunity to examine them in a pure state.

With respect to the calcareous earth in particular, I imagined that, when it is exposed to the action of a strong fire, and thereby converted into quicklime, the change it suffers depends on the loss of the large quantity of fixed air which is combined with this earth in its natural state; that this earth is expelled by the heat; and that the solubility in water, and the remarkable acrimony which we perceive in quicklime, do not proceed from any subtile or other matter received in the fire, but are essential properties of this earth, depending on an attraction for water; and for those several substances with which the lime is disposed to unite; but that this attractive power or activity remains imperceptible, so long as the lime or calcareous earth is in its natural state, in which it is saturated and neutralized by the air combined with it.

This supposition agrees much better with our general experience of the consequence of combining and separating different bodies in chemistry, than the opinion which then prevailed concerning the nature of lime. The established opinion was, that quicklime was a compound, formed by the union of the calcareous earth with a subtile and active principle, supposed to be communicated to it by the fire or heat. But subtile and active substances, when combined with others, do not in general communicate their activity to these. Our general experience shews us that activity is diminished by combination. We have a well known example of this in the combination of acids with alkalis. Both of these salts, in their separate state, have great activity and corrosive powers. When united, they form the neutral salts, which, instead of having the joint activity of their constituent parts, are mild and inert, if compared with either the acid or the alkali of which they are composed.

I therefore considered the calcareous earth as a peculiar, acrid, soluble earth, appearing commonly under a mild and insoluble form, on account of its union with fixed air; and I considered quicklime as the same earth deprived of its air: and therefore shewing its proper solubility and acrimony, or its natural attraction for water, and for various other substances with which it is then capable of being combined.

This idea of the manner in which the calcareous earth becomes quicklime, not only agreed with our general experience of the consequences of combination and separation in chemistry, but was immediately supported by some capital facts belonging to this subject; and which, at the same time, were quite inconsistent with the common opinion. It is well known, that when a calcareous stone or mass is burnt to quicklime, it does not acquire any additional weight in the fire; but, on the contrary, suffers a very great loss. The lime, when fresh drawn from the furnace, weighs generally no more than 60 per cent. of the weight of the limestone. And when I considered some experiments made some time before by Mr. Margraaf of Berlin, it appeared plain, that the matter separated from the limestone by heat, is an elastic aërial matter, incapable of being condensed by cold into a palpable form. These experiments are described in the Transactions of the Berlin Academy for 1748, and were made upon a particular calcareous substance of which he had undertaken the examination: it is called osteocolla. He put eight ounces of osteocolla, which is a calcareous earth, into an earthen retort, to which he joined a receiver, and set the retort in a proper furnace, where it was gradually heated to a violent degree. Nothing, however, was condensed in the receiver, except two drachms of water, which, by its smell and properties, shewed itself to be slightly alkaline. He does not tell us the weight of the osteocolla remaining in the retort. He only says that it was converted into quicklime; but this alone, and the heat he applied, are sufficient proofs that it had lost about three ounces of its weight; and as no more than the quarter of an ounce of water was found in the receiver, it is plain that this loss was occasioned chiefly by the separation of an elastic aërial matter which could not be condensed.

The same thing has since been more fully ascertained by Professor Jaquin of Vienna. In order to satisfy himself of the truth of my theory, he put a quantity of limestone, broken down to small pieces, into an earthen retort, and set it in a furnace, in which it might be heated to a violent degree. A receiver, with a very small hole drilled in the bottom of

it, was luted to the retort, perfectly air-tight: then fire was applied, and heat raised in a slow and regular manner.

1*st*, A very small quantity of water was condensed in the receiver. This all came over in the beginning of the process, and with a very low or moderate degree of red heat.

2*dly*, After this period of the distillation, no more water came, though the heat continued increasing; but an elastic fluid began to issue through the little hole of the receiver with a hissing noise, which continued a long time, but at last ceased. The limestone being then taken out, it was found to be excellent quicklime.

N. B. He repeated this process and varied it. When he withdrew the fire, as soon as all the water was expelled, there was no quicklime. And when he continued it until a part only of the air was expelled, a part only of the stones were changed into lime, viz. from the surface inwards, and to a greater depth in proportion as the heat was continued nearer to that period at which the eruption of the air commonly ceased. This supported the idea of quicklime which I had proposed.

But what further tends very much to support it, is the facility with which it enables us to explain the greater part, if not the whole of this subject. That you may be satisfied of this also, I shall now state some of these facts or phenomena which our theory explains.

Thus, to consider in the first place, the slaking of lime, the formation of lime-water, and some of the qualities of lime-water: the calcareous earth, in its quicklime state, or deprived of its air, as it has an attraction for water, will be found to resemble the salts in several particulars in the mode of this attraction. The salts, if we take them in their purest state, are disposed to combine with water in two different ways. With a certain quantity of water they unite closely, and with considerable force, to constitute the crystals of salts,....in which the water is joined with the particles of salt in such a manner as to become solid along with them. There are some of the salts which become very hot in uniting with this portion of water: such are Glauber's salt, Epsom salt, fixed alkali, and several others. This heat is supposed by most authors to come out of the salts: I am rather inclined

to think it comes from the water. After this, if more water be added, the salt unites with it in a different manner, so as to become fluid along with it, or form a solution or liquid, in which the salt is dissolved in the water; and, in this part of the process, cold is produced. In the same manner, if water be added to quicklime, a certain quantity of it is attracted by the quicklime, and deprived of its fluidity with violence and heat; and it adheres to the lime with considerable force, constituting with it a dry powder, which is called slaked lime. But if this slaked lime be mixed with a much larger quantity of water, a part of it is dissolved, and composes with the water, a lime-water.

The heat produced in slaking lime, is just one of the numberless examples of the emersion of latent heat. And if any person should think that the heat produced in some of these instances is too great to be explained in this way, let him consider that the 140 degrees, which escape from water in congelation, refer only to the difference between the heats necessary for appearing in the forms of water and ice. But we have no authority to say that the same abstraction of heat from the same quantity of water, will suit its subsequent appearance in a crystal of Glauber's salt, Epsom salt, or nitre. A much greater emersion may be necessary, or a much less; therefore, till the experiment be tried, we cannot say how much heat must emerge before the water can unite with quicklime in a solid form. And, let it be further remarked, that the heat extricated in this crystallization, can be very little diminished by the subsequent solution, because there is very little lime dissolved in the lime-water.

When this fluid is exposed to the open air, the particles of lime, which are at the surface, gradually attract fixed air, which is mixed with the atmosphere: but while the lime is thus saturated with air, it is thereby restored to its original state of mildness and insolubility. And, as the whole of this change must happen at the surface of the lime-water, the whole of the lime is successively collected there, in its original form of an insipid calcareous earth, called the cream or crusts of lime-water.

In forming this theory, I was necessarily led to perceive a distinction between atmospherical air, or the greater part of it, and that sort of air with which the alkaline substances are disposed to unite. It was plain that the lime of lime-water, for example, is not disposed to unite with the whole mass of atmospherical air that happens to be confined with it, or with every part of it equally. If this were the case, it would be impossible to preserve lime-water in good condition, without extraordinary precautions to keep the air from ever entering the bottles or other vessels in which it is contained. But we find, in fact, that it is not necessary for the preservation of the lime-water, that we keep the air out of these bottles, or exhaust them of air. They always contain as much air in the part of them that is not filled, as other bottles do in which we keep other fluids; and yet the lime-water may be preserved good in them for a long time. The only circumstances in which lime-water loses its qualities, and throws up the lime to its upper surface, are, when we expose it to the open air, or keep it in bottles that are left open. From this it was evident that the sort of air with which the lime is disposed to unite, is a particular species, which is mixed in small quantity only with the air of the atmosphere. To this particular species I gave the name of FIXED AIR, the only term then used to denote any air that is condensed and fixed in different bodies, and is a part of their constituent principles.

To return to the explanation of the properties of quicklime.....

When quicklime itself is exposed to the open air, it must gradually attract the humidity and the fixed air which are contained in the atmosphere. And as our atmosphere contains more of humidity than of fixed air, the change which the quicklime, when exposed, undergoes the most readily, is a change of it into slaked lime. But it attracts also some fixed air, and continues afterwards to attract more, until it is gradually saturated with it, and thus is restored to its original mild and insoluble state.

To explain all the effects which are produced by mixing the alkaline salts with lime or lime-water, we need only to suppose

that the fixed air is more strongly attracted by the lime than by the alkali. The lime in this case must attract the air from the alkali to itself, and must thereby return to a mild and insoluble state; while the alkali, on the contrary, becomes more corrosive,....that is, shews its proper degree of activity, or attraction for water, and its natural action on bodies of the inflammable kind, and those of animals and vegetables; which attraction, and consequent action, was necessarily weaker while the alkali was combined with its air, and in some measure neutralized by it. It therefore becomes what we call highly corrosive. And, in like manner, the volatile alkali, when deprived of its air by quicklime, besides shewing a stronger attraction for water, shews also its proper degree of volatility, such as we see it in the caustic volatile alkali prepared with quicklime; which high degree of volatility is diminished or repressed in the common volatile alkali by the air adhering to it,....in the same manner as it is repressed in various degrees, by the union of this alkali with the different acids, according to their degrees of fixedness.

In like manner, the effects of magnesia, applied in its different states to lime, or lime-water, are easily explained, by supposing that lime has such an attraction for fixed air, that it has the power to take it from the earth of magnesia. When the magnesia is added to lime-water, the air is separated from the magnesia by the stronger attraction of the lime; and as the lime, when saturated with air, does not become active, or perceptibly soluble in water, the lime-water becomes insipid,....the lime which it contained being deposited at the bottom of the mixture along with the magnesia. But, if we make this experiment with magnesia which has been deprived of its air by heat before it be added to the lime-water, this fluid suffers no perceptible change.

This account of the nature of lime recommended itself, therefore, by thus affording an easy explanation of many of the facts relating to quicklime and lime-water; and the effects of mixing these with alkaline salts, and with magnesia, in different states.

But, while I was employed in considering it with more attention, I found it to be necessarily connected with consequences which were contrary to what were at that time esteemed to be facts, or truths, established upon experience. And the consideration of these began to raise some doubts concerning the solidity of the whole of my system. In every other respect, however, it had so much the appearance of being well founded, that I resolved to consider more particularly these unavoidable consequences of the theory, and not to trust to the common opinion of what was fact, but assure myself of what was really so, by making experiments.

I therefore found, that the consequences I speak of were reducible to these propositions:

1. If we only expel fixed air from the calcareous earth when we burn it to quicklime, the quicklime thus formed must dissolve in acids without effervescence; and, notwithstanding the loss of weight it suffered in the fire, it must saturate the same quantity of acid as the whole of the calcareous earth would have done from which it was made. And the same qualities must also be found in the alkaline salts when rendered caustic by lime.

2. If quicklime be only a calcareous earth deprived of its air, and whose attraction for fixed air is stronger than that of alkalis, it follows, that, by adding to it a sufficient quantity of alkali saturated with air, the lime will recover the whole of its air, and be entirely restored to its original weight and condition. And it also follows, that the earth precipitated from lime-water by an alkali, must be the lime which was dissolved in the water restored again to its original mild and insoluble state, by having attracted the fixed air from the alkali.

3. If it be supposed, that slaked lime is an uniform compound of lime and water, and does not contain any parts which are more fiery, active, subtile, or soluble than the rest, it follows, that as part of it can be dissolved in water, the whole must be capable of dissolution in that fluid.

4. If the excessive acrimony of the caustic alkali depends on its being free from air, and not upon a part of the lime adhering to it, a clear caustic ley will consequently be found free from

any admixture of lime, except it should happen by accident, when the quantity of lime employed in making it is much greater than what is sufficient to extract the whole air of the alkali: for then we can imagine, that as much of the superfluous lime may be dissolved by the ley as would be dissolved by pure water, or that the ley may contain as much lime as lime-water does.

5. It was proved by the former experiments that alkaline earths lose their air when they are joined to an acid, but recover it if separated again from that acid by an ordinary alkali,....the air passing from the alkali to the earth at the same time that the acid passes from the earth to the alkali.

If the caustic alkali be destitute of air, it must, therefore, precipitate magnesia from acids in the form of a magnesia free of air, or which will not effervesce with acids. And the same caustic alkali must precipitate the calcareous earth from acids in the form of a calcareous earth destitute of air, and saturated with water only, or in the form of slaked lime.

These were the consequences of the theory which required the most attentive examination, as being either quite new and unheard of, or inconsistent with the established opinions. I was encouraged, however, to proceed in the inquiry by one or two facts which coincided with these propositions. One of these was the nature of the caustic volatile alkali. Mr. Boerhaave having prepared some of this with the greatest care, was surprised to find that it did not effervesce with acids. He calls it *liquor omnium acerrimus, neque tamen alcalinus.* Thinking effervescence with acids an essential character of alkaline substances, he thought that he had destroyed it. And the other was a passage in Hoffmann, in which he says, that in making some experiments with quicklime, he once found that it was dissolved by acids without effervescence.

I accordingly engaged in a set of experiments for proving the truth or falsity of these propositions. And the consequence was, that they, in general, proved true, or agreeable to the theory. But it may be proper to give a short account of the experiments, that I may have an opportunity not only to explain this subject more fully, but alo to mention some other discoveries which have been the consequence of this set of experiments.

Experiments to try the First Proposition.

To examine the truth of this proposition, it was necessary, in the first place, to learn the quantity of acid required to dissolve and saturate the calcareous earth in its natural state, in order to compare this quantity of acid with the quantity required to dissolve and saturate it when in the state of lime.

I therefore put 120 grains weight of chalk into a Florentine flask with a small quantity of water, and placing the flask on the scale of a balance, I counterpoised it by putting sand in the other scale. I then gradually saturated and dissolved the chalk with the muriatic acid diluted, as related in similar experiments on the fixed alkali and on magnesia: 421 grains weight of the diluted acid completed the dissolution of the chalk; and the loss of weight by the effervescence was 48 grains.

Being thus instructed by this previous experiment, I took another bit of chosen chalk, of the same weight with the former. I exposed it to a proper heat for changing it into perfect quicklime, in a small quantity of distilled water; and then dissolved it in the same manner as I had dissolved the chalk in the last experiment, and with some of the same diluted muriatic acid: 414 grains of this acid were required to complete the dissolution. This was accomplished without the least effervescence or loss of weight.

This experiment, therefore, established the truth of the first proposition, with respect to the calcareous earth, by shewing that quicklime, when well prepared, and made as perfect as possible, can be dissolved in acids, without effervescence, or any loss of weight. It is also a sufficient proof that quicklime requires as much acid to saturate and dissolve it as the quantity of calcareous earth of which it was made would have done. For although the quantity of acid required for dissolving the 68 grains of quicklime in this experiment was not quite so great as the quantity required for dissolving the 120 grains of chalk, the difference is so small that it is not worth notice. The difference of weight between the chalk and the lime was 52 grains in 120. The difference between the quantity of acid required for dissolving them was only 7 in 421,

and even this difference can be accounted for. We know by experience, that in separating volatile from fixed substances by the power of heat, a small portion of the fixed is commonly or often carried away by the volatile matter. It is therefore probable that a little of the calcareous earth or lime is carried away when this last is driven off by the action of a violent fire. This appears, I think, in Jaquin's experiment. The calcareous earth yielded, in distillation, water which was slightly alkaline. This water would have saturated some acid. For this reason the lime can be dissolved by a little less of the acid than if none of it had been lost.

It was, however, the established opinion at the time when I first made this experiment, that quicklime or slaked lime effervesced with acids as the calcareous earth does; the experiments before that time having been mostly made with imperfect lime, in consequence of the want of knowledge of the true nature of lime, and of what was necessary to make it perfect, and to preserve it in that state.

Having thus ascertained the truth of the first proposition, with regard to lime, I made some experiments with the caustic fixed alkali, to learn whether these also would agree with what was indicated in the first proposition.

I prepared a caustic ley by first slaking 26 ounces of very good quicklime made of chalk, with nearly seven times its weight, or eleven pounds of boiling water, in a glass vessel, and then adding 18 ounces of purified pearl ashes, dissolved in two pounds and a half of water. The mouth of the vessel was closely covered. This warm mixture was shaken frequently for two hours, at the end of which the action of the lime on the alkali was supposed to be over, and nothing remained to be done but to separate them again from one another. I therefore added 12 pounds of water; stirred up the lime; and, after allowing it to subside again, I poured off as much of the clear ley as possible, which was immediately corked up in bottles.

The lime and alkali were mixed together in this process at first by the medium of so much water only as reduced the mixture to the consistence of thick cream; for this reason, that they are thus kept in perpetual contact and equal mixture, until they

have acted sufficiently on one another. When more water is used in the beginning of this operation, the lime subsides to the bottom; and, though often stirred up, does not act so strongly on the alkali, which is uniformly dissolved in every part of the liquor. But I added more water afterwards to dilute the mixture, that the lime might subside, and the clear liquor containing the alkali might be decanted from it.

The caustic ley prepared in this manner was found, upon trial, to mix with acids, and to neutralize them, without the least effervescence or loss of weight. And when some of it was added to lime-water, it produced only a very small diminution of transparency, but not a precipitate, like that produced by an alkaline salt in its ordinary state. This was a sure sign of its being a perfect, or very nearly perfect caustic alkali, or of its being deprived of the whole, or very nearly the whole, of its fixed air, by which the common alkalis precipitate the lime from lime-water.

This is the severest test of a caustic ley. A remainder of air, which will not make any sensible effervescence with acids, is sufficient for saturating a minute portion of the lime contained in lime-water, and rendering it perceptible by a slight want of colourless transparency.

By evaporating a part of the ley, to learn the quantity or weight of the caustic alkali it contained, I also satisfied myself that the alkali was not increased, but diminished in weight, by being made caustic; and that it required much more acid to saturate it than an equal quantity of the common fixed alkali does.

I must observe that many precautions must be taken for this evaporation to dryness. The caustic alkali requires a low red heat for expelling all the water; and is so acrid in this state as to corrode common earthen ware, and even copper and iron. I evaporated it therefore in a thin silver bowl. It is not easy to know by the look of it when all the water is gone, for the salt is then fluid, and as transparent as the ley. I knew it to be as much cleared of water as I could hope to accomplish, by observing the bottom of the bowl beginning to be visible in the dark. It was then removed from the fire, and quickly congealed into a hard cake.

Thus far the experiments supported the truth of the first proposition, in every part, and gave encouragement to proceed to the verification of the other propositions, or to try if they would be verified by proper experiments.

Examination of the Second Proposition.

If quicklime be only a calcareous earth deprived of its air, and having an attraction for fixed air stronger than that of alkalis, then, by adding to it a sufficient quantity of alkali in its ordinary state, the lime should recover the whole of its air, and be restored to its original weight and condition. And it is also a consequence, that the earth precipitated from lime-water by an alkali must be the lime which was dissolved in the water, restored again to its original mild and insoluble state, by having attracted the fixed air from the alkali.

With respect to all these points, the following experiments were made:

A piece of perfect quicklime, made from 120 grains of chalk, and which weighed 68 grains, was ground to a fine powder, and thrown into a clear solution of an ounce of alkali of tartar in two ounces of water. This mixture, being digested some time, was then diluted with more water: and the alkaline liquor was carefully washed away from the lime by repeated affusions of pure water, and subsequent decantations of it from the sediment. The lime or sediment being then dried, weighed 118 grains, although the piece of quicklime from which it was made weighed only 68 grains. It was quite mild, and similar in every trial to a fine powder of common chalk. It effervesced violently with acids; and was therefore saturated with air, which must have been supplied by the alkali. The weight of it was not made up completely to the weight it had before it was burnt: but the deficiency is only of two grains: and this can be accounted for upon the principle I mentioned formerly, that a very small portion of the lime itself is volatilized and carried away by the air in a violent heat.

In order to examine the earth which is precipitated from lime-water by alkaline salts, 60 grains of the alkali of tartar were

dissolved in 14 pounds of lime water, and the earth thereby precipitated was carefully collected on a filtre and dried. It weighed 51 grains. When afterwards exposed to a sufficient heat, it was converted into a true quicklime, and had every other quality of the calcareous earth. And this experiment being repeated with volatile alkali, and also with the fossil alkali, the result was exactly the same as when the alkali of tartar was used; the precipitated earth being always a calcareous earth. This was a sufficient proof that the proposition was true.

Examination of the Third Proposition.

If it be supposed that slaked lime is an uniform compound of lime and water, and does not contain any parts which are more fiery, active, subtile, or soluble than the rest; it follows, that as part of it can be dissolved in water, the whole of it must be capable of dissolution in that fluid.

This proposition had, at that time, less appearance of probability than any of the former. It was universally believed that lime was only partially soluble in water; and different opinions were entertained of the proportion of it that could be dissolved. Dr. Alston contended that a fourth part of it, or perhaps a little more, might be dissolved, provided a very large quantity of water was employed; such as 500 times the weight of the lime. But the general opinion was, that a much smaller portion of it only was soluble and active. The question had never been decided by an accurate experiment.

I therefore chose a bit of chalk, which, when heated to a sufficient degree in a crucible, afforded a little mass of perfect quicklime, weighing eight grains.

This little mass was thrown, while yet warm, into a small quantity of warm distilled water in a phial, in which it was soon slaked, and formed a white mixture like milk. This mixture was immediately poured into a larger glass vessel, in which I had eighteen ounces of distilled water.

While the milky mixture was diffused through the water, the lime was seen to dissolve almost entirely. Nothing remained undissolved but a very light fæculency, which was almost trans-

parent, or only like thin clouds in the liquor. This fæculency, when it was allowed to subside, and was collected with the greatest care on a small filtre and dried, weighed only the third part of a grain. In some repetitions of the experiment, it weighed less, and in others a little more. Being examined by putting it on a plate of glass, and adding a drop of diluted nitric acid, it was dissolved in part, with effervescence; but a part of it remained undissolved, which was ochre of iron. It appeared, therefore, to be composed of a minute portion of the lime, which had somehow recovered fixed air, and of ochre of iron, and perhaps a little clay, which are well known to be often present, in small quantity, in chalk.

We may therefore reasonably conclude from this experiment, that lime, when it is quite pure and perfect, is totally soluble in pure water; and that the reason why it had appeared hitherto soluble only in part, was, that the experiment had never been made with perfect lime and with pure water. The water tasted strongly of the lime. It was a true lime-water, and yielded twelve grains of calcareous earth, when some alkali of tartar was added to it.

The event of this experiment was even more favourable than I had expected. I expected a much larger quantity of sediment produced from this lime when dissolved; chiefly because I suspected that the air, which we all know to be commonly dissolved in water, might be attracted by the alkaline substances, and therefore render the lime mild and insoluble. The result rather surprised me; and, raising new thoughts in my mind which seemed to lead to very extensive and important consequences, I was anxious to put it to some trial.

To learn, therefore, whether water saturated with lime had given up the air which it usually holds in solution, and whether that air is united with the lime, I made a very strong lime-water, and placed four ounces of it under the air-pump receiver, along with four ounces of common water in another vessel of the same size. The air was taken out of the receiver; and while this was doing, air bubbles formed and arose in both phials, in equal quantities, and in the same manner, as far as I could judge; and the lime-water continued perfectly transparent.

Hence it is evident that the air arising from the lime-water had been combined with the water, and not with the lime ; and the air which water commonly holds in solution is of a different nature from that which is attracted by lime and alkalis : for, had it been the same, and combined with the lime, as fixed air is, the removal of the atmospherical pressure would not have been sufficient for occasioning its separation.

Quicklime, therefore, does not attract the air that is usually contained in common water, nor does it attract the whole of the mass of atmospherical air, as I have already observed. It attracts only a particular kind of aërial fluid which is mixed with the air of the atmosphere, in the way of common diffusion, in a small quantity only. It is mixed as spirits are in water, or one metal with another, without any change of properties; and alkaline substances take out this air, as aquafortis takes out the silver which alloys a piece of gold.

Here a new, and perhaps boundless field seemed to open before me. We know not how many different airs may be thus contained in our atmosphere, nor what may be their separate properties. This particular kind has evidently very curious and important ones. It renders mild and salutary the most acrid and destructive substances that we know. I resolved to begin the study of them, by a closer examination of the species which I had fortunately discovered.

I gave it the name of Fixed Air, for the reasons already mentioned, a term which was then common to denote any elastic matter, capable of entering into the composition of bodies, and of being condensed in them to a solid concrete state, by its chemical attraction for some of their constituent parts. The name may perhaps be thought to be not very judiciously chosen, to denote this matter in its elastic state: and accordingly it has now been changed for gas. But I chose rather to employ a term already familiar, than invent a new name, before I was well informed respecting the peculiar properties of this substance.

It is somewhat singular, that when a solution of mild alkali is rendered caustic by lime, the specific gravity is considerably diminished. We should naturally expect the contrary effect, from the abstraction of so rare a fluid as air. But this shews, that in the solution the fixed air is rendered considerably denser than water, being reduced to less than $\frac{1}{800}$ of its aërial bulk.

I fully intended to make this air, and some other elastic fluids which frequently occur, the subject of serious study. But my attention was then forcibly turned to other objects. A load of new official duties was then laid on me, which divided my attention among a great variety of objects *. In the same year, however, in which my first account of these experiments was published, namely 1757, I had discovered that this particular kind of air, attracted by alkaline substances, is deadly to all animals that breath it by the mouth and nostrils together; but that if the nostrils were kept shut, I was led to think that it might be breathed with safety. I found, for example, that when sparrows died in it in ten or eleven seconds, they would live in it for three or four minutes when the nostrils were shut by melted suet. And I convinced myself, that the change produced on wholesome air by breathing it, consisted chiefly, if not solely, in the conversion of part of it into fixed air. For I found, that by blowing through a pipe into lime-water, or a solution of caustic alkali, the lime was precipitated, and the alkali was rendered mild. I was partly led to these experiments by some observations of Dr. Hales, in which he says, that breathing through diaphragms of cloth dipped in alkaline solution, made the air last longer for the purposes of life †.

In the same year I found that fixed air is the chief part of the elastic matter which is formed in liquids in the vinous fermentation. Van Helmont had indeed said this, and it was to this

* Dr. Black was at this time elected Professor of Medicine and Chemistry in the University of Glasgow....EDITOR.

† In the winter 1764-5, Dr. Black rendered a considerable quantity of caustic fossil alkali mild and crystalline, by causing it to filtre slowly by rags, in an apparatus which was placed above one of the spiracles in the ceiling of a church, in which a congregation of more than 1500 persons had continued near ten hours.. EDITOR.

that he first gave the name *gas silvestre*. It could not long be unknown to those occupied in brewing or making wines. But it was at random that he said it was the same with that of the Grotto del Cane in Italy, (but he supposed the identity, because both are deadly); for he had examined neither of them chemically, nor did he know that it was the air disengaged in the effervescence of alkaline substances with acids. I convinced myself of the fact by going to a brew-house with two phials, one filled with distilled water, and the other with lime-water. I emptied the first into a vat of wort fermenting briskly, holding the mouth of the phial close to the surface of the wort. I then poured some of the lime-water into it, shut it with my finger, and shook it. The lime-water became turbid immediately.

Van Helmont says, that the *dunste*, or deadly vapour of burning charcoal, is the same gas silvestre: but this was also a random conjecture. He does not even say that it extinguishes flame; yet this was known to the chemists of his day. I had now the certain means of deciding the question, since, if the same, it must be fixed air. I made several indistinct experiments as soon as the conjecture occurred to my thoughts; but they were with little contrivance or accuracy. In the evening of the same day that I discovered that it was fixed air that escaped from fermenting liquors, I made an experiment which satisfied me. Unfixing the nozzle of a pair of chamber-bellows, I put a bit of charcoal just red hot, into the wide end of it, and then quickly putting it into its place again, I plunged the pipe to the bottom of a phial, and forced the air very slowly through the charcoal, so as to maintain its combustion, but not produce a heat too suddenly for the phial to bear. When I judged that the air of the phial was completely vitiated, I poured lime-water into it, and had the pleasure of seeing it become milky in a moment.

I now admired Van Helmont's sagacity, or his fortunate conjecture; and, for some years, I took it for granted that all those vapours which extinguish flame, and are destructive of animal life, without irritating the lungs, or giving warning by their corrosive nature, are the gas silvestre of Van Helmont, or fixed air.

Some time after I had made, and published in my inaugural dissertation, the experiments you have seen, the attention of

some other persons was excited, and keenly engaged with this new and interesting subject. The late Dr. Macbride of Dublin began to attend to it, in consequence of some letters which I wrote to my friend Dr. Hutcheson, then lecturer on chemistry in Trinity College. In these letters I described to him some of my newly contrived experiments and apparatus, of which Dr. Macbride made use in his investigations.

He made a great number of experiments to shew that the air emitted from fermenting vegetables is, in all cases, an air of this kind; that it is attracted by alkaline salts and earths, and precipitates lime from lime-water. He also obtained some of this air from animal substances in a putrifying state. And he thought that when applied in quantity to putrefying animal substances, it stopped putrefaction, and even restored putrid substances to a sound state.

Concluding from what he thought was proved by his experiments, he considered this sort of air as an element necessary, or of great importance, in the composition of most kinds of matter. He imagined that the cohesion of the parts of solid bodies depends on it; and that putrefaction, and the concomitant resolution of bodies into their first principles, are entirely a consequence of the separation or loss of this kind of air, which he supposed to be the great cementing principle of solid bodies.

But this system was not well founded, and was not only not supported, but, in some measure, refuted afterwards, by the experiments and discoveries of other authors. The Doctor having observed that some effervescence or ebullition accompanies many cases of the dissolution of solid bodies by putrefaction, and some other natural operations, he supposed that in all these cases, air like this was separated from the materials, and that the separation of this air was the circumstance most effectual, or even essential to the dissolution.

But, by a little more knowledge of chemistry, he would soon have learned that he was wrong with respect to a great number of such cases; for later experiments on the putrefaction of animal substances have shewn that the elastic fluid matter emitted by these is only in part this kind of air,....by

much the greater part being an inflammable vapour, and other kinds.

Next after Dr. Macbride, the Honourable Henry Cavendish published, in the Philosophical Transactions 1765, some neat and ingenious experiments on this sort of air and some other elastic fluids.

He, in the first place, shewed that this air, when separated from alkalis or earths by acids, is beyond all doubt a permanent elastic fluid. He kept some of it twelve months in a vessel inverted into mercury, without any diminution of its elasticity.

Dr. Macbride had before discovered that water could absorb a quantity of this air, and become thereby capable of precipitating lime from lime-water. Mr. Cavendish demonstrated this by more decisive experiments, and has determined the full quantity which the water can absorb. When of a middle temperature of heat, or about 55°, it will absorb rather more than an equal bulk.

From Mr. Cavendish's experiments, it appears that when the water is warm, it does not absorb the air so readily, nor so much of it. and after cold water is saturated with it, if we make it hot to a certain degree, the air is separated, forming itself into bubbles which arise out of the water. It also escapes slowly and imperceptibly, if the water be left in an open vessel, atmospherical air having rather more attraction for this sort of air than water has.

Mr. Cavendish also discovered that other fluids beside water can absorb some of this air; as spirit of wine, which absorbs more than twice its bulk; and some of the oils absorb as much as water does. In these experiments with water and other fluids, he thought there was reason to infer that this air is not homogeneous, but that some parts of it are more absorbable than the rest, and that a certain part of it could not be absorbed. I suspect, however, that this was a deception, proceeding from the common air which water contains, and which arises with the fixed air during the extrication of this last from the alkaline substances.

From some of his experiments, Mr. Cavendish calculated with great exactness the quantities of this air contained in marble, in pearl-ashes or common fixed alkali, in volatile al-

kali, and in magnesia, when these alkaline substances are in their ordinary state. And he thereby explained some phenomena which occur in mixing the alkalis with solutions of marble, or of magnesia by acids.

Thus he found that marble contained $\frac{407}{1000}$ of fixed air.

Mild volatile alkali -	$\frac{533}{1000}$
Pearl ashes - -	$\frac{285}{1000}$
Crystals of soda - -	$\frac{423}{1000}$
Magnesia - - -	$\frac{594}{1000}$

And that a certain quantity of acid saturated—

Of marble - - -	1000 grains.
Mild volatile alkali -	1661
Pearl ashes - -	1558
Crystals of soda - -	2035

Crystals of soda effervesce with a solution of chalk in an acid. They do not precipitate magnesia without heat; and a considerable effervescence attends the precipitation. Mild volatile alkali effervesces also with a solution of magnesia in an acid; and frequently does not precipitate it, but yet detaches it from the acid, and redissolves it by the fixed air which is extricated.

He also ascertained the precise density of this air, which he has shewn to be greater then that of common air, in the proportion of 157 to 100; and has shewn that the air of marble and of fermenting vegetables agree in this as well as in other respects. In consequence of this, it lies at the bottom of a vessel, and may be poured out like water. When thus poured out on a candle, it extinguishes it as water would do. It affords an amusing spectacle by letting a large soap-bubble fall on it in a vessel. The bubble rebounds from it like a football, and seems to rest on nothing. A burning candle may be held in it, having the top of the wick about half an inch under the surface, in which case the flame will continue for a few seconds, but altogether detached from the candle. The wick remains hot enough to cause the tallow still to evaporate; and the vapour kindles at the surface of the fixed air. The floor of the Grotto del Cane, in Italy, is lower than the door; and this hollow is always filled with fixed air, which can rise no higher than the cill, or threshold of the door, but flows out like water. If a dog go in, he is im-

mersed in the fixed air, and dies immediately. But a man goes in with safety, because his mouth is far above the surface of this deleterious air.

He also mixed this air with common air, in different proportions to discover what effect these mixtures had upon flame or burning bodies. All his experiments are ingeniously contrived, and executed with accuracy.

Immediately after Mr. Cavendish had published his experiments, some of them, particularly those which shew that water is capable of absorbing such a large quantity of this air, recalled the attention of Dr. Brownrigg to an opinion he had long entertained, and had communicated, with his reasons for it, to the Royal Society so early as the year 1741. The Doctor had been at Spa, where the appearance of the waters had drawn his attention. They are among the most remarkable of those waters called *acidulæ*. They have a pleasant light acidity and briskness, and sparkle in the glass like a fermented liquor. They appear as if something very elastic and volatile were contained in them. He also observed, that not far from their fountain, there are caverns which contain the choke-damp, and that something like the choke-damp hovers upon the water, by which ducks are killed.

He therefore supposed that the waters derived these qualities from a quantity of this choke-damp combined with the water, the nature of which choke-damp, however, was at that time unknown, excepting its power to kill animals immersed in it, and to extinguish flame.

When Dr. Brownrigg saw Mr. Cavendish's experiments, he became still more inclined to this opinion of the nature of the waters at Spa; and very soon after going back to that place, he gave a full demonstration or proof of it, in a number of experiments made with the waters on the spot; which shewed that they do in reality contain a considerable quantity of a sort of air, which, when separated from the water by heat, kills animals. And it further appeared, by the experiments of others, that common water, when combined with this sort of air, extracted by art from alkaline substances, acquires all the remarkable qualities of the acidulous mineral waters. From hence has arisin the art of imitating those

waters exactly, by an artificial compound of this air with water, by small additions of some of the salts, or alkaline earths, or iron, which, by accurate analysis, have been found variously mixed in the composition of mineral waters. When this air is combined with pure water, the water acquires the briskness and light sourish pungent taste of the acidulous mineral waters; and, like them, has the power to change the infusion of litmus to a red colour.

Thus, Dr. Brownrigg explained some of the qualities of the most remarkable mineral waters, which had never before been well understood. But our knowledge of some varieties of natural waters was made still more perfect by the further discoveries of Mr. Cavendish and Mr. Lane. Many waters are well known to have a petrifying quality. They deposit a calcareous earth in the pores or on the surface of different substances which are exposed to them: or at least they cover the insides of tea-kettles with a calcareous incrustation. There are other waters which contain a small quantity of iron dissolved in them, but which are sure to deposit the whole of it in the form of ochre, if they are exposed to the air, or are corked up in bottles not sufficiently close. Mr. Cavendish, while employed in examining a water near London, at Rathbone Place, discovered that calcareous earth can be dissolved by aërated water; that it is deposited when such water is deprived of its air; and that the water of Rathbone Place actually contained calcareous earth dissolved in this manner.

This discovery explains the nature of most petrifying waters. They contain a small quantity of calcareous earth, dissolved in this manner, and some perhaps of the earth of magnesia: for this earth also can be dissolved by water charged with fixed air, and even more easily, and in greater quantity, than the calcareous earth. When such waters are boiled often in tea-kettles, the air is driven away by the heat; and the earth separates from the water, forming the earthy incrustation that is found on the inside of them. The earth is also deposited more slowly when such waters are long exposed to the air, or run along the surface of the ground, and suffer evaporation. The fixed air, in this case, evaporates,

and the earth often forms incrustations, and stalactites, and petrifactions.

It may appear to you surprising that the same substances which, added to lime-water, precipitate the lime, by making it insoluble, should also be the cause of its redissolution when added in larger quantity. But the fact is certain, and it is not singular. There are many other facts in chemistry which are similar to it: for example, most of the compound salts can be made more soluble in water than they are in their perfect or neutral state, by adding to them a superfluous quantity of acid. A certain quantity of this superfluous acid joins itself to the compound salt with a weak attraction, and forms an acidulous compound salt, which is more soluble in water than the perfect neutral. There is no exception to this but in the compounds with acid of tartar, which, in this acidulous state, are less soluble than in their neutral state; and differ also in this, that the superfluous acid is strongly united. All the other compound salts become more soluble in water by being acidulated with some superfluous acid; which however adheres to them with an attraction that is very weak. The phenomenon you have now seen appears to be analogous to this. The first effect of the aërated water on the lime-water is to precipitate the lime, by supplying it with that quantity of fixed air which changes the lime into chalk, which, though not perfectly insoluble, is very nearly so. But after this, if we add more of the aërated water, a superfluous quantity of fixed air joins itself to this chalk, and forms what may be called *acidulous chalk*, which is more soluble than chalk. But this superfluous quantity of fixed air adheres to the chalk with a weak attraction, and is separated and driven off from it by the heat of boiling water, and also by the attraction of atmospherical air. We cannot therefore reduce this acidulous chalk to a dry state. It is sure to lose its superfluous quantity of fixed air when we attempt to evaporate the water from it; and then it becomes common chalk. The solution of a saline crystal is also analogous to this phenomenon.

From all this, you will easily understand the necessity of one step of the process, which I recommended, for preparing magnesia from Epsom salt. The step I mean is the boiling

over the fire, for a little while, the mixture which contains the solution of Epsom salt and the solution of potash, by which the magnesia is precipitated.

The reason of the necessity for boiling this mixture is, that a great quantity of fixed alkali is necessary for the complete precipitation of the magnesia: and this proceeds from the great quantity of acid which is united to the magnesia in Epsom salt. I found that one pound of pearl ashes, or little less, is necessary for precipitating the magnesia completely from a pound of Epsom salt, although that salt contains one half of its weight of water in its crystals.

When the pound of alkali therefore unites with the acid, although there is no visible effervescence, so great a quantity of air is extricated from it, that this air is sufficient, not only for saturating the magnesia, but for acidulating both it and the cold water with which the mixture is made; and consequently, a great part of the acidulated magnesia is dissolved in the acidulous water. But the mixture being boiled, the superfluous air evaporates from the water and from the magnesia; and thus the magnesia is completely precipitated. This procedure, which explains a very extensive and curious natural phenomenon, was discovered by Mr. Cavendish. The nature of the volatile chalybeate waters, which, when fresh from the spring, hold some iron in solution, and sparkle in the glass, but lose their briskness and inky taste by careless keeping, and gradually deposit the iron in form of a red, or brown, or yellow ochre, were explained in the same manner by Mr. Lane. The iron had been dissolved by the acidulous water containing fixed air.

It will perhaps appear to some of you surprising that any physician should have been so bold as to think of giving this substance internally, when it is known to extinguish life so suddenly when applied to the lungs and organs of smell (for this seems a necessary condition). But the truth is, that these dangerous and fatal effects of it happen only if applied in that particular manner. It has no such effect when applied to the nerves of the stomach, or other parts. On the contrary, we have daily experience that it is grateful to the stomach, and has a most agreeable, refreshing, and cooling effect when applied there. This appears, both from the agreeable effect

of acidulous waters on the stomach, and from that of very brisk fermented liquors, such as champagne, beer, &c. which are highly grateful in hot climates. Even to the lungs, fixed air may be applied, not only with safety, but even with advantage, as we are informed by practitioners, who have tried it in consumption and ulcerated lungs. But it must be employed with four or five times its bulk of atmospherical air, or even in a greater proportion. Were it to be breathed in considerable quantity in its pure state, I have no doubt but that it would extinguish life in a short time.

Those who ventured to apply fixed air to the lungs, were induced to this by observing its effects on some very bad external ulcers, to which it proved an useful stimulant, and a powerful corrector of the putrid and acrid humours which bad ulcers often emit.

The first physician who formed an opinion of the salutary qualities of fixed air, was, I think, the late Dr. Macbride of Dublin. His opinion was formed very much on the theoretical views which I mentioned lately. Dr. Percival, of Manchester, esteems fixed air highly medicinal in pulmonic consumptions, and in maglinant fevers. The happiest effects have been experienced from the use of it, both external and internal. And he says that he does not know a more powerful remedy for foul ulcers, as it mitigates pain, promotes a good digestion of the sore, and corrects the putrid disposition of the fluids. He thought that he had reason to infer from several experiments that water with fixed air is a solvent of the urinary calculus; and that the urine of a person who drinks plentifully of such water becomes strongly impregnated with the fixed air, and dissolves the calculus. Some calculi are best dissolved by alkalis; others by acids. but fixed air acts on them all.

The late Dr. Dobson of Liverpool, afterwards of Bath, has published a number of cases in which he found it very useful and salutary; particularly, in putrid fevers, in the cure of ill-conditioned ulcers, and in certain relaxed and debilitated states of the stomach, occasioning want of appetite and indigestion. But he did not find it effectual in relieving symptoms of the stone and gravel; though it proved often useful in ulceration of the organs.

The *aqua acalina aërata* is certainly an excellent medicine in calculous cases,....not as a solvent, but as a most effectual palliative, ascertained by experience. I know no solvent to be relied on. Caustic alkali is very powerful: but, that it may not act on the bladder itself, it must be so employed, that its action on the calculus is very slow; and the patient is fatigued and tires. The aërated alkaline water continues agreeable.

I have now considered, at as great length as was proper, the properties of fixed air, considered as an object of chemistry, and have taken notice of its natural history, or the forms in which we meet with it, and also of the many sources from which it may be obtained by art. But there remain some observations on it, from which we are led to assign it a more remote origin, shewing it to be itself a compound substance. Soon after its properties and particular nature were fully made known by the gentlemen who occupied themselves so seriously with this discovery of mine, various opinions were formed as to its real origin. All these opinions were connected with the belief of the existence of a phlogiston; and, in one way or another, I believe all of them considered fixed air as an emanation from inflammable bodies, or as a compound of air with their inflammable principle, or something containing it. This was almost an unavoidable inference from our observing, that all fuel, and inflammable substances commonly employed for producing a burning heat, when burned in air, produce a great quantity of fixed air, and diminish the quantity of air in which they burn: and as all fixed air appeared to be of the same nature, phlogistication appeared the only way of producing it from such a variety of bodies.

But it was afterwards found that some bodies, not familiar indeed as fuel, or ever employed as such, yet which burn with great vivacity, spoil the air, making it lethal, and unfit for maintaining flame, yet void of the acid quality of fixed air, without attraction for alkalis or calcareous earth, and causing no precipitation of lime from lime-water. This is the case with sulphur, with phosphorus, with zinc, and some other metals, which we know burn like a bit of charcoal, or even with flame.

This was, I think, the first observation that made any change in the opinions formed on this subject, and caused the chemists to seek for the circumstance of resemblance among all the fuels whose combustion produced fixed air. I cannot say who was the first who observed that all such fuels will be changed, in one way or another, by great heats in close vessels, into what we call charcoal.* This is the case with all animal and vegetable substances in their natural state. Careful observation, and a well conducted chemical analysis, shew this to be equally true with respect to all the substances which art can any how extract from them, or form by mixing them. Even spirit of wine and æther, when properly treated, afford charcoal. One simple mode of treatment will have this effect on all. This is to mix them with vitriolic acid, so as to force them to stand a strong red heat along with it. Sulphurous acid is always produced, and sometimes real sulphur; but, at the same time, there is a black residuum in the retort, which is found a perfect charcoal. I believe it was among the French chemists who were associated with Mr. Lavoisier in his ingenious investigations, that the universality of this fact was first observed.

All such fuels produce fixed air by their combustion. Vegetable and animal substances alone are subject to the vinous and putrescent fermentations which emit fixed air. Charcoal seems the only common principle among them, distinguishing them from other combustible bodies. It was, therefore, a natural inference that charcoal is the primitive source of fixed air. Accordingly Mr. Lavoisier assumes charcoal for the radical or characteristic ingredient of this acid gas. But as common charcoal, from whatever substance we obtain it, contains an earthy uninflammable part, Mr. Lavoisier desires it to be understood, that it is the pure inflammable part only that he considers as the radical of fixed air; and, to distinguish this from any compound, he uses the word CARBONE. He considers fixed air, therefore, as a compound of oxygen and carbone, in the same manner as the vitriolic acid is considered by him as compounded of oxygen and sulphur. And, as he calls this the sulphuric acid, he calls fixed air the CARBONIC ACID.

* Dr. Hooke says this in many parts of his Cutlerian Lectures.....EDITOR.

Mr. Lavoisier has made some very ingenious experiments, which seem to demonstrate this composition. He burned small quantities of charcoal in pure oxygen gas, in close vessels, and he found that a part of this gas was converted into fixed air. He separated this from the rest of the oxygen by means of caustic alkali, and weighed the alkali after it had attracted the fixed air. He also expelled the air again by an acid, and examined its bulk. Thus he learned the weight of the air, and what measure of it had been produced. Then, comparing this weight with that lost by the charcoal which had been consumed, he found it to exceed greatly the weight of the charcoal, and was exactly equal to the weight of the charcoal and of that portion of the oxygen gas which had been changed into fixed air. He found that 100 grains of carbonic acid contained 72 grains of oxygen gas and 28 grains of carbone. This composition and this proportion of the ingredients, have been confirmed by many other direct experiments of the same kind; and they agree surprisingly with the results of more complicated experiments, in which this proportion is taken for granted in the explanation of other phenomena. I therefore readily adopt his denomination of carbonic acid as extremely proper, indicating the nature of the substance.

It appears then, from some experiments which have been mentioned occasionally, that this carbonaceous matter is separated and thrown off from the blood in the lungs in the act of respiration: for air that has been breathed always contains carbonic acid. In proportion to the quantity of this acid which air contains, it is deficient in its due proportion of free oxygen gas, a part of it having been changed into carbonic acid, by meeting with carbone in the lungs. This has been ascertained by the experiments of Scheele, Lavoisier, Dr. Goodwin, and Dr. Menzies; which two last gentlemen have published good experiments on this subject in their inaugural dissertations.

You will, therefore, easily understand what happens when atmospherical air passes through burning fuel. The oxygenous part of that air, and the carbone of some of the charcoal, unite and form a quantity of carbonic acid; and, when the air arise

from burning fuel, instead of being a mixture of foul air and oxygen gas, as it was before, it is now a mixture of this foul air, carbonic acid, and the remainder of oxygen gas, which has not yet been saturated with carbone, but would become saturated by a somewhat longer and more effectual application of the one to the other. The heat, which is produced in great quantity on this occasion, is supposed to have come chiefly from the oxygen gas, which, becoming more dense, and having its capacity for heat diminished by this condensation must throw out a considerable portion of heat which it previously contained, and along with the heat a quantity of light, which is perhaps the same matter, acting or modified in a different manner.*

Other names have been given to this fluid by the many chemists who were occupied on these subjects. I called it fixed air, because it was found by me fixed in a number of substances. Mr. Cavendish changed this name to fixable air. Many preferred the name gas, and called it acidulous gas. Mr. Henry of Manchester, and Professor Bergmann, called it the aërial acid. Mr. Fourcroy called it *acide erayeux*,....acid of chalk; but all seem now agreed in giving it the scientific name carbonic acid.

In conformity with the general plan of their reformed chemical language, the French chemists have named the compounds which contain this acid *carbonats*. Thus, chalk or limestone is the *carbonat of lime;* mild vegetable alkali is the *carbonat of potash;* mild fossil alkali is the *carbonat of soda;* crude magnesia the *carbonat of magnesia;* and mild volatile alkali the *carbonat of ammonia*, &c.

Thus, gentlemen, have I thrown together the chief discoveries which have been made concerning the nature and chemi-

* This Lavoisierian theory of the combustion of charcoal is precisely the same with that published by Dr. Hooke in his Micrographia, in 1664-5, (page 103), as a general theory of combustion. All combustion is, according to him the solution of what we call the combustible body in the pure nitro-aërial spirit which makes part of the atmosphere. In the case of certain bodies, there is not only no incombustible or recrementitious matter, but the compound itself is volatile, and is dispersed in the air. The great heat proceeds entirely from the nitro-aërial spirit; and the light is the the vibratory pulse produced in the æther, whose undulations produce in us the sensation of light.....EDITOR.

cal properties of the elastic fluid which I discovered in 1756. These discoveries have been made at very different times, and by many different authors. For the public attention continued for a long while to be very much turned to this substance, which comes so often in our way in chemical processes, and also in the great operations of nature. The curiosity of philosophers being thus turned to a very novel kind of object, an elastic fluid, this gave rise to a new kind of manipulation, and a new apparatus, and a manner of management equally novel,....all which made it give much entertainment. And in this new path a number of other objects of the same uncommon kind came in their way, and increased the interest taken in the study. Curious chemists even tried to produce new airs, as they were called, by every possible means, in expectation of singular results and discoveries; and thus has arisen a quite new species of chemistry, which may be called PNEUMATIC CHEMISTRY, because occupied in the study of fluids permanently elastic, like air. In the prosecution of these investigations, chemical apparatus was greatly improved; and we can now manage those slippery substances as easily as we formerly managed the solids and liquids in our ordinary vessels. The boundaries of chemistry have been wonderfully enlarged, and discoveries have been made of the most unexpected nature. Common water, which, from the dawn of natural science, has been considered as an unchangeable element, is now found to be a compound of two kinds of air. Diamond, seemingly the purest and most unchangeable of things, is now found to be coal. And all our former notions of chemical relations are now changed.

Among these new chemists, Dr. Priestley is certainly one of the most eminent. He was one of the first in respect of time; and he has surpassed them all in the number and variety of his experiments, and I may add, in his discoveries. Dr. Priestley first narrated a number of experiments on fixed air and some other elastic fluids, in several succeeding volumes of the Philosophical Transactions in 1772, &c. and then published them in several separate volumes. The elastic fluids which engaged his attention were, 1*st*, *Fixed Aair*. 2*d*, *Atmospheric Air*, in its ordinary state, and as changed or vitiated for the purposes of

life by various means. 3*d*, What he called *Marine Acid Air*, which is nothing else than the incoercible vapours of pure muriatic acid without water to condense it. 4*th*, The incoercible vapours of the suffocating sulphurous acid, named by him *Vitriolic Acid Air*. 5*th*, The incoercible vapours of pure volatile alkali, which he calls *Alkaline Air*. 6*th*, The highly inflammable elastic fluid which we have long known by the name of *Inflammable Air*. 7*th*, The incoercible vapours which escape from a solution of metals in nitrous acid, which he calls *Nitrous Air*. 8*th*, That surprising sort of air in which inflammable substances burn with extraordinary rapidity and brightness, and which supports animal life and flame four or five times better than common air. This he called *Dephlogisticated Air*. In giving the name air to some of these elastic fluids, he followed the practice of others. But he was the first who applied this term to them all. He has not been followed in this practice by many chemists. The most general practice has been, to denominate all permanently elastic fluids, except air, gas,.... a name first given by Van Helmont to the vapour which is emitted by fluids in the vinous fermentation. *

Dr. Priestley's writings contain the description of various and very curious experiments, by applying water and many other substances to these airs; by exposing in them living ani-

* This is probably a latinisation of *gæscht*, a vulgar word for leaven, whence we have our word yeast; it is likely derived from *gahren*, to ferment. Van Helmont calls the vapour emitted by fermenting liquors, *gas silvestre*, an epithet borrowed from Paracelsus, who calls it *spiritus silvestris*. Van Helmont considers this as of the same kind with that of the Grotto del Cane in Italy, because both kill breathing animals and extinguish flame. He mentions, however, several such vapours which he considers as of a different nature,....*gas ventosum*,....*flammeum*,....*pingue*, &c.; and he says, that these gases do not exist in their elastic form in the bodies from which they proceed,....nor indeed exist at all in them, but arise from new combinations of the ingredients, which cannot exist in a solid or liquid form, but which require particular circumstances to change their former combinations, and enable the ingredients to form these new ones. His notions on this subject are wonderfully sagacious, and even precise, considering the time in which he wrote, when vague and indistinct conceptions seemed to be more generally acceptable. (See his *Complexionum atque Mixtionum elementarium Figmentum*.)

EDITOR.

mals and vegetables, or animal and vegetable substances under the vinous, acetous, or putrescent fermentation; by burning bodies, or by calcining or reducing metals in them; or by mixing the different airs together, and treating the mixtures with great heats, or the electrical spark, &c. He notices many properties of the air which we have been so minutely considering; but I suspect that he has not good authority for some of his notions on this subject. He has made many surprising discoveries. But his experiments are so numerous, and the succession in which they were made and published is such, that no general account can be given of them. It will be better for you to read his own accounts of them, when you are farther advanced in this course: for you must be acquainted with a great many more chemical substances and general facts, before you can peruse Dr. Priestley's writings so as to understand them. I shall have occasion, in the rest of this course, to notice the greatest part of his leading experiments and discoveries.

Soon after Dr. Priestley, or much about the same time, the late Mr. Lavoisier in France, a gentleman distinguished for his love of science, and particularly of chemistry, eminent also for a penetrating genius, sound judgment, and logical accuracy; and having an ample fortune, which enabled him to execute the most extensive and costly experiments,....this gentleman, I say, made and published experiments on this very subject. He began, by repeating with scrupulous exactness, and on a large scale, and with fine instruments, the experiments already made by others. But he afterwards pushed on his investigations much farther, and made some decisive experiments, which led him to great discoveries, and enabled him to explain many general phenomena of nature, and to compose a new system or theory exceedingly ingenious and ably supported by numerous and convincing experiments. This theory has changed the whole face of chemistry. I shall have an opportunity very soon to take further notice of the outlines at least of this new chemical philosophy.

While Dr. Priestley in England, and others elsewhere, were attending to these objects, Dr. Scheele of Sweden, whom I formerly had occasion to mention, engaged in an inquiry into the

nature of fire and light and heat; and, without any knowledge of what was done and doing by others, carried on a most ingenious investigation, in which he was led, by the train of his researches, to make many of the experiments and discoveries already made by these gentlemen. He added many of his own. His work has been translated, but very badly indeed, by J. Rheinhold Foster, and is entitled, "Scheele on Fire."

Among the remarkable discoveries which these experiments on gases have produced, perhaps the chief is that of VITAL AIR, by Dr. Priestley. It is this, in combination with Lavoisier's theory of combustion, that has totally changed our notions of the chemical relations of most substances, and made a revolution in all the leading doctrines of chemistry. I have already taken notice of its remarkable property, when we were considering the decomposition of nitre, in order to obtain its acid. We shall meet with it again, almost at every step; and its various chemical relations will be discovered as we proceed.

Scarcely inferior to vital air in chemical importance is the *foul air* of Dr. Scheele, which I mentioned on the same occasion, as that noxious portion of atmospherical air which remains when the vital air has been absorbed by the *hepar sulphuris*. I must here observe, that this portion of our atmosphere was first observed in 1772 by my colleague Dr. Rutherford, and published by him in his inaugural dissertation. He had then discovered that we were mistaken in supposing that all noxious air was the fixed air which I had discovered. He says, that after this has been removed by caustic alkali or lime, a very large proportion of the air remains, which extinguishes life and flame in an instant.

Soon after this, Dr. Priestley met with this noxious air, which was produced in a variety of experiments, in which bodies were burned, or putrified, or thickened in certain cases, or metals calcined, or minerals effloresced, &c. &c. In all these cases, he thought that he had reason to believe that phlogiston had quitted the substances under consideration,....had combined with the air,....and had thus vitiated it. Now saturated with phlogiston, the air could take no more, and therefore extinguished flame. He called all these processes *phlogisticating processes*, and the air thus tainted *phlogisticated air*.

In these processes the air was not only spoiled, but also diminished in bulk. This had been observed long before by Boyle and Hales. They ascribed this to a diminution of its elasticity. Dr. Priestley ascribed it to the precipitation of fixed air. Mr. Cavendish ascribed it to the combination of some of its ingredients in such a manner as to form water. His celebrated experiment, by which he demonstrated the composition of water, will be mentioned particularly in another place.

Dr. Scheele chanced to take a very different view of the whole of this subject,....led to his singular notion of it by some preconceived and very strange theory of fire and heat. But Scheele found that this diminution of bulk was owing to a real abstraction of all the vital air which the atmospheric air contained. For when any of these phlogisticating processes of Dr. Priestley were performed in vital air, it was *totally* absorbed. The remainder therefore, when the experiment was made in common air, was considered by him as a primitive air, unchanged in its properties. He called it *faul air*, which may mean either *rotten* air, because it is produced in vast abundance by putrefying bodies, or simply *foul air*, i. e. tainted occasionally, when the phlogiston is more than will saturate the vital air. When he burned phosphorus in atmospheric air, he found the remaining noxious air free from all admixture.

Mr. Berthollet obtained this faul air, not only from animal and vegetable substances in the putrefactive fermentation, but also in great abundance, by pouring nitric acid on the fresh muscular fibre. Fourcroy found that it was contained almost pure in the swimming bladders of carp, bream, and other fishes. Other chemists have found it in volatile alkali, as will be particularly noticed afterwards.

In all these methods of procuring it, it must be cleared from fixed air by means of lime or caustic ley.

This air, having been procured in so many different ways, appeared in different lights to the discoverers, as you have seen, and got different names,....phlogisticated,....foul,....mephitic,.... choke-damp (in German), &c. Mr. Chaptal, and other chemists of the first rank, gave it still another, and perhaps more proper name, calling it *nitrogen*. This took its rise from a celebrated

discovery of Mr. Cavendish, recorded in the Philosophical Transactions of 1783. A train of experiments, begun several years before, ended in his combining seven parts of oxygen and three of this air, by means of repeated discharges of electricity. The mixture was wholly absorbed by a solution of potash, and *formed perfect nitre*. Therefore, he concluded that this proportion of these two airs composes that remarkable substance, nitrous acid. Hence these gentlemen called this gas nitrogen, with as much propriety as inflammable air was called hydrogen. But Mr. Lavoisier, after having repeated the experiment of Cavendish with complete success, and after being convinced, by the comparison of numberless facts, and particularly, after reflecting on all the processes for producing saltpetre, all of which employ animal and vegetable substances in a state of putrescence, in the free air,....after this full conviction that this was really the composition of nitrous acid, rejected the appellation of nitrogen, and called it AZOTIC GAS, from its deleterious quality. This denomination has taken place of all others; and I shall abide by it in the rest of the course, although I think that a better name might have been found than this, which really is no distinction, because all the gases are azotic, that is, deadly to breathing animals, except those which contain a very great proportion of oxygen gas, or vital air. *(See Note* 37. *at the end of the Volume.)*

In the mean time, this discovery by Mr. Cavendish is one of the most important in the whole science of chemistry. I mean, the discovery that AZOTE is the radical or characteristic ingredient of the nitrous acid. I have given you only that simple fact, by which the truth of this doctrine was established by that gentleman. Numberless proofs, both by composition and decomposition, will come before us, as we proceed in the examination of other bodies. I only remark at present, that the proportion of ingredients, in the experiment of Mr. Cavendish, corresponds to the most fuming state of the acid that can be prepared. It is even redundant in azote, which the nature of the experiment did not permit Mr. Cavendish to observe. The acids are susceptible of different proportions of oxygen, as we shall afterwards see clearly; and, in these different states, they are

permanent, and have very distinct properties and modes of action. None of them is so remarkable in this respect as the nitric acid. And the knowledge of its distinctions will lead us through the most intricate paths of the investigation yet before us,....so that it is with great justice that I have said that this discovery by Mr. Cavendish is one of the most important in the science.

In nitric acid, which is its most perfect state as an acid, the proportion of oxygen to azote is nearly that of 80 to 20. Nitrous acid, or *spiritus nitri fumans Glauberi*, has that of 75 to 25. Nitrous gas, which escapes from nitrous acid when inflammable substances are mixed with it, has the proportion 68 to 32 nearly. But this is scarcely, if at all acid. You will learn all this by degrees, when you previously know the nature of the substances mixed with the perfect acid.

With respect to the other properties of azote, I cannot say much at present, because you know as yet but few of the substances to which those properties relate.

It is rarer than common air, about $\frac{1}{18}$th. The specific gravities of atmospheric air, oxygenous gas, and azotic gas, are 1,0000, 1,0625, and 0,9444 *.

Azotic gas does not mix with water.

It has no acidity. It does not affect the ordinary test colours, nor contract any union with alkaline substances: therefore it does not precipitate lime from lime-water.

Although it combines with oxygen, by means of the electric spark, and composes nitrous acid, and although there is always this mixture in the air, we do not find nitrous acid there. These gases are susceptible of simple commixtion, as water mixes with spirits, or one metal with another, yet they retain their properties unchanged, like the mixtures now mentioned. It is not simply a high temperature that will cause them to combine:

* A thousand cubic inches, or a box, whose length, breadth, and depth is 10 inches, contains, in the ordinary pressure of the atmosphere, and temperature 55° of Fahrenheit, very nearly the following quantities:

Common air	315 grains Troy.	One inch =	0,315
Oxygenous gas	335		0,335
Azotic gas	297		0,297

EDITOR.

for they do not combine when forced through a red hot tube of glass. *(See Note 38. at the end of the Volume.)*

I have been led into this long digression by the experiments adduced in support of the third proposition of my theory of lime. These gave me an opportunity of explaining to you, by means of the acquaintance which you have already acquired with several chemical substances, the properties of the three remarkable gases,....fixed air, vital air, and foul air; or, as I shall now call them, carbonic acid gas, oxygenous gas, and azotic gas. The knowledge of their leading properties will greatly expedite our progress through the rest of this course. I now return to the theory of quicklime.

The experiments made to try the fourth and fifth propositions were found to agree equally well with the theory. Several of them concurred, in the first place, to shew that the caustic alkalis do not contain any lime or limy matter combined with them. I satisfied myself of this by three trials: 1*st*, Evaporation to dryness, and examination of the dry caustic alkali. 2*d*, Saturation with sulphuric acid. This, if there be any lime, should produce a selenite almost insoluble in water. I found none. I observe some experiments of others in which a precipitate was observed; but, by the very account given, it appears to have been vitriolated tartar, which a large quantity of hot water would have dissolved. 3*d*, Exposition to the atmosphere, to learn whether crusts of calcareous earth would be formed on its surface, like those on lime-water. But no such thing appeared. All these trials verified the fourth proposition, shewing that caustic alkalis contain no lime.

And in my experiments relative to the fifth proposition, I succeeded perfectly in changing the calcareous earth into lime, without exposing it to the action of heat. The precipitate from a muriate of lime by a truly caustic alkali proved a perfect quicklime dissolving completely in water, and making lime-water.

It now it appears that by whatever way we contrive to separate the carbonic acid from calcareous earth, even without mak-

ing use of fire, the earth is thereby rendered active, and appears in the state of acrid and soluble lime. We have, therefore, abundance of reason to conclude, that the state of solubility and activity of this earth depend on its being simply reduced to a state of purity, or freed from the carbonic acid with which it is combined in its natural state. The same conclusion must also be admitted with respect to the volatile alkali, when we consider the processes by which it is made to appear in its caustic or most active form. The particular nature of this alkali enables us to deprive it of its carbonic acid, or make it free of it, by a greater variety of methods than can be followed with either of the fixed alkalis, or with quicklime. And, whatever way we take to free it from this acid, we are sure to find it caustic, or in its liquid, or its highly acrid and volatile form. The common way of obtaining it is by decomposing sal ammoniac by quicklime. In the ammoniacal salt it has no carbonic acid. It is plain that it must also be obtained in the same state, for the same reason, if the sal ammoniac be decomposed by the action of a caustic fixed alkali. Accordingly, in this way also are we sure to have the volatile alkali in a caustic state. But what may appear the most satisfactory, is a way discovered by Mr. Margraaf for obtaining a volatile alkali from an ammoniacal salt by heat alone,....namely, from the essential salt of urine, or microcosmic salt. This salt is an ammoniacal salt, at least in part, or contains the volatile alkali, which may be separated, as from other ammoniacal salts, by either fixed alkali or by quicklime. And, in these cases, we obtain the volatile alkali in the same state as we would obtain it by the same processes from other ammoniacal salts. But Mr. Margraaf discovered that the sal microcosmi will yield its volatile alkali by the action of heat alone, because the acid is of the most fixed kind. He put some of this salt into a retort, and fitted to it a receiver having a small perforation. First of all escaped some incondensible matters with which we are now pretty well acquainted. These were followed by the volatile alkali in a most pungent state. Some of it condensed with water in the receiver: and he was surprised to find that it did not effervesce with acids.

There is, therefore, no doubt, that if we could separate the fixed alkali from an acid by an operation as simple, we should have it also in a caustic form. But I am not acquainted with any instance of such separation in chemistry. There are two which might at first sight appear of this kind. The first is the separation of the fixed alkali from nitric acid by deflagration with charcoal; and the second, its separation from the vegetable acid merely by heat. But in neither of these cases is the alkali obtained free from carbonic acid. On the contrary, it contains a good quantity of it, and is disposed to effervesce strongly with acids. And the reason is, that in the first case the nitric acid and the charcoal, in acting upon one another, produce a great quantity of carbonic acid, of which a part, it seems, is attracted by the alkali. It is easy to understand how this carbonic acid is produced. It is produced from the charcoal, and the vital air which the nitre affords in very great quantity when exposed to the action of red heat. And in the second case, the acetous acid is not simply separated. It is destroyed by the fire, and converted into water, oil, charcoal, and a large quantity of carbonic acid, which, together with the charcoal, is found adhering to the fixed alkali*.

In every case, therefore, in which we contrive to have lime or the alkaline salts in a pure state or free from carbonic acid, we find them in their state of greatest activity, or causticity, as it was formerly termed. And if we examine the converse of these experiments, and consider the different ways by which quicklime or the caustic alkalis may be rendered mild, we shall find that their return to a mild state is always attended with the recovery of their carbonic acid, and is evidently a consequence of it.

One example of this is the restoration of the caustic volatile alkali to its milder state, by an experiment which I made in the year 1757 or 1758, and communicated, with some others, to my friend Dr. Hutcheson, of Trinity College, Dublin, and which has been published by Dr. Macbride in his Essays, page 50. A small quantity of caustic alkali is put into a phial. In another phial an effervescing mixture

* Nitre deflagrated with zinc gives caustic alkali....EDITOR.

is put: and the fixed air expelled from it is made to pass through a siphon tube fixed into its mouth, and having the other leg inserted into the caustic alkali. By this simple, apparatus, the fixed air is made to rise through the alkali, which rapidly absorbs part of it, and soon acquires so much as to effervesce briskly with acids. If a bladder, fitted up like a common medical injection bladder, with a pipe and a cork, be distended with fixed air, and the pipe (having put in the cork) be now inserted into the phial containing the caustic alkali, and if the pipe fit the mouth of this phial so as not to allow air to get past it, then, on pulling out the cork, the compressed fixed air will be forced in among the alkali, and will be gradually absorbed by it, and we shall see the bladder collapse by degrees, till perhaps all be absorbed. The alkali will now effervesce with acids. The pure fixed alkalis are also easily restored to a mild effervescent state by the same process. They absorb the carbonic acid gas very quickly, even more quickly than milk of lime; not because they have a stronger attraction for it than lime has, (for the contrary is the fact) but because we can employ a much stronger solution of these alkalis than the solution we have of lime in lime-water.

It is scarcely necessary to remark that the caustic fixed alkalis become mild also by communication with the atmosphere for a sufficient length of time; and that when they become mild in this way, it is by attracting carbonic acid. This happens more quickly than ordinary, when solutions of them are boiled over an open fire: the reason of which you will easily perceive to be the quantity of carbonic acid which is incessantly forming by the consumption of the fuel.

They are rendered mild also by adding to them a proper quantity of magnesia, that has not been calcined, (now named carbonat of magnesia) or a proper quantity of common mild volatile alkali (the carbonat of ammonia); the fixed alkalis having a stronger attraction for the carbonic acid than either of these two alkaline substances; of which I assured myself by direct and conclusive experiments.

From the knowledge we now have of the effervescence of alkaline salts with acids, it is easy to explain the very

remarkable manner in which the vegetable alkali, in its ordinary state, effervesces with some of the weaker acids, of which you saw an example, when the acetite of potash was described, and the process for preparing it.

The same phenomenon occurred to me also when I tried to make a borat of potash by saturating the common alkalis with sedative salt.

Borax has sometimes been referred to the class of alkalis, on account of some resemblance its bears to those salts. But it has been demonstrated by accurate experiments, that we should rather consider it as a neutral salt; that it is composed of an alkali, and of a particular saline substance, called the sedative salt, which adheres to the alkali in the same manner as an acid, but can be separated by the addition of any acid whatever, the added acid joining itself to the alkali in place of the sedative salt. As this conjunction of an acid with the alkali of borax happens without the least effervescence, our principles lay us under a necessity of allowing that alkali to be perfectly free of air, which must proceed from its being incapable of union with fixed air, and with the sedative salt, at the same time: whence it follows, that were we to mix the sedative salt with an alkali saturated with air, the air would immediately be expelled, or the two salts, in joining, would produce an effervescence. This I found to be really the case, upon making the trial, by mixing a small quantity of the sedative salt with an equal quantity of each of the three alkalis, rubbing the mixtures well in a mortar, and adding a little water. It is, however, proper in this place to observe, that if the experiments be made in a different manner, they are attended with a singular circumstance. If a small quantity of the sedative salt be thrown into a large proportion of a dissolved fixed alkali, the sedative salt gradually disappears, and is united to the alkali without any effervescence. But, if the addition be repeated several times, it will at last be accompanied with a brisk effervescence, which will become more and more remarkable, until the alkali be entirely saturated with the sedative salt.

This phenomenon may be explained by considering the fixed alkalis as not perfectly saturated with air: and the supposition will appear very reasonable, when we recollect that

those salts are never produced without a considerable degree of heat, which may easily be imagined to dissipate a small portion of so volatile a body as air. Now, if a small quantity of the sedative salt be thrown into an alkaline liquor, as it is very slowly dissolved by water, its particles are very gradually mixed with the atoms of the alkali. They are most strongly attracted by such of those atoms as are destitute of air, and therefore join with them without producing an effervescence; or, if they expel a small quantity of air from some of the salt, this air is at the same time absorbed by such of the contiguous particles of it as are destitute of it; and no effervescence appears, until that part of the alkali which was in a caustic form, or destitute of air, be nearly saturated with the sedative salt. But if, on the other hand, a large proportion of the sedative salt be perfectly and suddenly mixed with the alkali, the whole, or a large part of the air, is as suddenly expelled.

In the same manner, we may also explain a similar phenomenon, which often presents itself in saturating an alkali with the different acids. The effervescence is less considerable in the first additions of acid, and becomes more violent as the mixture approaches the point of saturation. This appears most evidently in making the sal diureticus, or regenerated tartar. The particles of the vegetable acid here employed, being always diffused through a large quantity of water, are more gradually applied to those of the alkali; and, during the first additions, are chiefly united to those that are freest of air.

But still this explication rested on a supposition, and there was no necessity for letting it rest there. It was easy to try whether this supposition was agreeable to truth by an experiment.

I exposed a small quantity of a pure vegetable fixed alkali to the air, in a broad and shallow vessel, for the space of two months; after which I found a number of solid crystals, which resembled a neutral salt so much, as to retain their form pretty well in the air, and to produce a considerable degree of cold when dissolved in water. Their taste was much milder than that of ordinary salt of tartar: and yet they seemed to be composed only of the alkali, and of a

larger quantity of air than is usually contained in that salt, and which had been attracted from the atmosphere: for they still joined very readily with any acid, but with a more violent effervescence than ordinary: and they could not be mixed with the smallest portion of vinegar, or of the sedative salt, without emitting a sensible quantity of air.

Thus, therefore, I learned that the fixed alkali, in the ordinary state of it, is never completely saturated with carbonic acid, or combined with the largest quantity of it which it is capable of receiving. And further experiments on this and the other alkalis shewed that they contained more or less of it according to the process by which they have been prepared, or the treatment they have undergone in preparing them; but that they may be all completely saturated by different methods, especially by exposing them to the gas of fermenting liquors, or to the gas expelled from chalk by the sulphuric acid. As they are usually prepared, I believe the mildest or most nearly saturated with fixed air, is that called black flux, which is tartar no farther burnt than to destroy the acid, and intimately mixed with charry matter, from which it may be obtained pure by lixiviation. The chemists of last century, or rather the pharmacists, mention a general class of alkaline salts by the name of salts of Tachenius, which were remarkably mild (in a medical sense). By the account given of their preparation, they must have been mild in the sense which I have affixed to the term. They were prepared from vegetables by a smothering heat, which did little more than char the plant, and must therefore have retained a great portion of carbonic acid. Pearl-ashes comes next to black flux in saturation with carbonic acid. White flux comes next to pearl-ashes, and should be followed by potash, which is often pretty acrid by long continuance in the melting heat. Of the volatile alkalis, the mildest is surely the volatile ammoniac prepared with chalk. Next to this is salt of hartshorn, tainted with much burnt oil;....*spiritus cornu cervi* is more acrid,....so is *spiritus salis ammoniaci*, as prepared with fixed alkali.

The result of all this investigation is, that the alkaline substances, in their mild state, are to be considered as compound salts, consisting of the pure alkaline substances united to the carbonic acid.

As this is to be considered as a new acid, and must be added to our list of simple salts, we have a new column to be added to the six already placed in your table of compound salts. We must, therefore, see what is to be the arrangement of this column, having carbonic acid or fixed air at the head.

1*st*, then, It is evident from the whole tenor of the investigation, that pure quicklime must be placed first in the column of alkaline substances. The process for caustic fixed alkali, and the precipitation of lime from lime-water by a mild alkali in a mild state, prove it in respect of the fossil alkalis. That the attraction of lime for carbonic acid is greater than that of the volatile alkali, is also evident by the process for caustic volatile alkali without heat, and by the precipitation of lime from lime-water in a mild state by mild volatile alkali.

Lime must also come before the pure earth of magnesia: because crude magnesia precipitates lime in a mild state from lime-water.

2*d*, The fixed alkalis come next in order: for they will render a solution of volatile alkali caustic. Moreover, a caustic ley becomes mild, or will effervesce with acids, if we put into it crude magnesia, and digest the mixture for a little while.

3*dly*, Magnesia comes before the volatile alkali: for caustic volatile alkali makes no change on crude magnesia;....but calcined magnesia will effervesce with acids after being digested with mild volatile alkali.

The column must therefore stand thus:

Carbonic Acid.
Quicklime.
Fixed alkali.
Magnesia.
Volatile alkali.

It remains to determine the proportion of the attractions of quicklime, and magnesia, and the alkalis for the other acids.

1*st*, Fixed alkali has a stronger attraction for the other acids than quicklime has. This appears from the process by which

we make quicklime, by precipitating it from a solution in any acid by means of a caustic fixed alkali. We have also seen, that fixed alkali, in its pure or caustic state, precipitates magnesia from the acids in a non-effervescent state;....and we know that it disengages the volatile alkali without heat.

2*dly*, Quicklime must have the next place: for we have seen that the precipitate by means of lime from a solution of magnesia was not a quicklime, but a pure non-effervescing magnesia. Also we found that quicklime, whether ground with sal ammoniac in a dry powdery state, or put into a solution of it in water, instantly detached the volatile alkali. It is true that a mild volatile alkali will precipitate calcareous earth from an acid. But the precipitate is a carbonat of lime: and the change has been effected by a double elective attraction, proving that the partiality of the volatile alkali for any other acid is greater than that of the quicklime. The precipitation of calcareous earth, in a mild state, by carbonat of magnesia, is explained in the same way. The precipitate is a carbonat.

I cannot decide, by any experiment that has occurred to me, whether magnesia or volatile alkali has the strongest attraction. I am therefore obliged to class these two substances in the same line of the column. And it stands thus:

Acids.
Fixed Alkali.
Quicklime.
Magnesia....Volatile Alkali.

This undetermined situation of magnesia and the volatile alkalis relates only to their mixture and action on each other in the ordinary low temperatures. For it is plain that if we employ great heats, the volatility of the ammonia disposes it to quit the more fixed base to which it is joined. Magnesia, treated along with this compound, tends, by its attraction for the acid, to repress the volatility of the acid. This will evidently still further promote the separation of the volatile alkali: and thus magnesia will certainly decompose the ammoniacal salts with

the assistance of heat, and disengage the alkali, either caustic or mild.

I cannot better conclude this inquiry, than by mentioning some important consequences which have resulted from the discovery of the carbonic acid. Besides the improvements in chemical science to which it has led us, it has also given rise to some useful inventions, and has enabled us to decide questions which occur in some of the most interesting of the arts. We know now, that the alkalis are compound salts, of immense demand in the arts of bleaching, dyeing, soap-boiling, glass-making, &c. In their ordinary state, we have learned that they contain a very considerable proportion of a substance which is of no value in those arts, that we know of as yet, and which therefore diminishes the value of the commodity. The artists who employ them can now ascertain with a certain precision, in what degree any parcel offered to them is of use, and can choose or reject, or correct them as they see occasion.

Thus, in agriculture, a question is now decided which has been often put to me,....whether fresh or acrid lime is better or worse than such as has been long exposed to the air. The effect of marles and of limestone gravel, which are known to be the most excellent of natural manures, decides this question. The only useful purposes of burning limestone seems to be the reduction of its weight, and the easy method of reducing it to powder, and thus fitting it for being uniformly spread on the ground.

The value of marles is also easily ascertained by these doctrines. Marles are valuable only in proportion to the calcareous matter they contain. Some do not hold $\frac{1}{20}$th of their weight; and it is a very rich marle that holds $\frac{1}{4}$th. Suppose a marle to contain $\frac{1}{10}$th, a farmer will consult his interest if he pay ten times the price for a cart of lime that he must pay for marle at the same distance; for he will bring home the same quantity of the useful material with $\frac{1}{10}$th of the labour and carriage.

Now of all the modes of trial of the quantity of calcareous matter in marle, the one best suited to the unlearned farmer is, to observe how much fixed air it contains. And this he will learn certainly, within $\frac{1}{50}$th of the truth, by dissolving a little of

the marle in an acid, the muriatic, for example, and observing what portion of its weight it loses. Thus, if any little quantity, suppose half an ounce, loses 40 grains he may conclude that it contained 100 grains of crude calcareous earth, or 60 grains of lime. Or he may reckon $2\frac{1}{2}$ grains of lime-stone, or $1\frac{1}{2}$ grains of lime, for every grain that his marle loses by this operation. But he must take care to make the trial in a deep glass, that sparks of water may not be lost, and computed for limestone. For the same reason, the acid must be weak, that the effervescence may be very gentle. Vinegar, however is too weak, and will not detach all the air. It becomes clammy also in the operation, which makes the froth remain on the surface for days: and this entangles much air that has been really disengaged. Let the acid be such muriatic acid as is sold in the shops. Dilute it with twice or thrice as much water, and keep it for use. Weigh the marle exactly, and also the quantity of acid which is to be poured on it, taking care that it be more than enough for dissolving all the calcareous matter. When the solution is over, after repeated agitation without more effervescence, weigh the whole. The weight lost is two-fifths of the weight of the calcareous matter.

Should we attempt to measure this by solution and precipitation, we are led into a number of examinations which will puzzle even an experienced chemist.

And having now finished the chemical history of the calcareous earth and mgnesia, I must take notice of some compounds produced by nature, in which the calcareous earth is combined with acids, and which are worthy of your attention.

Calcareous earths combined with acids.

These compounds are, 1*st*, Gypsum, or the sulphat of lime. 2*dly*, Fluor, or the fluat of lime, which is formed by a very peculiar acid not yet described. 3*dly*, Phosphat of lime, which contains another peculiar acid not yet described. 4*thly*, Borat of lime, but lately discovered, which contains the sedative salt; or boracic acid, combined with lime and with magnesia.

1....*Gypsum.*

GYPSUM, the most abundant of these calcareous compounds, was formerly considered as a peculiar species of earth. But now we are better acquainted with its nature; and are well assured that it is a compound of the calcareous earth with the sulphuric acid; or is, in the new language, a SULPHAT OF LIME.

This compound is found in nature under several forms, or in several states. The greatest part is found in the form of stony masses, which, however, are remarkably soft, so as to be easily scraped with a knife, or even with the nail. They are distinguished from alkaline earths and stones by not effervescing with acids, and from all other stony bodies, by making sulphat of potash with the mild vegetable fixed alkali, if boiled in water with this salt, or melted with it. When this vitriolated tartar is separated by repeated washing with hot water, the remaining powder is found to be a mild calcareous earth. The same materials also, with the addition of charcoal dust, form, by fusion, a *hepar sulphuris*, or *sulphurat of potash*. Thus, the ingredients of gypsum are made sufficiently evident. *(See Note* 38. *at the end of the Volume.)*

Gypsum is found in some places in great abundance. In the neighbourhood of Paris there are hills chiefly composed of it. In most places where it occurs, it is intermixed with a marly clay, forming separate masses interspersed through the stratum: and it is also sometimes found in veins. When pure, it is white and semi-transparent in the larger masses, and perfectly transparent in its small particles. The structure or aggregation of these masses has some variety. Often small crystalline grains are compacted together like sugar. This is called *gypsum*, and sometimes *alabaster*. A second kind is the *fibraria*, or fibrous gypsum, having a somewhat fibrous structure, or being composed of oblong crystallized concretions, closely compacted together, which are mostly parallel among themselves, but lie across the mass, from the upper to the under surface. This sort has varieties according to the size and regularity of the concretions of which it is composed. In some kinds, the concretions are

larger, and more irregular in disposition ; in others, more slender and regular. A third species is that which is composed of clear transparent plates, like the finest glass, lying parallel to one another, and in close cohesion through their whole extent, but easily separable by splitting them asunder with a knife. These plates are excessively thin, or can be subdivided, by splitting into very thin ones, and have an apparent flexibility, but no elasticity. This species is called *Glacies Mariæ*, and sometimes, but improperly, *Muscovy glass*, or *Muscovy talc*. A fourth appearance of this substance is in the state of separate crystals, in the forms of which there is some variety. They are found, I believe, in those strata of clay which contain gypsum in some of the other states already described ; and these separate crystals were especially named *selenites*, by naturalists. Fifthly and lastly, it is very often met with in waters, in a dissolved state ; for it is evidently capable of dissolution in water, though only in very small quantity, like the artificial gypsum, requiring not less than 500 times its weight of hot water to dissolve it. But it can be dissolved more plentifully, if it be acidulated with some superfluous sulphuric acid. It occurs dissolved in the waters of many springs and wells, and is the most general taint of what are called hard waters ; but most copiously in sea water. When water containing gypsum is slowly evaporated, the gypsum separates, or is deposited in a white sediment, which, by the microscope, is seen to consist of minute crystals, like hairs.

The composition of gypsum was first clearly explained by Margraaf, in the Berlin Transactions. He first shewed it to be a compound of calcareous earth with vitriolic acid. And by thus knowing that it is a saline compound, we can more easily understand some of its properties.

When gypsum is exposed to a moderate heat, it loses its transparency and glittering appearance, and becomes a white opaque mass like chalk, in which the former appearance of its structure is destroyed. It also becomes very friable, rather more so than chalk, whatever may have been its former firmness. During this change, we hear a continual crackling. This must be considered as a sort of decrepitation. If powdered first, and then heated, it swells; seems

as if set afloat; and is agitated like a boiling fluid. This is occasioned by the water being extricated from its crystals, which are thus destroyed. But after some time, it subsides into a dry powder. In close vessels it emits water, and some kinds of it a little sulphurous acid. After being heated in this manner, until the bottom of the vessel begins to grow red, if it be then cooled, it is disposed to concrete with water in a very remarkable manner. When mixed hastily with water, to the consistence of very thick cream, it remains in that state without any perceptible subsidence. After a little while it grows sensibly warm; and, in a minute or two after, it is solid, and a little enlarged in bulk. This concretion seems to be a hasty and confused crystallization, or return of the gypsum to a crystallized state, or state of combination with water, which is the natural state of it. In this state it is extremely porous and light, when thoroughly dried; because the water employed in diluting it is of more bulk than the gypsum. It is used for casting figures and impressions of every kind, and it gives them with wonderful sharpness. If one of these casts, of a medal, for example, be laid on the surface of melted white wax with the impression uppermost, it fills itself completely with the wax, and has the appearance of a piece of fine sculpture in marble, or of a porcelain cast.

If gypsum be exposed to a very violent heat, it is at last brought into fusion, without the separation of any considerable part of the acid, provided, however, it be heated without touching the fuel. If it be allowed to come into contact with the fuel, a very different effect is produced. The inflammable matter of the fuel acts on the acid, and volatilizes the greater part of it, in suffocating vapours of sulphurous acid and vapours of *hepar sulphuris*. Another part remains adherent to the earth, in the form of imperfect sulphur, or sulphurous acid, and forms with it a particular species of phosphorus, of which hereafter. The other qualities of gypsum will be easily perceived from the nature of its two constituent parts. And it is needless to take notice of the action of alkalis and acids upon it.

The uses to which it is applied, are, the casting of figures

in what is called *plaster*, or *plaster of Paris*, and for making the moulds in which they are cast; also for ornaments in *stucco*. And at Paris it is much used in the building of houses. In Minorca, they have a coarse and strong kind in plenty, which is employed in building. They form arches and floors of it, without needing timber to support their work. It also has great effect as a fertilizer of land. Its effect is greatest upon the legumina and leguminous grains. Grain, however, is not so much improved by it as by lime. Its effects last two years, and are greatest upon strong and rich land. One of the best ways of using it is to scatter it upon wheat-stubble, to promote the growth of clover sown in the spring, and harrowed in among the wheat. The gypsum must be thrown on the stubbles in autumn, or the following spring. If done sooner, it would fill the wheat with weeds. The quantity need not exceed that of the grain sown. It is used in Switzerland, even at a very great expence, both in a raw and calcined state; chiefly on the grass lands, as a top dressing. I do not find, however, that the trials made of it in this country have been successful. Yet it seems unwarrantable to doubt the numerous and circumstantial accounts given by the Economical Society of Berne, composed of perhaps the most intelligent practical farmers in Europe.

2.—*Fluor, or Fluat of Lime.*

Since the compounded nature of gypsum was discovered by Mr. Margraaf, another kind of stony matter, which was formerly known by the name of *fluor*, and *fluor mineralis*, and considered as a particular species of earth, has been found to be another compound of the calcareous earth with an acid. We owe this discovery to Dr. Scheele of Sweden, whom I have often had occasion to mention with praise: and in consequence of the light he has thrown upon the compound I speak of, it deserves now to be considered as one of the most remarkable objects of philosophical chemistry.

The stone or stony substance I speak of, is called by the Ger-

mans *flus*, or *flus spat;* in the books of natural history, *fluor* and *fluor spathosus*. It had these names from its effect in promoting the melting of ores and minerals in metallurgical operations.

Its appearance and more obvious qualities are these: It is a stony substance, which, so far as I know, never composes strata, but is always found either in veins, or in small masses. It has a close glassy texture, and receives a fine polish, and generally is transparent, though often tinged of a green colour, or purple, or yellow, or deep blue. There is much of it in Derbyshire; and on account of these colours, it is called in England, *blue John;* and formerly in apothecaries shops, *false emerald*, *false amethyst*, &c.

It is often found crystallized in the cavities of veins: and the most regular form of its crystals is cubical.

In point of hardness, it holds a middle place between the calcareous stones and the stones of the hard class; being too hard to be easily affected by the edge of a knife, but not too hard to be cut or scraped with hard steel, and capable of being wrought by the turner with proper instruments, and formed into very thin and delicate vessels.

It has a quality which is found also sometimes in the crystals of calcareous spar; but this stone has it more generally: I mean a power to emit light, or a subtile luminous volatile matter, when the stone is heated. After it is once red hot, it shines no more. I said "emits a luminous matter,"—for the phosphorescence of fluor is accompanied by a pretty strong unpleasant smell. And there is a kind of it mentioned by Mr. Wedgewood, junior, in his observations on phosphorescent bodies, which is fœtid when rubbed, and this kind is much more luminous than the others. The light is first green, then verges to a purple or lilac. *(Phil. Trans.* 1791.*)*

When we apply a violent heat to this substance, it melts most perfectly; and is very powerful in promoting the fusion of other earthy substances,—especially if calcareous spar and it be mixed together; then flowing almost as thin as water. Whence it is much valued for the smelting of ores. If we melt any con-

siderable quantity of it in a crucible by itself, or without adding any thing to it, such is its power to dissolve other earthy substances in the fire, or to promote their fusion, that it will melt the bottom of the crucible and run out.

The most surprising part of this substance is the acid which it contains, and which can be expelled from it by the sulphuric acid. To effect this separation of the acid, the fluor must be reduced to a very fine powder, and an equal, double, or even triple, weight of the strongest sulphuric acid must be poured on it in the retort. As soon as the materials are mixed, they begin to act slowly on each other. We must apply heat to quicken their action, and join a receiver, previously warmed (to expel some of its air) having water in it to promote the condensation of the acid. While the water attracts and condenses the vapours, a white and very tender spongy earth is usually deposited on its surface, and hinders the further condensation. We must agitate the vessels to break this crust, and then the condensation is renewed. And thus, by frequent agitations, we condense the whole acid. Such a quantity of earth is precipitated as to make the water quite thick. The glasses are found much corroded by this process. For a more particular account of it I refer you to Scheele's Essays,—Essay 1.

Dr. Scheele called this acid the *acid of spar*, or *acid of fluor*. It is now called FLUORIC ACID: and its compounds are called FLUATS. It is very volatile, like the muriatic acid, and will not condense without water. But it differs from the muriatic acid by many properties; as, 1*st*, By forming with calcareous earth a compound perfectly insoluble in water. 2*dly*, It has the power to dissolve, and even volatilize, the silicious earth, which is perfectly insoluble by other acids. And 3*dly*, It has a greater attraction for lime than for alkalis: and it forms peculiar compounds with the alkalis, alkaline earths, and metallic substances.

Dr. Scheele learned by a number of experiments, that this fine earth, which is mixed with the acid in the receiver, has all the qualities which belong to the silicious when in fine powder. And a further investigation by Dr. Scheele, and by other che-

mists, has proved that this silicious earth is generally a part of the materials of the glass vessels dissolved and volatilized by the acid, but deposited again in part, when the acid vapours unite with water. This was proved by distilling the spar in a retort of lead, and condensing the vapours in a receiver of lead, or of glass defended with wax. Thus we obtain a pure acid, not tainted with silicious earth. There are, however, some varieties of this spar unfit for this experiment, on account of their containing some silicious earth in their composition, which is dissolved and volatilized by the acid during the distillation. I could find no difference between this curious compound, and the purest silicious earth that I could obtain from liquor silicum by precipitating it by the sulphuric acid. I subjected these compounds to a great variety of trials. But whether the acid be tainted with silicious earth in this manner, or in consequence of its being distilled in glass vessels, there is a method by which the silicious earth can be separated and the acid obtained pure, viz. by saturating the acid with volatile alkali, which precipitates the whole silicious earth from it, and forms with it an ammoniacal salt, purely saline. If a quantity of this ammoniacal salt, be prepared, and then decompounded with sulphuric acid in leaden vessels, a pure spatose acid is thus obtained; sometimes, indeed, not quite pure, but tainted with a little muriatic acid. But Dr. Scheele has taught a method, by means of silver precipitated from nitrous acid, for separating this also. The fixed alkali cannot be employed to precipitate the silicious earth and to form a pure saline compound. It has an attraction itself for the silicious earth, and forms a triple compound, from which it is impossible to obtain by crystallization a pure neutral salt.

Dr. Scheele discovered many other qualities of the acid of fluor which it shews in mixture with metals, &c. for which I refer you to his essay.

Some of the French chemists committed great mistakes and errors in their first experiments and reasonings concerning fluor and its acid. You will see Dr. Scheele's remarks on them in his essays. And Dr. Scheele himself was at first in a mistake

with respect to the origin of this silicious earth, which this acid deposits in uniting with water.

Fluor is dissolved by nitric acid or muriatic acid. Sal tartari precipitates calcareous earth from this solution. But caustic alkalis, or aërated volatile alkali, precipitate fluor in fine powder. Sulphuric acid precipitates gypsum. A gypsum is also formed by adding to the solution Epsom salt, or vitriolated tartar, or vitriolic ammoniac, which also acts by sublimation, in decompounding fluor by double elective attraction.

Phosphoric acid decompounds fluor by distillation, and the residuum is a substance perfectly the same with bone ashes.

Distilled vinegar and acid of tartar have no effect on fluor.

Caustic fixed alkali melted with fluor, does not decompound it, but may be afterwards separated by water, and it leaves the fluor unchanged. Mild fixed alkali, four parts, melted with powdered fluor, one part, decompounds it. The fixed alkali joins with the fluoric acid, and forms a salt not deliquescent. The rest is mild calcareous earth. A solution of mild fixed alkali decompounds by digestion fluor made of lime-water, and fluoric acid.

The acid of fluor may be obtained without employing any fossil acids. Melt the fluor with mild fixed alkali, and extract the compound salts from the mixed matter by means of water. To the solution add acetated lead. We obtain a precipitate, which, when exposed to a strong heat in a retort with charcoal dust, gives reduced lead and the spatose acid.

Fluor mineralis, if pure from quartz, can be dissolved completely by aqua regia. The fluor must be in fine powder, and must be digested with a sufficient quantity of the aqua regia. Bergmann (*on Elective Attractions*, *p.* 123.) proposes this as a trial, to learn whether the fluor had contained any quartz.

The most remarkable property of the acid of fluor is its action on silicious earth, which is susceptible of no union with any other acid, so far as has yet been discovered. Bergmann has given a curious example of this. He put into a phial some finely powdered quartz, and having filled it with diluted acid of fluor, he closed it up. After two years, he found intermixed

with the flinty powder thirteen crystals as big as small pease. They were of various forms. Some were hexahedral pyramids: others were similar pyramids on the end of hexahedral columns: most of them, however, were cubes, having the angles cut off. They had all the chemical qualities, and wanted little of the hardness of perfect quartz. Hence he was induced to believe that this acid had great influence in forming the hard-figured fossils.

This action on silicious earth has been applied to a very curious purpose, namely, engraving, or more properly speaking, etching on glass. A German nobleman, and Mr. de Puymarin of Thoulouse, without knowing of each others labours, reflecting on Scheele's experiments, applied the acid to this use. The plate was covered with engravers varnish, and traced with points in the usual manner. A border of wax being also made as usual round the plate, it must be covered with a mixture of equal parts of pounded fluor and vitriolic acid, and left there two or three days.*

Phosphat of Lime.

The next singular and remarkable compound of the calcareous earth with an acid, is the PHOSPHAT OF LIME. This was first discovered and analysed by Dr. Scheele, in company with another Swedish chemist, Mr. Gahn.

This compound consists of lime, or calcareous earth, com-

* This action on glass has been known long before. In 1670, an artist at Nurenburgh, named Schankhard, practised it. Also in 1725, one Pauli in Dresden, employed it for etching on glass. (See *Beckman's History of Inventions*, *t.* iii. *p.* 547. *Also Breslaw Collection*, xxxi. 1725. *p.* 107.) Little seems to have been done with it; and it was forgotten till Scheele's experiments revived the art on principle.

The etching done in this way is far from being neat. As soon as the acid gets at the glass, it eats away sideways below the varnish. Also the lines are extremely shallow, and when viewed through a microscope, shew us that the acid acts unequally on the different ingredients of the glass. The glass seems to exfoliate.—EDITOR.

bined with a particular acid which was discovered first, or first described with precision, by that excellent chemist, Margraaf of Berlin. It is now called the phosphoric acid. He found it in the salt which first crystallizes from urine, when it is evaporated to about $\frac{1}{30}$. This is called *sal microcosmi*, *sal microsmicum*. He also discovered that the phosphorus of urine, of which we shall speak when we describe the inflammable substances, is converted into this acid by inflammation. It was therefore called PHOSPHORIC ACID.

The phosphoric acid resembles the boracic, by enduring, in its pure state, very strong red heats, without being changed into vapour. It only melts very easily into a transparent substance like glass. This glassy-like matter dissolves, however, easily in water, but cannot be crystallized. It forms with the water a liquid acid, from which the water can be evaporated again. But, near the end of the evaporation, the remainder of the water is strongly retained; and when forced off by heat, carries away a part of the acid, as you know happens with the boracic.

Mr. Margraaf discov[redacted]properties of this phosphoric acid, which are detailed in the [redacted]lin memoirs. But he did not know that it existed in any other natural productions excepting urine, and the seeds of some plants in which he discovered it.

More lately, however, since the study of the productions of nature has so much engaged the attention of philosophers, the phosphoric acid has been found in other states or conditions. The first example of this was discovered by Dr. Scheele, and Mr. Gahn of Sweden, who were making a set of experiments in company. They made some on the earthy part of bones and horns, commonly called bone-ashes, that is, the white matter which remains from bones and horns, when all the inflammable matter has been completely burnt out of them. This white matter was formerly kept in our apothecaries shops, under the name of *cornu cervi calcinatum:* and it was supposed to be an alkaline earth. I gave a few experiments on it in the essay on magnesia, which shewed that it had very little of an alkaline quality. But

the Swedish chemists, having examined it with different views, and in a quite different way, found it to be compounded of calcareous earth and phosphoric acid. Their first process for decompounding it has been reduced to greater simplicity by other chemists. This simpler process is given very distinctly in the last edition of the Edinburgh Pharmacopœia, as a step in the process for preparing the *soda phosphorata*, which is a phosphat of soda, recommended lately by Dr. Pearson of London, as a pleasant and effectual laxative and purgative.

Since Scheele and Gahn published their process for analysing bone ashes, a similar compound, or phosphat of lime, has been found in vast abundance among the fossil productions of nature. The first example of this was communicated by a letter from Mr. Proust, an able chemist, in the service of the King of Spain, to Mr. Darcet of the late French Academy of Sciences, and published in the Journal de Physique June 1788, informing him that in Estremadura it constituted extensive rocky strata. Mr. Proust found it in a stone so abundant in the province of Estremadura, that it is quarried and employed in building. In appearance, it resembles a stone composed of felt spar. But it consists of the calcareous earth saturated with phosphoric acid, or at least containing it in the same proportion with the earth of bones, that is, nearly one-fifth. It is highly phosphorescent when heated. It is also found in Saxony and in Bohemia. Mr. Werner discovered it similar to the Spanish in Saxony. At Schlackenwaldt, in Bohemia, it is found crystallized; generally in six-sided prisms, and also in the forms of tables and plates. It is seldom solitary, but generally mixed with fluor, spar, litho-marga, steatites, and several of the metals. It is rarely accompanied with quartz, as it is in Spain. The Germans say that it contains 45 parts of phosphoric acid per cent.: and they call the compound *apatit*. I suspect that there is something like it in the north of Ireland, near the Giant's Causeway. And, perhaps the fœtid marbles, and *lapis suillus*, are of this nature.

The phosphat of lime is used in making vessels for the refinement of silver and gold, to be described hereafter. From it too the phosphoric acid is now obtained. And lately, it has

been recommended by a French practitioner as a remedy for the rickets. We shall have a better opportunity for treating of its decomposition, when we consider it as the matrix of phosphorus. This interesting process has occasioned this compound to be tortured in every way that chemistry can discover.

4.—*Borat of Lime.*

There now remains to be mentioned but one more compound, formed by nature, of the calcareous earth with an acid: And it has been but lately discovered, (in 1791.) It is a compound of this earth, and partly too of magnesia, with the boracic acid. It is found crystallized. From its hardness, it was mistaken at first for silicious matter. The above crystals are found near Lunenburgh, in the Dutchy of Brunswick, in a vein of a mountain which abounds with gypsum. It is called cubical quartz. For an account of it see the *Annales de Chymie*, *tome* ii. *p.* 101, by Mr. Westrumb, and *p.* 132, by Mr. Heyer. It contains about two-thirds of its weight of sedative salt, about one-eighth of magnesia, one-tenth of lime, and some other earths.

SPECIES III.—BARYTES.

Thus far we have been employed in considering the common calcareous earth, or lime, and some remarkable compounds which it forms in nature with different acids.

I am next to make known to you two other kinds of earthy or stony bodies, which bear a great resemblance to the calcareous by some of their properties, though they are quite different from it by others: and the differences are of great importance.

One of the earths I now mean had first the name of Terra Ponderosa, on account of its being remarkably heavy. Now that name is changed to Barytes, derived from the Greek, and alluding to the same property.

When reduced to its purest state, it has the acrimony and ac-

tivity of lime, which it shews by its acrid taste and corrosive quality, like those of common lime. It likewise dissolves in water, so as to form a lime-water, which, however, contains less of the earth dissolved in it than common lime-water does, viz. only $\frac{1}{900}$th; that is, very little more than half a grain to the ounce.

In this pure and active state, it also decompounds the ammoniacal salts readily, and dissolves sulphur, by boiling in water, as common lime does.

It has a strong attraction for fixed air, or carbonic acid; and, when joined with it by art, forms a species of chalk, quite insipid, and which effervesces with acids. The attraction of this earth for fixed air is so strong, when it is pure, that it readily takes it from the alkaline salts, and renders them caustic: and the air is with difficulty separated from it by fire. It contains, however, much less fixed air than crude calcareous earth, and vastly more water, almost one-third of its weight.

When combined with fixed air, or in the state of a chalk, it can be dissolved in small quantity by aërated water. When calcined, it dissolves sulphur.

In all these particulars, therefore, it agrees with the common calcareous earth.—It differs from the same earth,

1. By its weight, or the weight of the compounds which it forms with acids. They are all much heavier than the corresponding compounds formed by the calcareous earth.

2. It differs from the calcareous earth by having a stronger attraction for acids in general, and especially for the vitriolic acid. It has the power to separate most of the acids, but especially the vitriolic acid, from the fixed alkalis, as well as from lime. This constitutes a very remarkable, and often a puzzling distinction.

3. The compound which it forms with the vitriolic acid is much more dense and heavy than common gypsum: and it is *perfectly* insoluble in water.

4. With nitric or with muriatic acid it forms saline compounds, soluble in water, but not deliquescent like the compounds of the same acid with lime. On the contrary, the nitrat and muriat

of barytes are easily crystallizable. The crystals of the nitrat are of various flattish forms, as if they were slices of a very low pyramid. The crystals of the muriat are also slices of a very low pyramid: but their base is always an oblong rectangle, but generally having the four angles truncated, so as to make it an octagon, having very unequal sides.

With the acetous acid barytes forms a deliquescent saline compound, not crystallizable; the reverse in this respect of the compound formed by lime.

After the vitriolic acid, the acid of sugar has the strongest attraction for barytes, and, next to it, the acid of sorrel. These are very remarkable distinctions.

The state in which barytes is most commonly or abundantly found in nature, is combined with the sulphuric acid, or under the form of a sulphat of barytes. In this state it occurs most frequently in the veins of the mountains in which ores of metals are found: for which reason it is called by some authors MARMOR METALLICUM. But in some rare veins it has also been found combined with the carbonic acid, or in the state of carbonat of barytes. It is found in this state in the mine called Anglesark, near Chorly, in Lancashire. *(Vide Manchester Memoirs.)*

This earth has lately become an interesting object, since it has been found to have very uncommon and valuable powers in medicine. This appears from Dr. Crawford's trials of it, in a number of cases published in the second volume of *Medical Communications* of a Society at London. He gave it in cases of scrophula, or bad sores, and obstructed glands. Its sensible effects were gently to increase appetite, and the discharge by urine and perspiration. These effects were in some cases impeded at first by plethora, or an inflammatory diathesis, which was removed by a vegetable diet. He has published all the cases in which he has tried it, which is a very candid way of communicating the knowledge of any new medicine. And it evidently has eminent healing powers. Much caution, however, is required in the use of it, as too large doses of it might prove a poison. He, therefore, warns practitioners to diminish

the dose, when it produces nausea or giddiness. Mr. Watt poisoned dogs with half a drachm of it. Professor Blumenbach, of Gottingen, found that the warm-blooded animals only are with certainty poisoned by it; while both the warm and cold-blooded animals may take with safety the similar compounds of an earth which has been confounded with it, and will be described in the next place.

SPECIES IV.—STRONTITES.

The other alkaline earth, which I said resembles the calcareous, by several properties, has been known for some time in this country as occurring in some of our mines, and was supposed to be the barytes, or a mixture of it with calcareous earth; until lately that Dr. Hope of Glasgow employed himself in examining it, by a number of experiments, which he communicated to our Royal Society. His experiments were very judiciously planned: and the conclusions he drew from them are perfectly well supported. I shall now give a general abstract of them.

He finds reason to conclude that it is a peculiar species of alkaline earth, different from any described before. The mine in which it is found intermixed with other spars is in the west of Scotland, near a village called Strontian: He therefore gives it the name of Strontites.

1. The carbonat of strontites of Dr. Hope is of a specific gravity from 3.650 to 3.726. The natural carbonat of barytes is 4.338. The carbonat of lime is about 2.700.

2. Its external characters are,—considerable hardness, fibrous or crystallized texture, muddy transparency, and colour inclining to yellow or green.

3. It is insipid, but has a little solubility in water. Four ounces of distilled water being boiled with 10 grains of it in fine powder, dissolved $2\frac{1}{2}$,$=\frac{1}{768}$.

4. The gas extricated during its effervescence with acids is carbonic acid gas: and it loses 30.2 per 100 during effervescence.

5. The greatest heat of a common open fire is not sufficient to expel its air; but only makes it decrepitate a little, and become opaque by the loss of some water.

A violent heat in a smith's forge, of 45 minutes, applied to a small mass of strontites inclosed in a Sturbridge clay crucible, and which softened the crucible, melted the outside of the mass into a green glass; while, within this vitrified crust, the rest was white, opaque, and caustic. When it is thus rendered caustic, it loses 38.79 per 100 of its weight. With water it now unites in the same manner as quicklime, but more violently, and is slaked by the air in the same manner. The vitrified part being dropped into muriatic acid, is slowly acted on. At length a jelly is formed, which becomes perfectly fluid by the addition of water; a minute portion of powdery matter, which probably comes from the crucible, remains undissolved.

Dr. Hope was not able to vitrify strontites with the flame of the blow-pipe. This makes it emit a brilliant light. (*Fourcroi.*)

The constituent parts of natural carbonat of strontites, are by the above experiments, in 100 parts,

Earthy basis, ...	61.21
Carbonic acid, ...	30.20
Water, ...	8.59
	100.00

6. Hot water dissolves a much larger quantity of pure or caustic strontites than cold water; and in cooling deposites the superfluous quantity in crystals. It is very remarkable by the great quantity of heat which is extricated from it in slaking. A few small bits thrown into a flask of hot water, make it boil violently: and the ebullition may be kept up for a great length of time by fresh additions. Nine ounces and a half of water yielded by refrigeration rather more than an ounce of transparent crystals. A hundred grains of these crystals contain 68 of water, one part of which is easily expelled from them by heat, at first without fusion: but at last a part of the water adhering more strongly, makes them undergo a watery fusion, which ceases when the water is totally evaporated. These crystals must be kept in phials very closely stopped; otherwise they at-

tract carbonic acid, and fall down in powder. The great quantity of water rendered solid in these crystals, and so strongly united, accounts for the great heat produced by mixing calcined strontites with water.

One ounce of water at 60° Fahrenheit, dissolves slowly 8.5 grains of these crystals. One ounce of water kept boiling dissolved no less than 218 grains. These solutions have all the alkaline qualities of lime-water.

(N. B. Dr. Hope discovered that barytes can also be crystallized in the same manner.)

7. Sulphuric acid forms with strontites a compound more difficultly soluble than gypsum. Four ounces of distilled water, boiling, dissolved only one-half grain. The solution was rendered turbid by carbonat of potash, by barytic water, and by muriat of barytes.

Sulphuric acid dissolves the sulphat, and dilution makes it separate again.

8. Nitric acid diluted dissolves it totally, but does not act on it when not diluted. It rather precipitates a nitrat previously formed. The solution easily yields crystals, which are octohedral, or formed of two four-sided pyramids joined by their basis. One ounce of water, at 60°, dissolves one ounce of these crystals; and at 212°, one ounce seven drachms fourteen grains. In dry air, a part of their water is evaporated from them. In very moist air they deliquesce. They deflagrate with combustibles, and give a bright red flame or light. Or if they be exposed to heat alone, they lose the acid, and the pure or caustic earth remains.

9. Muriatic acid must also be diluted to dissolve strontites. And the solution gives long slender six-sided crystals, often disposed in a radiated form. (N. B. By this mode of crystallizing, this earth is distinguishable from others. By putting a little of the muriat on a plate of glass, it will evaporate and crystallize. The muriat of barytes crystallizes into plates which are much less soluble in water.) These crystals are not pulverised by the air; but in extremely damp air shew a tendency to deliquesce. One ounce of distilled water, at 60°, dissolves one ounce four drachms one scruple of them. One ounce of

water kept boiling, dissolves four ounces, or more. They contain 42 per cent. of water, and undergo the watery fusion. But the acid is not easily separated by heat. The muriatic acid may, however, be expelled from the strontites, by the heat of a blow-pipe applied to it in a platina spoon.

10. Acetous acid dissolves strontites slowly. The solution tinges vegetable colours green; and by spontaneous evaporation, gives minute undiscernable crystals. One ounce of water dissolves, in a boiling heat, 196 grains of them, which remain dissolved when the water cools.

11. The oxalic, tartarous, and fluoric acids, form very insoluble compounds.

12. Phosphoric acid, applied in large quantity, dissolves it slowly; but if we attempt saturation, the whole compound precipitates. Four ounces of boiling water dissolved only one grain from 10 of this precipitate.

13. With succinic acid it forms crystals which are durable in the air.

14. Acid of arsenic forms a solution which cannot be evaporated by heat, without undergoing a change in which the earth is more closely combined with the acid, and also with a smaller quantity of it than before: and this new state of combination renders the compound insoluble. One ounce of boiling water was able to dissolve little more than one grain.

15. With boracic acid, it is sensibly alkaline, and water dissolves $\frac{1}{130}$.

16. With carbonic acid it presents the same phenomena as those which are exhibited by lime.

17. Strontites, and all its compounds, give a red colour to flame. The muriat does it most; and is best used for this purpose by putting a crystal of it on the wick of a candle. Muriat of lime also produces this effect in some degree. But muriat of barytes gives a greenish colour to flame. A certain portion of humidity is necessary to enable these compounds of strontites to tinge the flame. Without it they have no effect.

18. Aërated alkalis precipitate strontites from its solutions; at first in form of a gelatinous matter. But by adding more alkali, and agitation, an opaque white curdled precipitate is formed,

which Dr. Hope calls *artificial carbonat.* It loses its air more easily in the fire, and dissolves more quickly in acids than natural carbonat, but is in every other respect the same.

19. The prussiat of potash or of lime do not in the least precipitate strontites from its solutions in acids; in which property it differs remarkably from barytes.

20. With sulphur it forms a hepar, either in the dry or humid way in the same manner as lime.

21. Crystals of caustic strontites were dissolved, but very sparingly, by alcohol, which afterwards burned with a reddish flame.

The following is the order of attractions of the acids for strontites: Sulphuric acid, oxalic, tartarous, fluoric, nitric, muriatic, succinic, phosphoric, acetous, arsenical, boracic, carbonic.

Strontites, compared with other alkaline substances, in its force of attraction for the different acids.

Sulphuric Acid.	Oxalic Acid.	Tartarous Acid.	Fluoric Acid.	Nitric Acid.
Barytes,	Barytes,	Lime,	Lime,	Barytes,
Strontites,	Lime,	Barytes,	Barytes,	Potash,
Potash,	Strontites,	Strontites,	Strontites,	Soda,
Soda,	Potash,	Potash,	Potash,	Strontites,
Lime.	Soda.	Soda.	Soda.	Lime.

Muriatic Acid.	Arsenical Acid	Boracic Acid.	Phosphoric Acid.	Carbonic Acid.
Barytes,	Lime,	Lime,	Lime,	Lime,
Potash,	Barytes,	Barytes,	Barytes,	Barytes,
Soda,	Potash,	Strontites,	Strontites,	Strontites,
Strontites,	Soda,	Potash,	Potash,	Potash,
Lime.	Strontites.	Soda.	Soda.	Soda.

GENUS II.

PLASTIC EARTHS.

WE shall now proceed to study the second order of the earths,—the PLASTIC, which are commonly called in our language CLAYS, or CLAYEY EARTHS.

The natural earths which are assembled under this division, all contain more or less of a particular kind of earth in their composition, which gives them their plastic qualities; or gives them, in different degrees, the qualities which belong especially to itself.

The earth I now mean is at present considered by the chemists as another of the pure elementary earths, and is called the argillaceous. It is distinguished from the earths hitherto described by these properties:

1*mo*, It does not effervesce with acids when they are simply mixed with it.

2*do*, It is composed of exceedingly fine impalpable particles. It therefore feels fat or smooth between the fingers, like marrow; and is not in the least gritty between the teeth.

3*tio*, When a dry mass of it is applied to the tongue, it imbibes the superficial humidity of that organ so strongly that it adheres to it: and it gives a peculiar odour on all these occasions when humidity is applied to it.

4*to*, If it be mixed and well kneaded, and worked with a proper quantity of water, it forms a soft and plastic mass, not easily diffusible or dilutible in more water; and which, if dried well, and afterwards burned with a strong heat, becomes very compact and hard, and impenetrable by water.

5to, It has some notable qualities which it shews in mixture with acids; the most remarkable of which qualities shall be mentioned presently.

The plastic earths, therefore, all contain more or less of this simple earth: and they constitute every where numerous strata. They also make a part of every strong and rich soil.

That property of plastic earths, by which they become so tough a paste, and so difficultly diffusible or penetrable by water, when wrought and compressed with a proper quantity of that fluid, occasions their being employed for confining water in canals, and ponds, and reservoirs, and other works in which large quantities of water are to be confined, or preserved from being wasted by soaking through the soil. It also explains the bad effects of what is called *poaching* clayey grounds; that is, allowing cattle to tread on them much when they are wet or soft; as they are thus reduced to that plastic state in which they do not transmit water easily, but occasion it to stagnate on their surface, and to rot or sicken the plants; and at the same time they are so dense and viscid, that the roots of plants cannot penetrate them without the greatest difficulty. The remedy for this is, to plough them when they are moderately dry, and when dry weather or frost is expected. If the clods once become dry, the first rain will make them moulder down, and alternations of dry weather and showers will completely divide them.

Mr. Bergmann says that a fine clay does very well for washing and cleansing linens. Though it does not chemically combine with greasy filth, it adheres to it, and carries much off with it by rubbing. *Smectis*, or *fuller's earth*, is a marly clay, and is much employed in this way.

There is great variety of the earths which come under this division, and under the common denomination of clay. They are various by their colour; by the fineness and smoothness of their particles; by their degree of cohesion when we attempt to diffuse them in water, and the degree of toughness, or plastic quality, which they assume when wrought or kneaded with a proper quantity of that fluid; and also by their qualities with respect to heat, or the changes they undergo from the dif-

ferent degrees of its action on them. But all this variety is produced by the various admixture of siliceous earth, or magnesia, or calcareous earth, or iron, or inflammable and other matters, in various proportion with the argillaceous earth. It is so liable to admixtures of this kind, that a pure argillaceous earth is one of the rarest productions of nature: and in the very few examples that have occurred, it was in small quantity.

The clays which contain it in the greatest quantity, or in a state less impure than ordinary, are either naturally white; or, if they have a dark or dull colour, it proceeds from a small quantity of inflammable matter: and they become white when burnt in an open fire. Those that become red in the fire contain iron.

Clay, by being kept very long in a wet state, becomes evidently sour to the taste and smell. I was assured of this fact by Mr. Wedgewood, who is, perhaps, the most perfectly acquainted with all the qualities of the plastic earths of any person in Europe, and the most interested to know them in their state of greatest purity. The fact is curious, and perhaps important to the chemical philosopher. Perhaps it receives some explanation from another fact which he also told me, viz. That by long exposure to the air, the surface appears powdery: and when this dust is carefully swept together, it is found tainted with a calx of iron. It is not unlikely that this arises from a minute portion of pyrites, which is known to decompound by humidity, and to yield its acid. May not this also account for the hardening of clays by the fire, even in their purest state?

The most useful qualities of clays in the arts are,—their disposition to constitute, with a proper quantity of water, that ductile plastic mass, which is easily formed on the potter's wheel, or otherwise, and which can be baked afterwards by fire to a stony hardness. In consequence of which, they are employed for the manufacture of numerous vessels, tiles, bricks, and many other useful productions of art. The best kinds of it acquire different degrees of compactness and hardness in the fire, according to their dryness in the first kneading, and the violence of the heat.

When clay has been made very soft, by kneading it with much water, in order to make it work easily on the potter's wheel, it must be very porous when burnt to a tile: for whatever quantity of water is employed, the piece does not contract much by drying; and by no means in proportion to the water in it. Such ware, therefore, must be very open and spongy, and may be used for filtres.*

In a moderate red heat they become hard, but porous; and are formed into tobacco-pipes, &c. In a much stronger one they are rendered compact and hard like flint. But pure clays never melt in ordinary furnaces or fires. The more coarse and impure clays have these qualities in inferior degrees. They do not grow so hard in moderate heat. And many of them cannot withstand a strong fire without melting, on account of the mixture of different earthy substances and other matters which they contain, and which give them this disposition.

Experiments made with clays, in the way of mixture with other substances, have shewn that the argillaceous earth, although it does not effervesce with acids, can be combined with them; and that, when combined with the sulphuric acid, it constitutes ALUM.

This, however, is a late discovery; for although alum has long been in use, and well known to contain the sulphuric acid combined with an earth, the nature of this earth was not distinctly understood, until two of the academicians of Berlin, Pott and Margraaf, published their experiments on this subject, in which they made perfect alum by dissolving the argillaceous earth of clays in the sulphuric acid. Mr. Pott made the first step in this discovery: and Mr. Margraaf afterwards brought it to perfection.

* Accordingly, vessels of this porous ware are used in the hot climates for cooling liquors; which service they perform by the copious evaporation from the surface. Vessels are also made in this country as porous as possible, and have their external surface turned into deep notches, or furrows, on the potter's wheel. They are filled with water; and small seeds, such as those of cresses and mustard, are sprinkled into those furrows, where they receive enough of moisture to make them grow, and cover the outside with foliage. A sallad is thus easily raised at sea, and in winter in a warm room.—EDITOR.

It was ascertained by Mr. Margraaf's experiments that the argillaceous earth can be combined with the vitriolic acid in two different proportions, or so as to form two compounds considerably different. One of them contains a large proportion of the acid, and is very soluble in water, and deliquescent, and cannot be crystallized. This is called *alum liquor*. The other, viz. *alum*, contains a small proportion of acid to the earth; is but moderately soluble in water; easily crystallizes, and is not at all deliquescent, but rather calcines spontaneously.

The first of these two compounds is almost always formed when we attempt to make alum by combining its two ingredients, which may be done by boiling the best kinds of clay in strong sulphuric acid until the mixture is dry, and then adding water to dissolve the alum or aluminous compound which has been formed. We thus procure an alum liquor, or acidulous liquid alum, from which it is necessary to abstract a part of the acid, by adding a small quantity of an alkaline salt, or by a proper degree of heat, before we can have alum that can be crystallized.

Mr. Beaumé of Paris has made an addition to these discoveries of Margraaf. He discovered that a third compound can be formed of the sulphuric acid and aluminous earth;—a compound in which there is still less of the acid than in perfect alum; and which is therefore not soluble in water. This compound is formed by boiling a solution of alum in water with some of the pure argillaceous earth; the consequence of which is, to change the whole of the alum into this third compound, which subsides to the bottom, and forms a sediment which cannot be dissolved.

All these particulars have been discovered by the experiments made to combine the sulphuric acid in different ways with the argillaceous earth.

It is not, however, in this way that alum is manufactured for the purposes of different arts. It is obtained from materials which afford it much cheaper, by a process which was long practised before it was well understood. You will see a full account of the processes by which alum is manufactured, and of the materials employed in making it, in Fourcroy's Elements, under the article ALUM; and in Chaptal's, where he describes a new

process of his own. Bergmann also has given an instructive essay on the manufacture of alum.

Alum is generally manufactured from a soft laminated stony matter found in strata, (and which bears some resemblance to slate, but is softer, and commonly dark grey or black), called *alum ore; aluminous schistus*,—*Schale*. It is composed of clay combined with sulphur, and very often some bituminous matter. It hardly ever produces alum until after it has been burned with a very slow heat for a considerable time, which consumes the bituminous matter, and changes the sulphur into sulphuric acid. It is accordingly burned by setting fire to very large heaps of it, which are covered up in such a manner as to occasion a slow and long-continued inflammation and very gentle heat. There are some of these ores, however, which, when formed into heaps, take fire of themselves, and burn slowly, without needing to be set on fire by means of fuel. And in some volcanic countries, they find materials which are already prepared for affording alum, in consequence of their having been affected by the volcanic heat. In some few cases also, the action of the atmosphere alone, continued for a length of time upon such materials, prepares them for affording alum, although they never have been set on fire. They are observed to be covered with a whitish dust, which, when examined, is crystallized alum. When this is washed off, more forms in a day or two. Such matrices properly built up, so that the rain may wash it off into gutters which lead to a cistern, afford a lixivium ready for boiling. There is at Hurlet, in the neighbourhood of Glasgow, a stratum of shale which has been left in the old workings of coal mines, which, by the singularity of its situation, exhibits a wonderfully rich appearance. It is about ten inches thick; and, if cut out from a newly opened pit, does not yield an atom of alum. But lying in the open waste for more than a century, it has decomposed, and effloresced. Moreover, there is above it a vast thickness of shale, which is too poor for working; but in the process of time, has afforded, by filtration, enough to enrich the stratum below, which effloresces, and thus renews its waste. The result of this has been, that each lamina of the schistus has not only separated from the next, but the interstice is filled with

crystals continually increasing; so that in some places the stratum of ten inches has swelled so as completely to fill the space from which the coal has been taken. I thought this singular fact not unworthy your notice.

In all these cases, whether the alum ore has actually been set on fire and burned, or whether it be prepared by the long-continued action of the air alone, the change produced is a combination of the sulphur with vital air, and consequently a change of it into sulphuric acid, which acts on the clayey matter; after which, being steeped in water, it affords an aluminous liquor, which requires the addition of some alkali, fixed or volatile, to prepare it for affording good crystals of alum by evaporation. The use of the alkali is partly to precipitate some calx of iron, which is commonly dissolved in this liquor with the alum, and partly, as is supposed, to saturate a portion of superfluous sulphuric acid. The crystals are first obtained of a moderate size; but are afterwards united into large masses by *roaching*.

Mr. Chaptal's process is very refined and artificial. He observed that a gentle roasting of clay disposes it to a more ready union with the acid, especially when this is in the form of steam. He therefore makes up the clay into small balls, and roasts them in an oven or kiln. One effect of this must be the driving out the water, and leaving the whole mass very porous and accessible to the steam of the sulphurous acid. The balls are now spread out on the floor and shelves of a great room, whose walls and ceiling are covered with a fat luting impenetrable by the fumes. There is a furnace constructed in a corner of the room, wherein sulphur is made to burn in a manner which disperses it through the room in steams of the suffocating acid. The balls are penetrated, and the clay unites with it. When judged to be superficially saturated with it, and alum formed in them, which requires some days, the room is opened, and the balls taken out and exposed to the air under cover. The volatile acid becomes sulphuric by extracting oxygen from the air, and dissolves the clay: and the balls are then lixiviated. This manufacture is said to be very profitable. (*Ann. de Chem.* vol. 3.)

The most instructive dissertation that I have seen on this manufacture is, *Disquisitio Chemica de Confectione Aluminis, Auctore Gustavo Suedilio, Upsal*, 1767.

The appearance and more obvious qualities of alum are more or less known to you. It is exposed to sale in large crystalline masses containing much water. By the application of heat it melts, swells, boils, and dries; and is then called *burnt alum*,—*alumen ustum*, which has often a good effect on foul ulcers. In a greater heat, it does not undergo real fusion, but part of the acid is dissipated. It dissolves in cold water, but slowly, and in small quantity. Hot water dissolves it much better.* Its taste is sweetish, sour, and astringent. It tinges some vegetable blues red. These last qualities it derives from the acid, which is so little neutralized by the earth, or is present in the alum in such quantity, that it is less changed in its properties than in other cases. It is also united with the earth by a weak attraction. This appears from the facility with which alum is decomposed by other substances; for not only the fixed alkalis, but calcareous earth, the volatile alkali and magnesia, if added to a warm solution of alum, cause effervescence and precipitation. The effervescence shews that the argillaceous earth is not disposed to unite with the air, or with very little of it, if the solution be warm. This earth, when properly separated from the acid and neutral salt, is purer argillaceous earth than any clay; and if it be precipitated from a cool solution, so that the earth may unite with a portion of the air of the alkali, it has the plastic qualities in the highest degree of perfection.

* It therefore readily crystallizes by cooling. In repeating Mr. Lowitz's experiment with a mixture of alum and nitre, I observed the whole alum crystallized in one form (octaëdral) which I had never seen before, it being commonly a mixture of both kinds. The observation of Mr. Lowitz naturally made me think it probable, that not only the alum alone was made to crystallize by touching the mixed solution with a crystal of alum, but also that the form of the crystal presented would dispose the whole to the same aggregation. The notions which I had of crystallization lead almost necessarily to this. I tried it, by presenting to the same aluminous solution a cubical crystal: and the effect was as I expected. All were cubes or composites of cubes. I have found the same thing to happen in some other salts, which often appear in truncated crystals.—EDITOR.

The French chemists have given a new name to this pure earth; *alumine* in French, and *alumina* in Latin. I confess I do not like this *alumina*. If a name is to be contrived, I would make it *argilla*.

Great quantities of alum are employed in the arts of dyeing, and in printing or painting of linens and cottons.

To complete the natural history of the argillaceous earth, we may remark, that it is found in many other natural productions beside the plastic earths or clays; in the *alum ore*, for example, which is indurated clay with sulphur; in what is called *black halk*, in which there is some inflammable matter which gives the blackness; in *slate*, which appears to have been formed from clay, indurated naturally by length of time and subterranean heat. There is a very great variety of strata of this kind, which have different degrees of hardness and cohesion, and are more or less laminated like slate; all of which contain some of the argillaceous earth mixed with others. And they appear evidently to have been clays, which have been indurated more or less by some operations of nature, until many of them have acquired great degrees of hardness and durability. The general denomination for them all is SCHISTUS. The hardest of them are so closely concreted, that the strata they form, called GNEISS, are among the most durable. The less hard constitute different kinds of SLATE, and the softer ones SHALE. In the neighbourhood of Geneva, and I suppose in France, some are called PIERRE DE CORNE.

The argillaceous earth is also a principal article in the composition of some of the hard stones, as we shall notice hereafter.

GENUS III.

HARD STONY BODIES.

IN this section I comprehend most of the stony substances called SILICEOUS, or FLINTY, by natural historians.

They are eminently hard, and they are unfusible by the most violent heats of common furnaces or fires. Their hardness is such, that they are not affected by the hardest steel, but on the contrary scratch it, and strike fire with it. And they also scratch or cut glass.

The greater number of the stony substances which belong to this division have also been called crystalline and vitrescent,—*crystalline*, on account of their being oftener found in the form of regular and transparent crystals than other kinds,—and *vitrescent*, as being the principal ingredients in glass, and more disposed than any other earthy or stony matter to produce good glass with proper additions.

All the stony bodies of this division contain a particular kind of earth, which I have had occasion several times to mention, but not yet to describe in this course. It predominates or bears a principal part in the composition of this order; and is at present considered as one more of the *simple elementary earths*. It has been commonly called the siliceous earth. The French chemists lately contrived the names for it, of SILICE in French, —and a barbarous term, SILICA, in Latin.

We can easily extract it by a chemical process from the stones of this division. And the nature of the process is such,

that the earth is obtained in the form of a precipitate, which is an exceedingly tender, light, and spongy earth.

The properties of it are these:

1*mo*, It is not dissolved or otherwise affected by any acid, except the fluoric, which, when applied warm to it, and especially in the form of vapour, not only dissolves this earth, but volatilizes it.

2*do*, It is not fusible in our most violent fires.

3*tio*, When mixed in powder with half its weight of potash or soda, or the carbonats of those alkalis, the mixture can be melted easily in a strong heat; and forms a perfect glass. It is even in some measure dissolved or combined with potash, by boiling in a strong watery solution of that salt. This experiment will not succeed with any siliceous substance reduced *mechanically* to a powder, however subtile. The utmost effects of mechanical division and trituration fall infinitely short of the subtile division and attenuation which we obtain on many occasions by chemical solution and precipitation. And this earth, in order to make it combine with an alkali that is dissolved in water, must either be in this state of the most subtile and tender powder, or it must be previously combined with a smal proportion of alkali in the dry way, or by fusion.

This experiment and others enabled me to understand the nature of an earth which occurs in some parts of Scotland, in the form of a sediment or mud, at the bottom of lakes of fresh water. There is a lake in Galloway in which it is found. Samples of it were brought to me a long time since, to know if it was a marle. I quickly perceived that it was not a marle: but the properties of it were such, that for a considerable time I was at a loss to give it a name. At last I found that the qualities of it were those of the silex, or siliceous earth, and that it was principally composed of this earth. It may therefore be named *limus siliceus*, or *silex limosa*. It is undoubtedly deposited in those lakes, in consequence of the demolition and decomposition of stones and rocks, which contain it in the higher parts of the country, from which those lakes are supplied with water.

This completes the list of the earths that are at present considered as the most remarkable and most abundant *elementary*

earths. They are six in number, distinctly known, namely, the *calcareous earth* or *lime*, *magnesia*, *barytes*, *strontites*, *alumina* or the *argillaceous earth*, *silica* or the *siliceous earth*.

We have been lately informed of a very few more lately discovered, which appear to be simple earths, and yet are different from any of these. But they are produced by nature in very small quantity, and have only been found in the composition of some particular and rare stony concretions of a small size; *nor have they yet been sufficiently examined*. I do not, therefore, think it proper at present to take up your attention with them. You will see mention made of them in the new systems of mineralogy which I lately recommended to your notice.

To return to the consideration of the hard stony bodies.—They appear to have their hardness more or less from the siliceous earth, or silica, in their composition. But they contain it, however, in different proportions, or in different states of purity. I shall first enumerate those which contain it in largest quantity, or in a state which approaches the nearest to purity. These are,

1. Crystal, or rock crystal, which is transparent.

2. Chalcedony, which has an imperfect transparency resembling that of whey.

3. Quartz, which has a whiteness like that of milk and water, and shattered appearance, and breaks with an uneven surface, not a plated structure like spar. It is abundantly produced by nature.

4. Agate, in which the stony matter is diversified with streaks and spots, whitish, or of other colours.

5. Flint, silex, which has an uniform dark colour like dark coloured horn, but becomes white in the fire.

6. An exceeding fine loose earth found at the bottom of some of our lakes in the mountainous parts of this country. It may be called *limus siliceus*, *or silica limosa*.

These varieties of hard stones contain the silica the most abundantly, or most approaching to a pure state.

But in many of the other stones of this order it is very impure, or mixed with a large proportion of other matter.

When iron is mixed with it in such quantity as to colour it strongly, and render it opaque, it forms Jaspers of various

colours. These are distinguishable from flint by breaking without the smallest lustre, like dry clay, and void of all transparency. Or if the quantity of the iron is less, and the stone is semi-transparent, and of a red colour, it is named CARNELIAN, from the resemblance of its colour to that of raw flesh.

These are the principal appearances of the hard stony matter. But it may also be proper to give a general view of the various situations and collections of the hard stones in nature.

1*mo*, They are found constituting numerous and extensive strata: and those which are the most abundant, are the strata of common sand and gravel, and sand-stone, and gravel-stone, which are very numerous and common, and of great extent. The origin of sand and gravel was formerly explained.

Some sands are white, or free from any colour, and are totally composed of small grains of crystal or quartz, such as the sand from Lynn in Norfolk. It is the fittest of all for fine glass.

The greatest number of sands, however, are variously coloured, by the admixture of other matter with the siliceous in the composition of many of the grains. And some are perfectly opaque, and dark coloured, and even black, from the large proportion of iron.

2*do*, GRAVEL is in many places of the same nature as common sand; and is found in the composition of strata, either by itself, or more commonly mixed with sand or clay in different proportions. It consists principally of the same kind of matter as the sands, only in larger grains or masses, more irregular in their form and size, and more coarse and opaque by the more plentiful admixture of other earthy matter with the siliceous earth. Gravel is, however, of very different kinds in different places: and it must be so, as being formed of the hardest fragments of the stones of the country in which it is found.

3*tio*, SAND-STONE is the third kind of stratified matter, which I said is found in great abundance; and which, in most places, is composed of hard stony materials. It has evidently been produced from common sand concreted together.

When the sand of which it is composed does not cohere too strongly, this stone is employed in buildings which are erected with hewn stone, and it is then called FREE-STONE. All the

free-stone of this country is composed of siliceous sand, and is therefore remarkably durable: and we have plenty of it. The sand of which it is composed was first collected and washed clean by water in the long lapse of time, and was afterwards cemented together by some operation of nature. The proofs of this are, an undulated appearance which often occurs in the surfaces of its strata, and which is exactly similar to the undulated surface formed on the sands of the sea-shore, or of lakes, by the action of the waves. And we often find also in the strata of sand-stone the relics of sea productions. There is, in particular, a very remarkable object found in many free-stone quarries in this country. The stone itself is observed to take the form of a plaited (not twisted) rope, of considerable thickness, and generally flattish, the greatest diameter being horizontal. In the different plaits of it there is a small indentation: and the plaits are most regularly disposed. When broken across, it has a sort of core, black and soft: and fibres are observed to go out from this to the indentations on the surface. This object is sometimes of great extent, traceable through the stratum in a horizontal direction many yards, varying in diameter from half an inch to five or six inches, and sometimes sending off branches. An example of it was seen lately in a quarry on the sea-shore near Musselburgh, which resembled the trunk of a vast tree sending out branches in all directions.

Sand-stone is of very various hardness. In some the sand has but a weak degree of cohesion. In others the grains are so closely and strongly coherent, that the stone has the appearance of solid flint, and cannot be wrought as a free-stone.

4*to*, The strata of what I called gravel-stone have been formed in the same manner as sand-stone, only that gravel is intermixed with the sand in the composition of the stone. From its appearance this stone is named by the English *pudding-stone*; and the name has been adopted by foreigners.

Such are the strata, principally or totally composed of the hard stony bodies. There are also some kinds of rock in which more or less of them is contained, as granite, to be soon described; and the more compounded kind of rock which abounds in this country, named WHIN-STONE, some kinds of which are

a more coarse and compound granite. The whin-stone often contains nodules and pebbles of all different sizes, some of which are hard stones.

The schistuses also, or indurated argillaceous strata, often contain a large proportion of quartz irregularly intermixed through them.

The hard stones constitute therefore a great part of the materials of many strata and rocks. They are also found often in *veins*, or otherwise interspersed through rocky or stratified matter. The species most frequently found in this state is quartz; but we also find occasionally, crystal, chalcedony, agate, jasper, and flint.

There are great quantities of flint in England, interspersed in a very irregular manner through the calcareous strata of chalk and limestone, traversing and running through them in different directions. As found in chalk, it is more especially named *flint;* as occurring in limestone, it is named *chert* by the English.

From the appearance of this matter, as found in this state, there is reason to be convinced that it has been introduced in a very fluid state, or that it has been produced in these strata by the action of some very fluid matter which has penetrated them. The proof of this is, our finding shells, lithophyta, and other marine productions, originally calcareous, but which are now completely penetrated by this sort of matter, and seemingly converted into flint or agate, without losing their external form. The same fact is further established by the quantities of fossil wood penetrated and petrified with this matter, found in many parts of the world. It is found in all states, from that of stony wood, still combustible, to that of pure flint.

It also deserves notice, that the nodules of flint found in chalk and lime, often in very strange forms, are not simply lying there, but seem forming, or else decaying, in that situation, being always surrounded by a crust, which changes gradually from a calcareous to a siliceous nature.

Another curious fact relating to this stony substance is, that masses of it are sometimes found which include water perfectly

inclosed in the hard stone. This has been observed in crystal, in common flint, and in agate.

In whichsoever of these states the hard stones are found, when masses of them occur that are not solid, but have vacuities within them, in these we find their matter crystallized, and very often into remarkably regular and transparent crystals. Such are often found in hollows of veins, and of pebbles. They are generally columns of six sides, terminated by a six-sided pyramid: or sometimes they are pyramids alone. All these crystals are chiefly found in cavities or veins of hard stones.

I have yet to mention one other state or condition in which the silica has been found, and that is, dissolved in water. There is one very remarkable example of this in Iceland, particularly at the celebrated *Geyser*, where some hot springs contain so much as to form siliceous petrifactions.

These are the different forms and states in which we find the hard stony bodies. We are now to take notice of their chemical properties.

The purest kinds, or those which contain the most of the silica, when they are exposed to a strong heat, generally become opaque, white, and brittle. But they sustain the most violent heat without melting, or being softened by it. We can melt them, however, easily and perfectly, with fixed alkaline salts, with which they unite in the fire to form a perfect and workable glass. By workable glass, I mean a glass, which, while it is allowed to cool from its melted state, continues soft and ductile a considerable time, and passes through all the degrees of softness before it becomes hard and rigid. During these states of softness it has great ductility, and can be wrought or moulded to any form. Glass that is workable in this manner is one of the most valuable productions of chemistry.

All good glass contains siliceous matter and a fixed alkali as its only or principal ingredients. And sand, when it is composed of pure, or nearly pure, siliceous matter, is preferred to the other forms of the hard earths, on account of its being easily mixed with the alkali and other materials, without requiring the expensive operations that would be necessary for re-

ducing to powder, or to small grains, the hard masses of other siliceous matter.

In the composition of some kinds of glass, other materials are added to the sand and alkali. But the effect of these other materials is chiefly to increase transparency, or to affect the colour, or to diminish expence.

The siliceous matter and alkali must bear certain proportions to one another, to make good glass. If the alkali be deficient in the due quantity or goodness, the siliceous matter is not completely dissolved, and the glass not sufficiently transparent. If the alkali be redundant, the glass is liable to be corroded, or to have its surface tarnished by damp air. By increasing the alkali to twice the weight of the siliceous matter, we make a sort of glass which dissolves completely in water. Thus is produced what is called the *liquor silicum*, which coagulates into a jelly by exposition, or by the admixture of acid, or by volatile alkali (according to Neumann). This is the chemical process by which we obtain the pure siliceous earth.

Although glass turns out very faulty when it thus contains an over proportion of alkali, it is however found necessary, in making good glass, to use rather more alkali than what is barely sufficient to melt the sand; and then, by a continuance of the fire, to evaporate the superfluous quantity. Thus we are more certain of perfect solution or fusion of the siliceous matter.

It is also common to use a quantity of nitre in place of part of the fixed alkali, in making the finer kinds of glass, to consume the inflammable matter: and borax likewise is frequently added in small experiments. A mixture of these salts with a very pure or chosen sand, or other siliceous matter, produces glass of uncommon brightness and transparency, which can be coloured by the addition of metallic substances; and gives those imitations of the gems which in this country are called *pastes*.

The author who has given the best account of the art of making glass of different kinds, especially the fine and coloured glasses which are made in imitation of the gems, is Kunkel, in an edition he gave of *Neri's art of making Glass*.

In the finer kinds of glass, therefore, the siliceous earth is combined chiefly with a pure fixed alkali, and brought into a vitrified state by means of that salt; for when nitre is used, it is changed into pure fixed alkali. The calces of lead, as they were named formerly, such as white-lead, and red-lead, are employed in the manufacture of the English FLINT GLASS, so remarkable for its pure transparency, which fits it for being cut into facets, and other ornamental forms, and gives it remarkable brilliancy. In making the coarser and cheaper kinds, as bottle glass, window glass, and the like, they do not use a pure alkali, but take the ashes either of land vegetables, or kelp, or barilla, which are the ashes of marine plants, with the salts they contain. And these ashes are mixed with sand, or other siliceous matter, to make such kinds of glass. In this case, the earthy part of the ashes, which in part consists of alkaline earths, assists the fixed alkali in bringing the siliceous matter into fusion, and enters into the composition of the glass. It is not nearly so powerful a solvent, however, as the pure fixed alkali: and therefore we must employ, in the composition of such glass, a smaller proportion of siliceous matter than when the glass is made with pure alkali. And it is also necessary to frit the materials before they are melted in the pots in which the glass is formed. This is exposing the materials in a furnace, generally adjoining to the working furnace, and deriving its heat from it. This is a reverberatory, where the materials are spread out on its hearth, and kept roasting for many hours, or even days, with a red heat. This is necessary, for two reasons: 1*st*, and chiefly, to consume completely all remains of the inflammable matter of the ashes. 2*dly*, To expel from the fixed alkali and ashes some part of their fixed air.

The earthy part of the ashes of vegetables always contains some iron, which gives a green colour to such glass. I must observe, that the coarsest kind of glass, on account of the large quantity of earthy matter which it contains; and the penury of salt, is fitted for giving what is called Reaumur's porcelain of glass. This is a curious change produced on those hard glasses, by long exposition to a red heat in contact with sand, gypsum, and other substances. The glass gradually acquires a crystalline structure, formed in fibres which are perpendicular to the

external surface. The longer the piece is continued in that situation, this singular arrangement penetrates deeper, till the growth from each surface meets in the middle of the thickness. After this, if much longer continued, the fibrous structure becomes somewhat granular, and the grains in the middle become large and detached, and sometimes the piece separates in the middle of its thickness. When this change is completed, and no more than completed, the glass has greatly changed its nature with regard to the effects of heat. It is now infusible by the heat of a glass-house furnace, and will bear to be plunged into water when red hot. It is also extremely hard, and cannot be scratched by the hardest file. Mr. Reaumur discovered this by accident; and recommends this preparation for retorts, mortars, and other chemical vessels, where these qualities are of importance.

It is a curious circumstance in glass, especially the coarser kinds, that when allowed to cool very slowly in great masses, it takes a crystalline opaque form. When broken, it would be taken for a natural fossil. The structure is fibrous: and the fibres all converge to centres; but are commonly interrupted by others converging to other centres. The whole is extremely like, and may be mistaken, even by a fossilist, for a zeolite. Sometimes we find, in large lumps of green glass, little round balls like pin heads, or pease, of the same dirty white colour. These, when examined by a microscope, are found to be crystallizations of the same kind,—the fibres all standing inwards, perpendicular to the spherical surface. Now, looking at the confused crystallization of the great masses just now mentioned, we see that they affect the same arrangement: and we can trace the circumference of each sphere, of which these radiated crystals are a portion. By the way, this appearance puts an end to the doctrine of those who ascribe all crystallization to watery solution. Here we see it produced altogether by heat. Indeed we know that many metals, and sulphur, always crystallize in cooling, and will congeal in no other way.

After this digression on the nature and manufacture of glass, which its importance will sufficiently justify, it is proper to consider a little more the union of the alkali and siliceous earths.

I observed that they not only united by melting, but even by boiling the earth in a watery solution. When the liquor silicum is mixed with an acid, the earth is precipitated in an impalpable powder, which will be completely redissolved by adding more acid, and again precipitated by adding more alkali; and this may be repeated as often as we please. But there are differences in this respect which are remarkable. The Chevalier Dolomieu observed, that when quartz was precipitated in this way, it would not be redissolved by acid, if kept in the state of a precipitate even for a few hours. This, with some other peculiarities of the quartz, attracted his attention. Quartz emits a very peculiar smell when rubbed or struck by another bit of quartz, and emits much light. If the dust struck off be examined with a microscope, particles of it are found scorified, and spungy. Quartz froths when melted on charcoal. He therefore suspected that it contained elastic and imflammable matter.

He mixed 10 drachms of quartz with a solution of caustic alkali in a retort, joined to a pneumatic apparatus. By gradually raising the heat to the greatest intensity that his retort would bear, he expelled from it, 1*st*, 22 inches of azotic gas; 2*d*, 12 inches of hydrogenous gas; 3*d*, 22 inches of airs, of which 16 were carbonic acid, and the rest a mixture of azotic and hydrogenous gas. The residuum was, in some cases, a spongy glass, and in others solid and green coloured.

He thinks that quartz, when dissolved in acids, has quitted the azote and hydrogen; and when precipitated by alkali, has regained it by decomposing the water. When deprived of these airs, it has an attraction for acids; but loses it when reunited to the azote and hydrogen and carbone; as lime has its attractions diminished by its union with fixed air.

Dolomieu subjoins to these experiments several ingenious observations on the siliceous earths, and substances which contain them, particularly the gems. Although he advances some opinions which seem to me very unwarranted by experiment, his observations are curious and interesting. You will find an abstract of his dissertation in the Journal de Physique, May 1772.

GENUS V.

FUSIBLE STONES.

THE ingenuity and industry of the modern chemists and natural historians, particularly of Margraaf, Woulfe, Bergmann, Scheele, Kirwan, and others, have discovered that the natural earthy or stony substances which I comprehend under the titles of FUSIBLE and FLEXIBLE, do not contain any simple elementary earth that is different from those six we have already described.

The fusible and flexible stones are all compounded of two or more of these six earths, intimately united and incorporated together.

You will find in Bergmann's Opuscula, and in Mr. Kirwan's Mineralogy, an account of the processes by which earths and stones may be analysed, and the simple earths of which they are composed, separated exactly from one another. We cannot describe these processes here. They are too complicated and tedious to be a fit subject for a lecture. A person who would make himself master of them must study them at home, and at leisure.

Professor Bergmann, in his *Outlines of Mineralogy*, and Mr. Kirwan, in his valuable work on the same subject, have formed their arrangement of the earthy and stony substances, and their distinctions of them, from the prevalence of the simple earths most abundant in the composition of each. And for this reason they have no divisions or classes which correspond to these two last of mine.

Their method, however, assembles together things so very unlike to one another in every other respect, that I have not chosen to follow it. The greater part of the gems, for example, the ruby, emerald, topaz, and others, are put into the same class with the clays, on account of their having more of the argillaceous than of any other simple earth in their composition.

But a person who wishes to have some knowledge of the riches and variety of nature in this part of her works, ought surely not to confine his attention too much to that point. There are many other differential qualities of her productions, which are more easily perceived, and more striking; and therefore more proper to be attended to in distinguishing and arranging them, and in giving general views of them. And this is the reason that has induced me to prefer the method I follow in giving a general account of the earthy and stony bodies. And I must premise that there is scarcely any method for these stones that is not very imperfect. This results from their compound nature. Accordingly, it is extremely difficult to class a specimen that comes in our way by means of the descriptions given by the fossilists. Nor are they agreed in their denominations. What one calls a granite, another calls a porphyry: and a third calls it a trap.

The natural stones which I think it is proper to assemble under the title of *fusible*, are of six kinds:

1. Feldt spat, or felt spar.
2. Porphyry.
3. The garnat.
4. The stony matter called schoerl or scherle by the Germans and natural historians, and cockle, by the English miners.
5. The zeolite.
6. The lavas, basaltes, pumice, and other fusible matters, which have evidently been thrown out of the bowels of the earth by volcanic fires and explosions; or which appear to have been formed and accumulated by them under the surface.

The first of the fusible stones, therefore, is the FELDT SPAR, the appearance and qualities of which are these:

It is a stone generally less transparent than quartz: some kinds are as white or free from colour. More commonly, however, it has a reddish tint or flesh colour. In hardness, it is nearly equal to the hard stones, and therefore strikes fire with steel. When it is broken we can always perceive by the reflection of the light from its surface, that it has a plated structure, and it has a disposition to be broken into rhombic fragments. These two qualities are never found in quartz.

FELDT SPARS are,

1*mo*, The most common, of a reddish colour.

2*do*, The white.

3*tio*, The crystallized.

4*to*, Crystallized and transparent,—*adularia*.

When feldt spar is exposed to the action of heat, it first becomes more brittle and pulverable. And afterwards, if the heat be increased to a violent degree, it melts into a viscid glass, which is white and semi-transparent; on account of which property, and some others, it is excellently fitted to be an ingredient in the composition of porcelain.

It has been analysed by Mr. Woulfe, Professor Bergmann and others: and the definition given of it by Bergmann, in consequence of this analysis, is,

"Siliceous earth united with argillaceous earth, and a small quantity of magnesia and sometimes barytes." The proportions have been found very different in different feldt spars, or in the different analyses that have been made of them, of which you will find a comparison in Mr. Kirwan's Mineralogy. From the whole he concludes, that any compound of silica and alumina, in which the silica predominates, and to which a smaller proportion of lime and magnesia, or of lime, magnesia, and barytes accedes, so as form a compound, fusible in a strong heat, may constitute a feldt spar. The magnesia and alumina may be exactly separated from one another by dissolving them in the muriatic acid, and precipitating by carbonat of ammonia. The whole of the alumina is precipitated, and the magnesia remains dissolved in the form of an acidulous carbonat.

Feldt spar abounds in the composition of the rock or stone called granite, and is the distinguishing ingredient in that stone. Granite has its name from being composed of angular grains of various sizes, in the different varieties of this stone; the greatest number of which grains are feldt spar; the rest quartz and mica, which we shall soon describe.

The granites form some of the highest and most extensive chains of mountains in many parts of the globe, being in general very durable stones, though some of them are not so remarkable for durability. And, as we never find any relics of marine productions in them, they are considered by many as original or primeval stones, and their formation as long prior to that of any stratified matter. But my friend Dr. Hutton, having visited some parts of this country where granite is found, and examined with attention those places where the granite was bounded by the stratified matter, or came in contact with it, he found the stratified matter, which was of the hardest and most durable kind, split and broke in those places in a remarkable manner, and the granite constituting or forming veins in it; that is to say, that the granite had penetrated into the fissures and rents of the stratified matter, and had filled them up completely: shewing therefore that the stratified matter had, in this case, existed first, and that the granite was applied to it with violence and in a fluid state. Some of the hardest granites that are known are rendered extremely friable by a very moderate heat, even that of a small bundle of straw burning in contact with them.

Feldt spar, besides entering thus largely into the composition of granite, occurs also sometimes by itself in veins.

The second species of fusible stone is PORPHYRY. It is of various colours, of which a dirty brownish green is the most common. It is also of a deep red, black, and rusty brown, and sometimes of a dark grey. All of them have spots; and the ground is compact, and breaks with somewhat less lustre than marble, but more than flint. The spots in it are feldt spar. Its hardness is greater than that of marbles, but inferior to that of hard stones: and it is easily fusible.

It forms large masses and rocks in the places in which it is

found; and some kinds of it have beauty, by their colour and capability of polish: but these are rare. The Upper Egypt alone supplied Rome with fine porphyries.

The third kind of fusible stony matter, the GARNAT, is very commonly crystallized into roundish polyhedral masses of a small size; and is generally of a deep red colour, and transparent. In some of these stones, the deep red colour is accompanied by great transparency and brightness: though in the greatest number it is obscured, by innumerable flaws and cracks, or the admixture of other earthy matter. By chemical analysis a considerable quantity of iron can be extracted from the deep-coloured garnats: and to this metal the colour is imputed. But some specimens of this stone contain little or no iron; and such have very little of the red colour.

It is found, and appears to have been formed, in stones that abound with mica or with feldt spar. It has its name, *granatus*, from its resemblance to the pulpy seeds of the granate apple, or granate fruit.

The fourth of the fusible stony substances is named SCHOERL; and is found in many compounded or mixed stones which never are of the stratified kind, but are some of the species of what I call rock.

The schoerl appears on these stones in the form of separate grains or masses, always crystallized into extended columnar forms, or into fibrous or plated masses. Sometimes it forms groups of straight fibrous crystals, like the bristles of a brush, or even more slender than fine hair; and in some cases is found in this form traversing transparent crystals. Another singular form is the *cross stone*, consisting of two of these crystals crossing each other, not as adhering, but crossing through the centre, some perpendicularly, and others in an angle of 60 degrees. A fine specimen was seen in this country in crystals, which were hexagonal prisms, some of them almost an inch in diameter, and some inches long. They were deeply indented transversely, as if made up of plates not all of one size. Examining some fine hair-like crystals in my possession with a microscope, I found

them of the same structure. It is often black and opaque: and some of these varieties are named *hornblend.*

Many kinds of it, however, are transparent, and have even the brightness of gems, with a green colour more or less deep. The colour and opacity in this stone always proceed from more or less of iron. The most remarkable of the schoerls is the *tourmalin*,—remarkable for its primitive and permanent electricity and electric polarity, perfectly analogous to magnetism.

All schoerls melt without difficulty in a strong fire, and form a black or dark-coloured vitrified mass.

The fifth kind of fusible stone in the enumeration I gave, was the ZEOLITE. It was first distinguished and characterised by Cronstedt. It occurs in general in the form of small masses involved in rocky stones, or forming veins in such stones. That part of the rock of Arthur's Seat, which shews a tendency to the form of six-sided columns, or prisms, contains small veins of zeolite harder than common.

The zeolite is always crystallized, or shews some regular external form or internal arrangement of its matter. Some of these forms are the most wonderful and beautiful of all that have been observed in the mineral kingdom. Some are hollow, and are formed within into transparent or whitish crystals; sometimes slender and long, like fine bristles, in diverging bunches. And sometimes even these bristly crystals of the zeolite pervade chalcedony: and sometimes small siliceous crystals like grains of corn are involved in them.

The chemical qualities of the zeolite are, to melt in the fire, or by the heat of the blow-pipe, with remarkable facility. And most kinds of it swell at first into a spongy mass like froth, or sometimes as borax does in its watery fusion. It is from this circumstance that it acquires its name. Indeed, they contain a considerable quantity of water in their composition; but that cannot be the cause of this fusion. But after this, by increasing the heat, the zeolite contracts again, and melts more perfectly, either into a clear and bright glass; or some kinds of it, which are more difficultly melted, form only a white opaque glass, or white enamel.

When diluted nitric acid is applied to the zeolite, this stone

is dissolved into a clear liquor, which after some time becomes a jelly.

These chemical properties of it were discovered by Mr. Cronstedt. But my friend Dr. Hutton proceeded farther in this experiment; and by examining the solution, and the gelatinous matter formed in it, he discovered that the zeolite is a compounded substance, and contains a fixed alkali combined with siliceous and with argillaceous earth. The proportion of the alkali to these earths is different in the several varieties of this stone: and this is the reason of the different degrees of fusibility which we find in them. They all contain a great quantity of water.

The last kind of fusible earthy and stony substances are those which are thrown out, or formed, by volcanic fires. Of these there is a considerable variety. We find among them what are called LAVAS and PUMICE, and what are called ASHES.

The lavas are very various. Some parts of them are black and perfectly vitrified, resembling the darkest and coarsest kind of glass. Generally, however, they are a mixture of earthy substances, which have not been brought to a state of perfect fluidity. Some of the materials only, were fluid when they came out of the volcano; and the whole had the consistence of thin mortar, or sometimes has been more fluid. When it cools, it has not an uniform or glassy texture, but is composed of particles and fragments of many different kinds, cemented together by the matter which was melted.

The fluidity of lava appears to me to depend on latent heat, combined with the materials by the long-continued action of subterranean fire. While they are still flowing, their heat is not very intense. (*Dolomieu Journ. de Phys.* 1793). Yet they retain part of this heat a long time, with some degree of fluidity or softness. A lava, erupted in 1614, continued to move for ten years, and in that time slipped downwards about two miles. It was probably soft below: and as it lay on a slope, the indurated mass above could slide a little way.*

* The spongy texture of the indurated matter must greatly retard the emersion of the latent heat, and consequently the congelation below.

EDITOR.

Most natural historians are now of opinion that the rocky stone, of which there are many varieties in this country under the name of WHINSTONE, but in other places called TOADSTONE, RAGSTONE, or ROWLEY-RAG, and also TRAP and BASALTES, and by other names, is of the same nature with lava, and belongs to this division of volcanic matter,—a matter which has been melted by subterranean fire. Dr. Hutton, however, makes a distinction between many, or most of these stones or lavas. He considers the term lava to be properly applicable to that melted matter only which has been thrown out by volcanoes, so as to flow down their sides, or along the surface of the earth. But there cannot be a doubt, that the same fires must produce, at a great depth, large quantities of melted matter, which is never thrown out, but continues melted a long time, and is driven by the immense force of the explosive matter in lateral directions, forcing its way between the strata which are around, or penetrating into the rents and fissures of these; and thus forming what we call dykes, or in other cases, flat and extended masses of unequal thickness, such as Salisbury Rock, and many others that are around it, and the toadstone of Derbyshire*.

Whinstone is called *basaltes*, when it is split into columns or prisms, most of them six sided, and standing in close contact together, generally upright, though sometimes inclined to the horizon, and even bent.

There are famous examples of this in the Giants' Causeway in Ireland, and in the island of Staffa, and other islands and rocks on the west coast of Scotland. And there is a tendency to it on the south-east side of Arthur's Seat here, beside many examples on the continent.

This columnar appearance seems to arise from a kind of shrinking, as the heat which gave it the imperfect fluidity gradually abates. I was informed by a gentleman who visited Iceland not long after the late eruption of Hecla, that the inhabitants shewed him extensive masses of lava of former eruptions, which were not thus shivered, when they had cooled so much

* A dyke of this kind pervades the coal strata in Newcastle Moor: and it has charred the coal on each side of it to the distance of several yards.

EDITOR.

that they could be approached, but that year after year, the regular columnar divisions appeared more evident, and at the time the gentleman saw them, they were very distinct basaltes. We observe an appearance very similar to this in common starch, which always separates by shrinking into pentagonal and hexagonal columns.

The opinion that this stone, and whinstone in general, has been formed from melted subterraneous matter, is founded on the similarity of its appearance to that of many lavas: and there is a similarity too in their constituent ingredients. And further, the lavas of some well known and now-existing volcanoes, have been found in some parts of them formed into these pillars; as the Chevalier Dolomieu observed in the lavas of Ætna.

In basaltes and whinstone we commonly perceive many particles which have a plated structure or extended prismatic figure, more or less resembling schoerl. The colour of the stone is commonly grey or black, or dark red; but sometimes, though rarely, light grey, or whitish.

There is a considerable variety of the stones or rocks which belong to this species, or may be included in it; and most of them are not formed into columns, but are in general split into oblong angular masses, which are often upright, as in Salisbury Rock; but in some cases inclined to the horizon. Some approach very nearly in nature to granite; others as nearly to porphyry. The rock of the Calton Hill is a stone of this kind, which has the nature of porphyry in some parts of it. The rock of the Bass approaches to granite.

They often contain nodules, or small masses of stony matter, different from that of the rock itself. These small masses are either siliceous, or calcareous, or barytic, or zeolite, or a collection of some of these stony bodies in the same mass. The greater number of agates, and especially the small ones, called Scotch pebbles, are small siliceous masses, which have been formed in rocks of this kind; and are found in the gravel and rubbish produced from the decay of these rocks.

The toadstone, of Derbyshire, is a whinstone containing nodules of calcareous matter.

It is always in these whinstone rocks too, and particularly the basaltic kind, that zeolite is found, either in nodules or in veins.

Anciently, whinstone and other fusible stones appear to have been employed, in this country, to construct walls or ramparts round little camps, or strong posts, into which the inhabitants retired when invaded by an enemy. And they appear to have been cemented by fire,—the external parts, on both sides of the wall being melted into an imperfect slag. There are ruins of such works in different parts of Scotland; the construction of which must have been long prior to any tradition that now remains, or to the use of lime. A description of some of them has been given in the Transactions of the Royal Society here, by my colleague, the Professor of Civil History.

Pumice is the next volcanic matter. It has the appearance of having undergone very perfect fusion. The most remarkable quality of it is its sponginess. It has nearly the contexture and appearance which glass would have, were it wrought up into a froth while it is cooling. The Chevalier Dolomieu, in his account of the *Isles Cyclopes*, a cluster of islands near Sicily, has given the natural history of pumice. And I have observed some facts and phenomena, occurring in some of the arts, which may suggest conjectures of the way in which it is formed, viz. what appears in slags of lead, and also slags of iron hastily cooled.

The last volcanic matter, called Ashes, is a sort of gravel and sandy dust, composed of vitrified and spongy particles of all sizes; and is undoubtedly a sort of rubbish, into which different materials are changed, when softened by the heat and exposed to the violent concussions and explosions which happen in the bowels of the mountains, or during eruptions. It is sometimes thrown up to a very great height in the air; and is then carried away by the winds, so as to fall, on some occasions, at a great distance from the volcano.

When this matter is amassed in great quantity, and compressed by incumbent weight, it concretes into a spongy soft stone, called *tufa* by the Italians. And other parts of it, which remain in the state of a sort of gravel, are excellently adapted for forming strong mortar with lime. They are brought from Italy for that purpose, and are called *puzzolana*. They are used for water buildings.

GENUS V.

FLEXIBLE STONES.

THE last section of the earthy bodies only now remains to be described,—that of the FLEXIBLE STONY BODIES. They are distinguished by being flexible, or easily divisible into parts which have great flexibility.

These are concretions which are in general so soft as to be easily scraped or cut with a knife; and do not suffer any change of their hardness or structure from the heat of a moderate fire: but in a strong one many of them are easily melted.

Two of the classes formed by Cronstedt, his *Micaceæ* and *Asbestinæ*, are comprehended in this section of flexible earths. And it may with propriety be distinguished into three subsections, the *plated*, the *fibrous*, and the *membranous* or *cellular* kinds.

The first of these subdivisions, therefore,—the plated flexible stony bodies, contains the micaceæ of Cronstedt, or the *talcky* fossils of the English naturalists; so called from the principal species long known by the name of mica or talc.

It is a stone which feels unctuous and slippery between the fingers, and splits easily with a knife, like the foliaceous gypsum, into innumerable and excessively thin leaves, not only very flexible, but elastic;—employed for confining the objects in microscopical observations. It is easily distinguished from the foliaceous gypsum by its elasticity, and by the effects of heat.

This stone is generally transparent in the thin plates, and often colourless. It is more commonly tinged, and sometimes quite opaque. The colour is very various,—dusky, greenish, silvery, golden, and many other glittering appearances, which often deceive those who are unacquainted with it. These appearances do not proceed from metal, but from the disposition of the plates.

Mica is found very plentifully in the composition of some kinds of rock, especially some of those which contain a large proportion of the fusible earths;—in granite especially, and in the schistuses which contain garnets or granates.

But it is mixed besides with some of the strata which have been formed from the materials of demolished rocks, as sand, and sand-stone, and gravel, and some clays.

The largest specimens of transparent mica come from Russia, where they have it in such plenty and perfection, that in some parts of the country it is used for windows and lanterns.

The flexibility of this fossil explains the flexibility of a stone which was exhibited here in 1791, and is now in the cabinet of Lord Gardenstone. It is about half an inch thick, and more than a foot square. It is flexible to a moderate degree, but without elasticity. It is composed of small thin plates of mica, all parallel to one another, and intermixed with thin discontinuous plates of quartz. The great number and smallness of the plates, and the presence of the quartz, prevent this stone from being elastic.

The second division of the flexible earths,—the fibrous,—comprehends fossils which have the same chemical qualities with mica, and differ from it chiefly in their structure, which is fibrous instead of being plated. There are many varieties of these, diversified by the fineness and flexibility of the fibres, and by the closeness or looseness of their connection. Those reckoned the most curious and perfect, called amianthus, may be teased into a matter like cotton, which, being mixed with a small quantity of flax, may be spun into yarn, and wove into a cloth, which does not suffer from ordinary fire. The only use that has been made of this fibrous stone, is one for which modern customs do not find room. The ancients made a sort of

cloth of it, on which they laid dead bodies on the funeral pile, to preserve the ashes of the body by themselves, and unmixed with those of the fuel. Some have attempted to form it into paper; but it makes very bad paper.

The other fossils which belong to this subdivision, are formed into membranes like leather, or elastic spongy masses like flesh or cork. These are named *mountain-leather*, *mountain-flesh*, and *mountain-cork*, by the miners.

All these fibrous or membranous flexible stones are found in veins, or cavities of veins: and all contain the silica in largest quantity, but intimately combined with magnesia, alumina, lime, and a small portion of iron. You will find the proportions stated in Mr. Kirwan's Mineralogy, and in Professor Bergmann's Essays.

Magnesia is always a constituent part of the flexible stones, and is generally their most abundant ingredient after the silica.

APPENDIX.

PRECIOUS STONES.

AND now, gentlemen, I have taken some notice of the different kinds of earthy and stony bodies that appear to be most remarkably distinguished from one another. Among all these, however, I have as yet made no mention of the PRECIOUS STONES, which may perhaps be thought a material omission.

The reason is, that this title does not assemble together a set of stones that are similar to one another by their nature or chemical qualities. It is a general name given to all stones remarkable for more or less transparency and brightness, or for some colour, or mixture of colours, or smoothness of surface, which has pleased the taste of mankind. And the stones, in which these qualities are found, happen to be very different with respect to their nature and to the materials of which they are composed. I shall here give a short enumeration of them.

I shall begin by making a division of them into STONES and GEMS. Under the first title I comprehend those produced by nature in large masses, or in considerable quantity. Under the second, those which occur of small sizes only, and much more rarely, on which account they are far more costly than the others.

To the first division belong,

1. Marbles.
2. Serpentines.

3. Alabasters.
4. Some Porphyries.
5. Some Granites.
6. The English Pudding-stone.
7. Some Spars.
8. Some Jaspers.
9. Some of the siliceous petrifactions of wood.
10. Some kinds of the Lapis Nephriticus.

1. *Of Marbles.*

The marbles are all limestones, or are composed of calcareous matter; and are different from the more common limestone only by agreeable colours, or mixtures of colours, and a more perfect compactness and greater hardness, which fits them for being more highly polished.

Many marbles appear to have been formed from small fragments of shells, ground down by agitation and attrition into sand, which has afterwards been cemented by some natural operation. In many others we see distinctly the relics of the shells or lithophyta entire, or in large fragments. Marbles, in which shells are seen in this manner, are named by the Italians *Limacelli.*

When marbles are clouded or spotted with different colours, this is produced, either,

1*mo*, By these relics of shells and corals appearing in them; or more generally,

2*do*, By an unequal and irregular intermixture of iron, or inflammable matter through the stone, so as to form streaks and spots which please the eye, by the contrast of their colours, and the variety of their shades and distribution; or,

3*tio*, The variety of colours in some marbles have been formed by an operation they have undergone. We can plainly perceive that the stone has been fractured into a number of pieces, which have been set afloat in a liquid marble paste of a different colour, and are now cemented together by it.

Such marbles are named *Breccia* by the Italians.

All these have more or less beauty. But we may reckon among the most valued marbles, the pure white statuary, and the perfect black. Such must naturally be rare. It cannot often happen that a block, of size sufficient for a statue or a groupe, is entirely free from spots or clouds, or streaks of a different colour or tint.

2. *Of Serpentines.*

The most obvious distinction of serpentines from marbles is by their colour, in which a deep and dusky green prevails: and this is a colour, but very rare in marbles. As to the nature of serpentines, some are partly calcareous; but all contain magnesia and iron. A species of porphyry is improperly called serpentine.

3. *Of the Alabasters.*

This name is applied by the lapidaries to white stones that are softer than marbles, but capable of being well polished. They are generally composed of the natural sulphat of lime. But often calcareous stalactites and spars are also named alabasters by the stone-cutters.

4. *Of the Porphyries.*

Of the porphyries there are only a few species reckoned precious or beautiful. One is dark green, with light green or white spots. Another is dark red or purplish, with whitish spots. And there are some, the ground of which is almost black. They are harder than the marbles, but softer than the hard stones. I rank the porphyries among the fusible stones, to which division they certainly belong by their properties and constituent ingredients. And many of our whinstones, and many lavas in the volcanic countries, are coarse porphyries.

5. *Of Granites.*

Some of the granites are also considered as stones of value. The nature of this stone was formerly described. The only certain species of it reckoned valuable are the Egyptian, the Russian, and the Scotch.

6. *Of Pudding-Stone.*

Many pieces of the pudding-stone or gravel-stone found in England are also reckoned beautiful and precious.

7. *Of Spars.*

The spars reckoned precious or beautiful are some few calcareous spars, but chiefly *fluors* and *lapis Lazuli*. Fluors, admired for their beauty, are found plentifully in Derbyshire. *Labrador-stone* is a feldt spar, or is nearly allied to it by its constituent parts. It derives its beauty from a certain disposition of its transparent elements, which, like those of pearl and mother of pearl, exhibit different lights as they are viewed in different directions. It frequently appears as if the surface was undulated, although it be perfectly flat. The opal has its beauty from the same cause. We see appearances of the same kind in some woods, such as mahogany, satin-wood, &c. and in these the microscope discovers the circumstance on which it depends. We even see a little of it in some slates. When examined in their natural plates, they are really undulated: but when the surface is made flat and polished, the undulated appearance is not entirely removed.

8. *Of Jaspers.*

The name of jasper is sometimes applied to some marbles, but improperly. When used with propriety, it means hard stones, opaque and agreeably coloured by admixture of other matter with the siliceous, especially iron. The most noted jaspers that are beautiful are Sicilian, yellow, red, and white; green jasper spotted red; Heliotropium.

9. *Of Siliceous Petrifactions of Wood.*

Some of the siliceous petrifactions of wood, when they happen to have the density of agate or Jasper, and are agreeably coloured, are also wrought by the lapidaries, as precious stones; and snuff boxes or other toys are made of them.

10. *Of the Lapis Nephriticus.*

Lastly, some kinds of the *lapis nephriticus* are in request, on account of their agreeable colour, and the polish or smooth surface that can be given to them. The Turks, in particular, are fond of this stone to make the handles of their scimitars.

Having now said enough of the first section of precious stones, those, to wit, produced by nature in large masses, we proceed to the second; in which I include the gems, or those produced in smaller masses, and more rarely.

The title of Gem was applied not long ago to a much greater number of stones than it is by late authors. I shall follow the old method, according to which the stones called Gems were divided into Semi-Pellucid and Pellucid Gems.

1. *Semi-Pellucid Gems.*

The greater number of these belong to the order of hard stony substances, and are chiefly composed of the siliceous earth. They are, in general, formed into small masses in some kinds of rock, or fill up small veins in it: or they are found among the gravel and earth into which such rocks are resolved, by the influence of time and the weather.

The siliceous matter, of which they are principally composed, has generally some degree of transparency. But this transparency is diminished, and in some cases a great degree of opacity induced, by the admixture of other matter. Often this diversity of materials is so disposed as to produce clouds, or spots, or streaks of different colour and appearance, which add to the beauty of these stones.

Among the most notable kinds of these stones, we may reckon,

1*mo*, Agates.—Great numbers of them are found in some parts of this country, [Scotland] of a small size, but some of them very pretty when polished,—called *Scotch Pebbles*. I have already pointed out the origin of them. The internal arrangement of their matter is remarkable, and will be explained by Dr. Hutton, in a work he is now publishing on the formation of stones.

2*do*, Chalcedony, of the colour of the whey of milk. It is much esteemed by seal-cutters, for a kind of *toughness*, as they term it, which makes it work without tearing up by their powders. This must arise from its having no grain or symmetrical arrangement of parts.

3*tio*, Carnelian, also valued by seal-cutters, as being very easily worked. The natural formation of carnelian is one of the most curious objects that mineralogy presents to our eye. It has certainly been fluid as chalcedony; and the fluidity has been imperfect or clammy, and has been a very slow exudation from the rock or matrix to which it adheres. It is found hanging in tears from the sides of the cavities: and these appear to have harden-

ed superficially as it sweated out; so that the long string is all incrusted with little excrescences, which have been, in succession, the end of the drop. These icicles often dip into a mass of chalcedony, whose surface is perfectly smooth and flat, as if it had been fluid in a dish, and the icicles can be traced through it, (it being in a small degree transparent) to the bottom, without mixing with this mass. The curious, and not inelegant form of the exudation, may be precisely imitated, by putting a lump of hard pitch on a shelf, in warm weather. It will soften and drop down from the shelf in strings, which are figured in the very same manner.

4*to*, Onyx, fit for cameos, by reason of its strongly contracted coats. Sardonyx is either a mixture of chalcedony and carnelian, or is a chalcedony spotted with small red points.

5*to*, Mocoe, finely diversified by tree-like figures, elegantly ramified.

6*to*, Opal, of varying colours like mother of pearl.

7*mo*, Turcoise.

2. *Pellucid Gems.*

Most of these also belong to the order of the hard stony substances: and some of them are the hardest substances produced by nature. A few belong to the fusible class. They are always found in very small masses, crystallized into regular figures, more or less peculiar to each kind; and when they are reckoned gems, have extraordinary transparency and brightness. They appear to be originally formed by nature in some kinds of rock, or in the veins of rock, and some are actually cut out of such veins. But most of them are picked up from among gravel or earth formed by the decay of such rocks which contain them.

The more common kinds of them, which bear but a moderate price, are siliceous crystals, composed of the siliceous earth, with very little admixture of any other.

But those which have the greatest hardness and brilliancy, and which are named by the jewellers *true* or *oriental gems*, have been found less simple in their composition. A number of

accurate analyses of them, by Achard of Berlin, Professor Bergmann, Mr. Kirwan, and others, have shewn that they contain the argillaceous earth in greatest quantity, intimately combined with a smaller proportion of the siliceous, and a still smaller of the calcareous, and of iron, to which metal they owe their beautiful colours. And it is only these transparent stones, which contain more of the argillaceous than of any other earth, which are distinguished by the title of gems by Professor Bergmann. I see no reason however for restricting the title so much.

We may here remark, that those gems which contain a larger proportion of the argillaceous than of the siliceous earth, have not the same chemical qualities as the other hard stones in which the siliceous earth prevails above all others. They not only resist the most violent heat without melting, when exposed to it without addition, but it is extremely difficult to melt them by means of alkaline salts, which easily dissolve the siliceous crystals into a glass. You may see, in Bergmann's Opuscula, the other particulars by which they differ from the siliceous crystals. Some of the siliceous crystals are tinged, as well as those reckoned true gems, with blue, or purple, or yellow, or other colours. But these are much rarer than the colourless crystal; and, when they have brightness they pass for gems: though, on account of their inferior hardness, they are not so highly valued, nor indeed have they so much brilliancy.

There are also siliceous crystals which have a dusky or brown colour, and yet have great transparency and brightness. Such are those found in the mountains of Arran, and some other mountains of this country. And some of these brown crystals, by being heated equally and cautiously, to a degree that is short of ignition, lose the brown colour, and retain a yellow one, which may be lost also if the stone be heated too much. I knew a person who made profit by collecting these brown crystals, and converting them into yellow ones. These convertible brown crystals are found in some mountains to the north-west of Aberdeen.

The pellucid gems may therefore be thus enumerated:

1*mo*, SILICEOUS CRYSTALS, colourless or coloured.

2*do*, The EMERALD, of a bright green colour, of which there are many varieties. It is much allied to schoerl: and some of the pale emeralds, named *aqua marines*, are true schoerls.

3*tio*, The TOURMALIN, though it be not a beautiful stone, being of a very dusky green, is however at present reckoned a gem. Its remarkable property is to be electrified by gentle heat alone, without being rubbed. It is also a schoerl.

4*to*, GARNATS, that have transparency and brightness, are used as gems. They have all of them a rich red colour, but differ very much in the deepness of this colour: when it is very deep, the stone has less brightness. The very bright garnats, in which the colour is less intense are named *scarlats*.

5*to*, The AMETHYST, of a bright and beautiful purple.

6*to*, The SAPPHIR, of a perfect and rich blue.

7*mo*, The TOPAZ, of a beautiful and brilliant yellow.

8*vo*, The RUBY, which has a red colour of great richness and brightness.

9*no*, The DIAMOND the most valuable of all. It is sometimes slightly coloured, and even dusky and opaque: but the most colourless and brilliant are the most highly valued. The diamond is remarkable for four particulars:

1. It is one of the rarest productions of nature. We are not certain that it is to be found any where except in the peninsula of India, and in the Brazils. In both places it is always found in detached solitary crystals, which are octaedral, or often prismatic, terminated by a pyramid. These have sometimes smaller crystals as it were growing out of them. But we have never met with the diamond in groups adhering to a shapeless base, as is the case in all other crystals. They have never been met with in the cavities of other stones: nor do we know any kind of rock or vein which may be said to be the matrix of diamond. All that have been hitherto seen, are found in loose gravelly earth, at no very great depth. This is washed and picked for the diamonds it may chance to contain. There are to be met with, in the cabinets of the curious, a very small number of diamonds terminated at both ends with pyramids. This is, indeed, a very rare crystal of any kind. From the circumstance of one

end wanting a pyramid, we are entitled to suppose, that, like other crystals, they have originally adhered to some matrix. But, as has been said, they have never been met with, except among what may be called the rubbish of some former condition of things. Several specimens have been found wholly or partly incrusted with an opaque whitish matter of great hardness, but yet so soft as to have all its asperities rounded by the attrition which the pebble had received. The jewellers call this mother of diamond, and, I think, with some propriety: for in some that I have seen, the transition from diamond to this substance is not abrupt, but gradual, as in the case of the onyx. It was in the course of this century that diamonds were discovered in Brazil: and their price is now greatly fallen.

2. Diamond is no less eminently distinguished by its extraordinary brilliancy and great refractive and dispersive power,—far exceeding all other natural crystals. Mr. Zeiher, a German artist, has approached very near to the brilliancy, and to the refractive and dispersive power of the diamond, in some of his compositions for imitating precious stones. But these fall infinitely short of the diamond in its next remarkable property, viz.

3. Its superior hardness. In this it exceeds all substances that are known. It is therefore employed for sawing and boring the hardest stones, and for engraving seals. For this purpose it is reduced to powder.

This powder is used in the same manner as sand, emery, or other cutting powders, are employed by the lapidaries, viz. by moistening it with empyreumatic oil, and applying it to their wheel or drill; or the metal point used by the seal engravers, like a crayon. The metal employed for this purpose is the purest and softest iron. This takes fast hold of the diamond powder,—it being pressed into it by the force exerted in the operation: and the little particle never quits its place to roll about, but is carried along by the tool, acting like the tooth of a file, and tearing up whatever it touches. There is something curious in the way in which diamond acts in cutting common glass. The glazier's diamond is by no means sharp pointed. I have seen them as blunt, and round, and smooth as the head of

a large pin. Yet this, with a moderate pressure, causes the plate to shiver under it wherever it is drawn. This is by no means a crack: but the glass being made somewhat weaker there, splits immediately, when gently patted on the other side with a hard body.

4. The diamond is still more distinguished from the rest of the gems by its chemical properties, or the effects produced on it by heat and mixture with other bodies. The utmost violence of heat, even that of a burning mirror, does not induce the least appearance of fusion. Its asperities are not perceptibly rounded, as has been observed in the ruby. The only effect of simple heat is, to dissipate certain foulnesses which sometimes taint its purity, or water, as it is called by the jewellers. But it makes no change in its texture, if the diamond has been free from previous cracks or flaws.

Nor does the utmost violence of simple heat volatilize the diamond. If it be protected from the action of the air, it suffers no diminution of its weight by the longest continuance in the fire. But if it be subjected to intense heat, and to a current of free air, it will be entirely dissipated, and this dissipation is accompanied by the emission of a dazzling white light. This was long thought to be a phosphorescence, as in the case of many other crystals and spars: and the dissipation was thought to be an exfoliation and dispersion, like the decrepitation of salts. But if this were the case, the dispersed dust might be found. As this has never happened, chemists began to conclude that the emission of light was an inflammation, and that the diamond was wasted by combustion like a piece of charcoal. The great rarity of diamonds, and the inability of most speculative chemists to afford the expence of the necessary trials, has retarded the decision of this question. But it is now past a doubt, that the diamond is a pure inflammable substance. I shall therefore defer the consideration of its combustion and its chemical relations, till I come to the consideration of that class of inflammables in which it must be placed.

Of the Corune, or Corundum.

After this notice of the gems, it may be proper to mention a singular fossil, which, though not a gem, (for it is totally destitute of beauty) is yet allied to some of the gems by its constituent parts, and by some of its properties. This is the CORUNDUM, or, as it is called by the British lapidaries, the *adamantine spar*. The first specimens of it came from China to Britain: and it was afterwards found, that it was to be had in India, not far from Bombay; and our naturalists have now found it in several granites of France and Spain. It is of a grey colour, like emery. The entire pieces are opaque: but very thin plates of it have considerable transparency. What comes from China has very evident hexagonal crystals: but all other specimens that I have seen, are of an indeterminate granulated structure. What comes from Bombay is more unlike to emery, and considerably whiter than all others: and it is this which is called corundum by the natives.

The remarkable quality of corundum, and for which it is chiefly valued, is its extreme hardness. It scratches every substance but diamond; and is therefore of great value to the lapidaries and seal engravers of this country, who employ it by the name of adamantine spar. It is but a little harder than the ruby, the sapphir, or the oriental topaz. It is far superior to emery, particularly for grinding on the wheel, to which it adheres like diamond dust. One part of it does as much work as four of emery, and does it in half the time.

The corundum unites with caustic soda, but with great difficulty. When the liquor silicum formed with it is decomposed by acids, it is found to consist of one-third of a peculiar earth, and two-thirds of clay.

Many of the precious stones are imitated by art; the marbles, and porphyries, and jaspers, by means of pastes composed of lime and gypsum, with other materials added to increase the

hardness and smoothness, or to give the colours. The art of making these imitations has been carried to a great degree of perfection. Large columns, pilasters, pannels, tables, mouldings, festoons, and other embellishments of the inside of buildings, have been executed very like to the more beautiful and costly kinds of marble and porphyry. And these imitations have the advantage of being procured at very little expence compared with the originals. But they are only fit for the inside of houses. The materials do not withstand the weather.

The pellucid gems are imitated with glass, made with great care and in small quantities for this purpose alone; the very purest materials being employed, and certain additions being made to improve the transparency and brightness of it, such as borax, and some of the metallic substances; some of which also give to the glass the different colours of the gems. The most celebrated authors who have written on this art, are Neri, Merret, and Kunkel, whose works appeared first in the German language, but have been collected together and translated into French, with the title of *Art de la Verrerie*,—the art of glass-making.

These artificial gems, or pastes, as they are called, by our jewellers, are very good imitations in some respects; and represent the beauty and brightness of the natural productions very nearly: but they cannot be compared with them in hardness and durability.

Setting aside, however, the attempt to imitate the natural gems, we may venture to say that art has in some respects far excelled nature in the productions it has obtained by working on the earthy substances. We have examples of this in the manufacture of the common kinds of glass, and in that of porcelain, and of the other beautiful and useful kinds of pottery.

The common kinds of glass must no doubt be allowed to be far inferior in brightness, as well as in hardness and durability, to some of the transparent stony bodies produced by nature. But the inferior hardness of glass is a great advantage in some respects, by rendering it more easily cut, engraved, and polished, and thereby making it a fitter subject for manufactures.

And the facility with which we can procure large masses and quantities of it, and the softness and ductility which it receives from heat, in consequence of which it is so easily formed into any shapes we desire, render it a most useful production; and raise its intrinsic value far above that of the gems, which are produced by nature in such very small quantities, and are with so much difficulty wrought into any form, that they are rarely applied to any other purpose than the gratification of weak-minded vanity.

Of Porcelain.

Porcelain is another production of art which has been invented upon principle, by making chemical experiments upon the earthy and stony substances, and which deserves to be admired for the elegance and usefulness of its productions.

The art of making porcelain was long confined to the eastern parts of Asia. It is now understood and practised in several parts of Europe, especially Dresden, Paris and some other places in France, and in several towns in England. It is a branch of the art of pottery, brought to an extraordinary degree of perfection, so as to produce vessels and other pieces of work, not only very elegant, and capable of high decoration, but which have the qualities the most desirable in vessels of earthen ware intended for the purposes of common life. The qualities I mean are, 1*st*, Great compactness of texture, by which it is both stronger, and made impenetrable and untainted by any thing put into it: whereas all the soft pottery is comparatively much weaker; and is moreover bibulous, and indelibly impregnated with almost every thing that we put into it; 2*dly*, A smoothness of surface which gives the vessels beauty, and makes them easily cleaned; 3*dly*, A texture which allows considerable alterations of heat and cold suddenly applied without cracking, as glass does.

We cannot tell by what steps this art arose to perfection so early in China and Japan, from whence the art was imported into Europe about fifty years ago. Du Halde has given a faithful account of the Chinese manner, as far as he understood it. But unluckily Du Halde was but a sorry chemist.

Perhaps the circumstance which gave origin to it in those countries was the abundance of proper materials, which are but rarely found in Europe. The materials of which the best kinds of porcelain are composed, are two. The first is a clay of the best and whitest kind, called by the Chinese *kaolin*. The other is a stone, which they are under a necessity of reducing to a fine powder, to prepare it for mixing with the clay in different proportions. This they call *petuntsé*. This stone is no other than either pure feldt spar, or, in want of it, a species of granite abounding with feldt spar, and quite free from any admixture of iron, or other dark coloured matter, which might spoil the whiteness of the porcelain. The effect of this stone, when added in moderate quantity to the clay, is to make it assume a greater degree of compactness in a moderate fire, and to give it semitransparency, without communicating too great a degree of fusibility. The Chinese call it the *flesh*, and the clay the *bones*. A granite, quite free from iron or other colouring matter, is rare in Europe. But there are places where such are found, particularly in Cornwall, where there is a great variety of granite, called *moor-stone*. And a company some time ago obtained a patent for the establishment of a porcelain manufactory of the best quality, in England, with intention to use that Cornish moor-stone.

Though these two ingredients are in general the constituent parts of the best porcelain, it has not been always necessary to mix them artificially together. It has happened both in China and in England that nature has in some places performed this part of the work, or furnished materials which do not need admixture. In some parts of Cornwall, where the granite or moor-stone abounds, they find a white clay mixed with the sandy rubbish of the moor-stone in such proportions, that, without any other trouble than separating it by water from the coarser particles, it makes excellent porcelain.

A considerable mass of Chinese porcelain clay was brought to this country some time ago, and worked up by our best artists. It makes perfect porcelain, but of that kind called *stone china*, viz. less transparent than common. To give it the degree of semitransparency expected in common porcelain, it is neces-

sary to add some of the *petuntsé*. But it may also be used alone, and then forms *stone china*, or *Nankeen china*. This kind of clay is manifestly produced by the gradual decay of the granite into rubbish and powder, during which decay it appears to lose some degree of its fusibility. We have proof of its origin by microscopic examination, by which we find in it the mica and quartz, and other materials of the granite. Magnesia, or the earthy bodies which contain it, are also excellent ingredients in the composition of porcelain. There is some of it contained in feldt spar and the granite, &c. Some of the porcelain manufactories in England employ the *soap-stone*, or *steatites*, in their compositions with good effect. The good qualities of this earth, are, 1*st*, To increase or improve the whiteness of the porcelain; 2*dly*, To preserve it from softening too much, or melting by heat.

The clay being worked into the intended form, is dried in the air, and then put into the kiln, and baked with a moderate heat, and for a short time. This brings it into the state of our soft potteries. It is then glazed and painted. The glazing is made by dipping it into a cream of powdered flint, with the addition of a little borax or barilla and other colourless materials, to make it take a thin fusion. Before dipping the piece, the blue colours have commonly been put on, because this colour is too apt to diffuse or run. The other colours are penciled on after it has been dipped. Many of the more ordinary European porcelains are covered with an opaque white varnish or enamel. But this is to cover ill-coloured clay, and may be known by its thickness and softness. The fine porcelain glaze is perfectly transparent, and as thin as a film of water. The piece is now baked again with a much greater heat, and for a much longer time; the particles now take a new cohesion and arrangement; and the piece becomes hard and compact, breaking with a dull lustre and somewhat of a granulous texture. But in the very finest porcelain no grain can be perceived, even with a microscope: and the fracture has scarcely any lustre, and resembles the fracture of white wax.

These are, therefore, the materials of the best kind of porcelain. But that we may not leave any part of this subject un-

touched, it is necessary to mention, that very near imitations of this kind of pottery may be made with materials different from these. And many of the manufactories which have been established in Europe make use of those other materials, and produce only imitations of porcelain. They must all employ a fine and white clay for one ingredient in the composition. In this they necessarily agree. But they have gone different ways in search of their fusible ingredient, which gives to the clay the proper degree of compactness and semitransparency. As a granite or feldt spar sufficiently free from irony particles occurs only in very few places of Europe, they have endeavoured to supply its place by other substances. Some have employed different kinds of gypsum, which, being fusible in a violent heat, answers in some measure the purpose of feldt spar. Others employ some of the alkaline earths, which, though not fusible themselves, produce fusible mixtures with clay and flinty earth. But greater numbers have had recourse to the ingredients of glass made into what is called frit, ground to a fine powder. The quantity of alkali in this composition is not sufficient to make it melt into a transparent and fluid glass, but makes it approach a little to that state, or makes it semitransparent. But these imitations are not porcelains. They are glasses or enamels not completely vitrified: and a greater heat will melt them. Even in inferior heats they go out of shape in the kiln by their own weight. Such ware cracks by any sudden change of heat. It is also soft externally, and soon scratched and sullied, because the ware will not stand the heat necessary for fusing a hard varnish. Mr. Reaumur, of the French Academy, who first examined the Chinese materials, was also the first who suggested this substitute of frit in place of petuntsé, where the latter could not be procured. And upon the same principle he attempted to change common glass into porcelain. He was led into this project also by accidental experience, as has been already mentioned.

Another author, in pursuit of the same object, sometime ago was induced to make a very great number of experiments, which have proved a considerable addition to our knowledge on the subject of earths. The author I now mean is the late Mr.

Pott of Berlin, who published these experiments in two small volumes, with the title of *Lithogeognosia*. But the nature of many of the earths and stones was not so well understood at that time as it is now; and he considered many compounded substances as simple earths. His experiments, however, excited a curiosity in other chemists to examine some of the purer earthy bodies in this manner. And there have since appeared, in the *Memoirs of Berlin*, papers, containing experiments of this kind, by Mr. Margraaf, and by Mr. Achard: and a multitude of experiments have been made in France, by Mons. d'Arcet, and by several others. Such experiments are interesting, as having a tendency to improve or illustrate the arts of pottery, glass-making, and metallurgy.

But no person has made, perhaps, so many experiments on the mixture of different earths for the composition of earthen ware and porcelain as Mr. Wedgewood. His object was to discover pastes, or compositions, which should have, not only the density and hardness of porcelain, but different colours. And he has succeeded in finding some of very agreeable colours,—such as what he calls his artificial jaspers, with which he executes beautiful pieces of workmanship, with figures in basso relievo, of the finest white porcelain, on a coloured ground. In this way he has imitated a famous vase, which is reckoned one of the most extraordinary examples of the excellence of ancient workmanship,—the Barbarini vase, now in the possession of the Duke of Portland. Mr. Wedgewood viewed this piece of antique pottery with the highest admiration, declaring that the artist deserved a thousand guineas for his work. The work in relievo is executed with the most perfect sharpness and precision, and is an enamel altogether opaque; so that where it is not so thick as the finest post paper, the colour of the ground does not appear through it,—an excellence which all his labours had not yet attained.

The true porcelains are now made in several parts of Europe in great perfection,—equalling the Asiatic in the beauty of the material, and even exceeding it in the most valuable qualities, of strength and ability to withstand great and sudden heats with-

out splitting or softening, and going out of shape. Saxony produced the first of superior quality: but it is now excelled by the porcelain of Seve in France. The manufacture is daily extending, by the discovery of more copious materials. But still, the Oriental is far cheaper than any European porcelain of equal goodness.

APPENDIX.

OBSERVATIONS BY DOLOMIEU ON QUARTZ AND PRECIOUS STONES.

(Observ. de Phys. May 1792.*)*

1. QUARTZ, or crystal, phosphoresces when heated or struck.

2. It also, when struck, emits a peculiar odour. These phenomena indicate inflammable matter.

3. It decrepitates when suddenly heated: and the more phosphorescent it is, the more it decrepitates.

4. It boils and bubbles very much when melted with the heat of vital air acting on charcoal; and is formed into globules, white or opaque, with air bubbles.

5. When melted with fixed alkalis, there is a great effervescence or boiling, although the alkali be caustic. (The author has also observed a flame come from this mixture: and so has also Mr. Pelletier.)

6. If there be enough of the fixed alkali, the compound dissolves in water, and forms the liquor silicum, which contains the siliceous earth, certainly different from what it was before. For, if we precipitate it with an acid, and instantly add superfluous acid, it is redissolved by that acid.

7. The author had long suspected that quartz contained some condensed gas, or elastic aëreal matter: and he at last made some experiments along with Mr. Pelletier. They put into an earthen retort of twelve cubic inches capacity, ten drachms of

levigated quartz, and two ounces of caustic potash, fresh made and quite dry: and set the retort in a reverberatory furnace, with a receiver and apparatus for elastic fluids, which were confined in this process by water. 1*st*, There came some air, which he expected to be atmospherical air, from the cavity of the retort: but after two or three cubical inches were come, all the rest extinguished flame, and appeared to be azote, to the quantity of 22 cubic inches. 2*d*, A little cessation happened in the emission of elastic matter: and a tendency appeared to the absorption or intropulsion of the water. The fire was therefore increased; and soon after, that is, when the bottom of the retort began to be red, an elastic fluid was again emitted, along with a good quantity of white watery vapours, and a white smoke, which, while it rose in bubbles through the water, was not totally dissolved or combined with it. This white smoke disappears after it has risen out of the water into the bell. During this second production of elastic matter, 12 cubic inches of it are obtained: and there is a limit here too, marked by a cessation, attended with still greater danger of intropulsion of the water than in the first instance. It must be avoided, either by letting in some air, or by increasing the intensity of the fire with bellows. The nature of this second product is different from that of the former. It is all inflammable air, which explodes with atmospherical air, excepting a small portion of it, which is mixed with air and gas azote. 3*d*, The third product, which requires a very strong heat to make it come, amounts to 20 or 22 cubic inches. About 16 of these are fixed air, which is gradually absorbed by the water,—the remaining five or six are a mixture of inflammable and azotic gas, in which the last prevails. After this, whatever heat be applied, no more elastic matter can be obtained. (The author observed signs as if some of this matter were attracted and absorbed by the water.) They repeated this experiment with levigated crystal of Madagascar, and caustic fixed alkali, which was prepared by Mr. Pelletier, with all precautions to have it pure and untainted with inflammable matter. And the process was twice performed with this crystal. The first time, the heat was not raised so high as to bring over the third product of gases. But the second was completed. The residuum in the retorts,

after the first and last experiment, was a white, vitrified, opaque, blown-up matter. That of the second experiment was perfectly vitrified, and proved a greenish glass. But all these three were very dissolvable, and even deliquescent; and were dissolved by water into a liquor silicum, which by rest deposited a fuliginous-like matter.

8. The author is of opinion that the inflammable and azotic gas come from the quartz, for these reasons; 1*st*, The alkali is not decompounded or destroyed; but can be separated again entire from the silica by acids. But the quartz is certainly very much changed, for it is become soluble in all the acids, even the acetous, provided these are added in a sufficient quantity, as soon as it is precipitated from the liquor silicum. The sulphuric acid sometimes redissolves it so quickly that the precipitation or separation of it from the alkali is not perceptible; and the same thing happens with any other acid, if the solution of the liquor silicum be largely diluted. That there is a real solution here by the acid, becomes evident when we add enough of alkali to saturate the acid; for then the siliceous earth is precipitated again, especially when the alkali we use is a mild alkali, and most certainly if the volatile alkali. For if we use a caustic alkali, it is necessary to take care that no more be added than just enough. A little superfluity of it redissolves the silica very quickly again: and thus it can be redissolved by acid or alkali as often as we please.

The author believes that the inflammable and phlogisticated airs come from the quartz; and that the boiling and blowing of it up into a spongy glass, when it is melted by the heat of vital air, is occasioned by the extrication of those airs from it; that the fire or light, and the smell of burnt air, produced by striking pieces of quartz against one another, are to be imputed to the bases of those airs in its composition; and that the difference between quartz in its natural state, and quartz fresh precipitated from liquor silicum, is somewhat analogous to that of quicklime and calcareous earth; the fresh precipitated silica, in consequence of its purity and simplicity, having an attraction for acids, which quartz has not. And as the quicklime recovers

its fixed air, if left exposed, the author is of opinion, that the precipitated silica can recover from water the principles which it lost when it was melted with the alkali; for the precipitated silica continues soluble in acids for a very short time only after it is precipitated. If we observe it while we are precipitating it, we can see intermixed with it, and forming around the particles of it, numerous little bubbles of aëreal matter, which rise afterwards to the top of the water. And heat promotes and increases this appearance, which is soon over: and then the silica is insoluble in acids, as much as quartz in its natural state. And if we now wash and dry it, and melt it again with an alkali, it gives the same effervescence that it gave at the first. It must be acknowledged that inflammable air is not absorbed by newly precipitated silica: but the author supposes that it is only the basis of it which is present in quartz; and that basis, when once combined with caloric, is not very easily separated from it.

If these airs are supposed to come from the alkali, how can we account for the effervescence or intumescence of pure quartz and crystal when melted with the heat of vital air; or for the light and the smell of burnt matter, which are produced by striking pieces of quartz against one another? The Chevalier de Lemanon, performing this experiment over white paper, and examining afterwards with a microscope the minute dust or particles which had been rubbed off from the quartz, found among them, particles which had been scorified, and which when rubbed or bruised on the paper, marked it like charcoal. (*Journ. de Phys.* July 1785.)

The matter we find thus combined with the silica in quartz is probably the matter, which, when combined with water at a great depth below the surface of the earth, enables it to dissolve quartz, and to transport it and to crystallize it, which matter cannot probably remain combined with water when it comes to the surface and is exposed to light. Bergmann was deceived when he imagined fixed air combined with water to be a solvent of quartz. The experiments of other chemists have not supported this opinion. I have not been able to make it dissolve

silica, even when fresh precipitated from liquor silicum. Siliceous crystals are often formed in nature on the surface of calcareous ones, without the smallest appearance of dissolution or corrosion in these last, which would certainly happen, were the solvent of the siliceous matter *carbonic acid water*. Mr. Morveau also mistakes this water. (*Encyclopedie Methodique*). For, in an experiment in which siliceous crystals were formed by shutting up in a vessel aërated water and siliceous earth, there was iron also, which became corroded and rusted: and the crystals were found among the rust of the iron. He had four glasses, containing aërated water and silex. Into one was put silex; into another limestone; into a third, argilla; and into the fourth, iron. After nine months, no change appeared, except in the last, in which both the pieces of quartz and the iron were evidently corroded, and small crystals found among the rust of the iron. Dolomieu therefore concludes that the hydrogen, separated by the action of the dissolving iron on a small part of the water, produced, in conjunction with the rest of the water, a solvent which acted on the quartz. He learned, however, by experiments, that iron has no effect on the liquor silicum, or the liquor on the iron. A bit of polished iron preserves its brightness unimpaired in this fluid. That the solvent of silica in nature is an inflammable substance, is also rendered probable by the dusky colour of some crystals and of flint, which dark or dusky appearance is dissipated by fire. He adds one more argument to support his opinion of the compounded nature of quartz and crystal. This is drawn from its inactivity, or want of attraction for most other substances.

He then enters on the consideration of the gems, which have still more inactivity, and are insoluble even by alkali, though they are penetrable by it to a certain degree. He appears inclined to suppose that these are still more completely saturated than quartz, with the matter which he has discovered in its composition. And some of the properties of the diamond may give room for supposing that it is the most completely saturated of them all, and therefore the most difficultly penetrable and dissolvable by the most active solvents.

He considers the argil, which is the most abundant ingredient in many of the gems, as dissolvable by the same solvent which is necessary to quartz. The argillaceous earth shews, by its odour when moistened, and by many other particulars, that it has a disposition to unite with inflammable matter.

He afterwards considers the different gems, as differing not only by the number and proportion of earths they contain, but also by the close coalition of those earths, which has been produced by the action of their common solvent; and supposes that the hardest and brightest of them retain a larger proportion of the remainder of this common solvent, or are more completely saturated with it, than the rest are.

But I refer you to the conclusion of his paper, which, I confess, is not so clear and distinct as the preceding parts.

CLASS III.

INFLAMMABLE SUBSTANCES.

THE third class of the objects of chemistry, in the plan which I have adopted, is that of the INFLAMMABLE or COMBUSTIBLE SUBSTANCES.

By the *inflammation* of a body, is meant a rapid destruction and change, which it suffers when exposed to the action of heat and air at the same time; which change is attended with the emission of a great quantity of heat and light, and ends in a total loss or privation of the quality of inflammability.

When the general effects of heat were formerly explained to you, some notice was taken of the phenomena of inflammation, and of the general nature of this class of bodies. And the opinions which formerly prevailed, as well as those which now prevail concerning the nature of it, were briefly stated, and have since been more fully explained to you occasionally.

The opinion that is now the most generally approved, had its rise from the numerous investigations and experiments that have been made during the last twenty or thirty years, on the nature and properties of the different elastic fluids which are found in nature, or may be produced by art.

After I had discovered the particular nature of the carbonic acid, and had shewn that some of it is produced by the action of air and burning fuel on one another, and also by the breathing

of animals, I supposed that it was formed by the union of common air, with a quantity of the phlogiston of the chemists, the existence of which was not doubted at that time. And I supposed, that atmospherical air had a strong tendency to unite with this principle, and to separate it on many occasions from other bodies.

This opinion, of a tendency in the atmospherical air to unite itself with the supposed phlogiston, was afterwards adopted by Dr. Priestley and others. But the Doctor did not admit the carbonic acid or fixed air to be produced in the manner I had supposed. He examined with more care than I had done the change which the air undergoes in contributing to the inflammation of burning bodies and the breathing of animals; and thus discovered the distinction between carbonic acid gas and azotic gas. This distinction had been in fact clearly pointed out before, by my colleague Dr. Rutherford, in his inaugural dissertation, printed in June 1772.

When atmospheric air is completely vitiated by the breathing of animals, or the burning of fuel, we find in such vitiated air a much greater quantity of the azotic gas than of the carbonic. Dr. Priestley was of opinion that the azotic gas was formed by the combination of the atmospherical air with the phlogiston. He therefore named the azotic gas *phlogisticated* air. The carbonic acid gas, he supposed, had existed before, but was concealed in the atmospherical air, or was intimately combined with it until phlogiston was added, which, uniting with the air, made it separate from the carbonic acid gas. Or, as he expressed it, the carbonic gas, or fixed air, was precipitated, or extricated, in consequence of the phlogistication of the atmospherical air.

So far had Dr. Priestley proceeded, when the late Dr. Crawford of London employed his attention upon this subject. By availing himself of the discoveries of others, and making use too of experiments made by himself, he formed a new theory of inflammation, which he published in his work on Animal Heat.

He made a number of experiments to learn what capacity for heat different substances have when compared with one another. These experiments were made in the manner which I pointed

out, by applying different bodies one to another, unequally heated. A part of the heat of one is communicated to the other, until they come to an equilibrium or equal temperature of heat. While this happens, the alteration of temperature in the one body is very different from that of the other, although the heat which the one receives be precisely the same quantity which the other loses.

This shews, therefore, that different kinds of matter have different capacities for heat; that some are more heated by the same quantity of heat than others; or that a smaller quantity of the matter of heat is sufficient for raising their temperature or thermometrical heat by the same number of degrees, (for this is the mark and the only measure of capacity).

Dr. Crawford, making a great number of experiments in this way, with different materials, thought that he discovered that those which he supposed to contain the phlogiston in their composition, had less capacity for heat than others, or required less of the matter of heat to raise their temperature; and that in proportion as they contained the more of the imaginary phlogiston, they had the less capacity for heat.

He therefore began to think that atmospherical air, while it received this phlogiston from burning fuel, must have its capacity for heat diminished, and must throw some of its heat into the contiguous bodies; and that the increase of heat which appears during inflammation, might be this very heat extricated and expelled from the air, and not from the burning body.

This led him to examine, by actual experiments, the capacity for heat of the air in its different states. And he thought that he discovered such a very great difference between the capacity of atmospherical or respirable air, and that of the azotic and carbonic gases, that he was able to shew by calculations, that this is sufficient to account for all the heat that appears during the inflammation of fuel.

These are the general outlines of his theory of inflammation, which he has applied also to explain the heat maintained in the bodies of animals. For particulars I must refer you to the first and second editions of his treatise on this subject, which

contains experiments made with amazing labour and much ingenuity.

While Dr. Crawford was thus employed, another person in a distant part of the world, had already formed for himself a very different theory of inflammation. This person was the late Dr. Scheele of Sweden, whom I have had frequent occasion to mention already in this course, as an eminent chemist and philosopher.

He engaged himself in an inquiry which had for its object the nature of inflammation, and how heat and light are produced by it. And he thought that he had discovered how they are produced. He thought he had reason to conclude that heat and light are compounded substances; that he could actually produce them, by combining together their constituent ingredients; and that he could decompound them, by separating these ingredients from one another.

Assiduously occupied in this research, he was one of the first discoverers of vital air, or oxygen gas. Dr. Priestley also discovered it about the same time, having obtained it from nitric acid, and from other things, in some of his numerous experiments. Mr. Lavoisier also discovered it soon after, while he was employed in investigating the action of air on the metals.

But Scheele was the first person, who, from a number of ingeniously contrived experiments, concluded by very fair reasoning, that atmospherical air is a mixed fluid, composed of about two parts of azotic gas, and one part of vital air or oxygen gas, along with a very small admixture of carbonic acid. The greater part of the carbonic acid gas, found in the air which has contributed to the burning of fuel, he supposed to be extricated from the fuel, most kinds of which he supposed contained this acid, or the basis of it. But he observed that there are some inflammable substances, which do not contain any of this basis, and therefore do not communicate carbonic acid to the air which contributes to their inflammation. Such are sulphur, phosphorus, and some of the metallic substances.

Scheele, after making many experiments with atmospherical

air, repeated them also with the oxygen gas, by burning some of the most inflammable substances in limited quantities of it, which he had confined in close vessels. And he found that in some of these experiments the *whole* of it was expended, or disappeared during the bright and violent inflammation which it occasioned. This he learned by opening the phials under water, after the experiment. The water was pushed in by the pressure of the atmosphere, and filled them quite full. He therefore concluded that the oxygen gas had penetrated through the glass of the phial, and had escaped in the forms of heat and light, into which forms it had been changed by uniting with the phlogiston of the inflammable matter. The heat, he supposed, was produced by a lesser, and the light by a greater proportion of the phlogiston combined with it.

We must not form a light opinion of Scheele's acuteness and judgment from the extravagance, and I may almost call it absurdity, of such a theory, as it appears to us at present. Scheele was one of the most judicious, as well as ingenious chemists that ever lived. But in the active time of his life, the existence of phlogiston was universally believed. It was so firmly established in the imagination of every chemist, that it presented itself to their minds on every occasion. It must be confessed, however, that he may be blamed for a gross oversight or neglect, in omitting to weigh the phial and its contents before and after the inflammation. Had he weighed it accurately, he would have learned that the oxygen gas had not flown away through the sides of the phial, but was still there, having only lost its elastic aëreal form. Had he examined the weight of the acid into which the inflammable body was changed, he would have found that this acid matter contained the oxygen in a condensed state; the weight of it being equal to that of the inflammable body and of the oxygen gas taken together.

When he performed the same experiment with atmospherical air, no more than one-third or one-fourth of it was expended, or had disappeared. The remainder was become totally unfit to contribute to the inflammation of burning bodies, or to sup-

port the life of animals by respiration. And when he examined it further, he found it to be either pure mephitic gas, in some cases, or a mixture of this gas with carbonic acid gas in others. He then, by the use of lime and water, separated the carbonic acid gas when it was present: and he added to the mephitic gas as much pure oxgyen as made up the whole to the original quantity of the atmospherical air with which he had begun the experiment. He found this mixture to be exactly similar, in its powers and properties, to good atmospherical air. He exhausted it of its oxygen, by burning bodies in the same manner as before. And he again renewed its powers in the same way several times over: and, as the quantity of the azotic gas always continued the same, he concluded that atmospherical air is effectual in promoting inflammation and supporting the life of animals, only in consequence of its containing near a third part of its bulk of oxygen gas in its composition; and that it is only this part of the atmospherical air that is capable of uniting with the phlogiston, and of being converted along with it into heat and light.

The most surprising and ingenious part of his treatise was the apparent facility with which he thought he could explain the various processes by which oxygen gas could be obtained in its separate state. They are all processes in which substances, which were supposed by the chemists to have a strong attraction for the phlogiston, were exposed to the action of heat. And he supposed that they decompounded the heat applied to them; that they attracted the phlogiston, and disengaged the oxygen from it. And no person discovered so many ways to obtain the oxygen gas in a separate state, or to extract it from so many different substances, as Scheele did.

You must perceive that all the attempts to explain combustion that have been mentioned, agree in supposing or assuming the existence of a common or general principle of inflammability contained in all inflammable substances. It is further supposed, that this is a most subtile kind of matter; and that it separated from such bodies with great rapidity during their i

flammation, appearing then in its separated state, according to the first opinion of the chemists, in the form of heat and light; or, according to the opinion which I had formed, and to that of Priestley, Cavendish, Crawford, Kirwan, and others, uniting, at least in part, with common air, and forming carbonic acid and azotic gas; or, thirdly, according to Scheele, uniting itself with the vital air of the atmosphere, and forming with it the heat and the light.

I must now make you acquainted with some other opinions which have been more lately imagined, and which are of a quite opposite and contrary nature to all those I have yet explained. The principal author of the first of these new opinions is Mr. Lavoisier, whom I have frequently had occasion to name as the author of many excellent experiments upon elastic fluids, as the subjects of chemical investigation.

Mr. Lavoisier was induced to form this opinion chiefly by a number of facts observed in the inflammation of bodies. Some of these have been already touched on occasionally, but must now be more particularly insisted on.

You will find the detail of these facts in a series of dissertations, published in the *Memoirs of the Academy of Sciences*, particularly in the volumes 1781, 1782, 1785;—in his *Opuscles Chymiques*, published in 1777; and in his *Elements of Chemistry*.

He remarks, that although it has been hitherto supposed by the chemists that a subtile kind of matter flies off from bodies, or is separated from them, during their inflammation, no person has been able, either to exhibit this common substance by itself, or to shew that the body, which was supposed to sustain this loss of matter, suffered any diminution of its weight. Just the reverse appears, in the greatest number of experiments, when the inflammable body is of such a nature, that we can collect accurately together all the inflammable matter that is left after the inflammation is over. In such cases, we always find that this matter exceeds in weight the inflammable body from which it was produced. This fact alone had long occasioned many to doubt of the existence of a principle of inflammability.

But further, among the numerous experiments which have been made of late upon different kinds of aëreal fluids, several

have been made by Mr. Lavoisier, in which the inflammable bodies were exposed to the action of *measured quantities* of air, in close vessels. They were burnt, in part: and nothing was lost or gained by the whole apparatus. This was weighed with most scrupulous accuracy before and after the inflammation. But the inflammable body was found to have gained a quantity of weight proportioned to the quantity that had been burnt. Moreover, the air was found to be diminished both in bulk and in weight. That a quantity had been absorbed by the burning body, or had somehow disappeared, was evinced by opening the vessels under water. The water rushed in, and occupied the room of the absorbed air. The specific gravity of the remainder being examined, and compared with the diminution of room, it appeared that the air remaining also weighed less than the air before the inflammation; and, lastly, it was found that the loss of weight in the air was exactly equal to the augmentation of weight in the remains of the inflammable body.

The most simple, elegant, and unexceptionable experiment to this purpose, is that of F. Beccaria, of Turin. Two small glass matrasses were joined hermetically by the necks. One of them contained a small quantity of an inflammable body which emitted no vapour in burning. The rest of the space in both vessels was filled with vital air: and the vessels were then sealed up and carefully weighed. This apparatus was accurately poised on an axis, so as to vibrate like a common balance which is in equilibrio. A burning-glass was now employed to kindle the body, and to keep up the combustion as long as possible. It was observed, that as soon as the combustion had proceeded a very little way, that end of the balance which contained the burning body, began to preponderate. When the burning could be maintained no longer by the action of the burning-glass, the balance remained in a very oblique position, shewing a great addition of weight on the side of the burning body. But, as the heat may be supposed to have expanded that arm of the balance, the whole was allowed to grow as cold as at the first. It required about 13 grains to be laid on the other end to restore the equilibrium.

Here, therefore, is an evident transference of matter from one

end of the apparatus to the other. For, when the apparatus was again weighed, it was found of the same weight as at first. The vessels were now opened, and air rushed in. It was again weighed, and had gained five grains. The ashes or remains of the body were now carefully collected and weighed. They were found seven grains heavier than before.

Nothing can be conceived more convincing and unexceptionable than this experiment, as a proof, that, in the inflammation of this body, it had united to itself part of the air contained in the two vessels. In other experiments made by Mr. Lavoisier and his copartners, contrived for ascertaining the precise quantities of air consumed or combined, and the weight gained, it was found that the one was precisely equal to the other.

It was chiefly on these facts that Mr. Lavoisier founded his new theory of inflammation and combustion. He was of opinion that there was no such thing as a principle of inflammability, the phlogiston, assumed by the chemists, nor any separation of a subtile principle from bodies, in the act of their inflammation. The very reverse of this happens, says he. The inflammable body sustains no loss, but receives a considerable addition of matter, which is now strongly combined with it; and, during its combination, produces a total change in its nature and qualities, making it appear a substance of a quite different kind from what it was before.

The matter thus combined with the inflammable body is supposed by Mr. Lavoisier to be the basis, or ponderable part of vital air. He considers this air as a compound of this matter, and of the matter of heat, or *calorique*, which calorique is so combined with the other matter as to give it the form of an elastic fluid, not condensable by cold, like the vapour of water, but requiring the application of some *proper* substance, for which it has a stronger attraction than for calorique. An inflammable body is a proper substance. But a certain high temperature is necessary for enabling them to act on each other. The basis of vital air then combines with the inflammable body; and the calorique is allowed to escape, in the same manner that fixed air is allowed to escape, when a mild alkali combines with an acid. The heat thus let go is sufficient to enable the adjoining parti-

cles of the inflammable body to act upon, and decompose more vital air, and besides, to heat all surrounding bodies.

This opinion of inflammation, and of the change which inflammable bodies undergo, was held by Mr. Lavoisier as proved by the most convincing experiments. For 1*st*, It is proved that vital air is absorbed during its action on inflammable substances; 2*dly*, Many of those substances which have been burnt, or have been exposed to the action of air and heat, so as to suffer a change similar to inflammation, can afterwards be made to afford, by means of heat, very considerable quantities of vital air. For the proof of this, Mr. Lavoisier refers to those very experiments in which Dr. Scheele supposed that such bodies decomposed the heat applied to them. Lavoisier could not conceive that heat could be decomposed in any of our experiments; and maintains that it acts simply by expelling the vital air from such bodies in which it is contained, by furnishing what is to be its latent heat when it is in its elastic gaseous form.

Mr. Lavoisier further says, that it has long been remarked, with respect to inflammable substances, that the incombustible matter into which they are changed during inflammation, is, in the greatest number of cases, either an evident acid, or has the qualities and appearances of a matter which contains a quantity of acid combined with it, and which it had an opportunity of getting during the combustion. This is eminently the case in the combustion of sulphur, of phosphorus, of charcoal,—from which we obtain the sulphuric, the phosphoric, and the carbonic acids. An acid is obtainable from the ashes or calxes of some metals destroyed by fire and air; and all these calxes are similar to what the metals are changed into by actually combining them with a due portion of acknowledged acids.

Mr. Lavoisier, therefore, induced by these general facts, supposed that vital air is the general principle of acidity. Although it has not the properties of an acid itself, it forms acids of different kinds, by combination with inflammable bodies. Combined with sulphur, it forms the vitriolic acid,—with charcoal it forms the carbonic acid, &c. &c. He therefore gave it the name of the oxygenous or acidifying principle. *(See Note 4 at the end of the Volume.)*

As to the heat and light which are emitted from these bodies in such quantity during their inflammation, or as Mr. Lavoisier views it, during their combination with the basis of vital air, he supposes that it is extricated chiefly, or rather solely, I think, from this air; which in its aëreal state, contains it in great quantity, in consequence both of what is necessary, as latent heat, for its aëreal form, and also because in that form it has a very great capacity for heat, requiring much of it to elevate its temperature any number of degrees.

This theory of Lavoisier is bold and ingenious. And, assuredly, it applies with great facility to explain very many of the facts which belong to this subject. We must certainly admit, as a thing proved by his experiments, that when bodies are inflamed, a great quantity of vital air is combined with them, and increases their weight. But there are many chemists, and chemical philosophers, who, although they admit this as a fact sufficiently proved, are not yet satisfied that nothing else happens in inflammation. They still suspect, or suppose, that the burning body sustains the loss of some subtile and active principle, (suppose it heat and light); and that it is the loss of this principle which disposes them to attract the air, and unite with it so strongly as they are known to do. For my own part, I was much disposed to this opinion, on the general tenor of chemical combinations. The uninflammable matter produced by combustion is generally a much more active substance, or has an attraction for a greater number of bodies, than the inflammable substance had, from which it came. This is manifest in sulphur and sulphuric acid, and many other instances. This disposed me to consider these substances as in a state of greater simplicity, when they were so much more active on other substances. But, when I considered that inflammation cannot now be viewed as a decomposition alone, it being now proved that the inflammable body is, in fact, combined with a great quantity of vital air, we cannot say that it is reduced to a state of greater simplicity than before inflammation: For, admit that t has lost one principle, it must be acknowledged that it has ained another, and therefore the observed increase of activity

does not entitle us to say that it is rendered more simple. It is a new subject, and has new relations: and we really do not know whether these are or are not more numerous and close than before*.

The difficulties, therefore, and objections against this theory, are now become so few and of so little weight, and the experiments which support it are so numerous, direct, and conclusive, that it is gaining the ascendency over all the others, and becoming the most general opinion among the chemists.

OBSERVATIONS BY THE EDITOR.

There were, however, some points that presented great difficulties, and almost put a bar in the way to the confident adoption of the theory, in the extent in which it was proposed. For it must be remarked, that Mr. Lavoisier's theory goes much farther than the mere explanation of the phenomenon of combustion. He states the basis of vital air as the principle of acidity: therefore the combination of this principle with an inflammable body is equivalent, chemically speaking, with the burning of that body. The theory, therefore, embraces almost the whole of chemistry. And combustion, the most remarkable phenomenon of material nature, and almost characteristic of chemistry, is now but a subordinate fact,—a particular mode of oxydation. But there were several effects of the vitriolic and muriatic acids which could not be explained by the theory in this its simple form. Most fortunately, some experiments were made by Mr. Cavendish at the very time while this theory was

* Dr. Black used to remark in some of his courses, that Mr. Lavoisier's system did not explain the remarkable effect of light on bodies; and that Dr. Lubbock had given some useful hints on this subject, in his dissertation *de principio sorbili*, which also professes to be a theory of combustion and acidification. But I do not see that Lavoisier is any how bound to explain this phenomenon. Berthollet and others affect to assign its mode of action, which is always accompanied with separation of oxygen. And they very frequently explain phenomena by shewing that they are really instances of this expulsion by means of light.—EDITOR.

in its cradle, which opened a way out of all the difficulties that then embarrassed it. The discovery of the composition of water by Mr. Cavendish in 1781, and fully demonstrated by him in June 1783, was carried to Paris by Mr. Blagden, secretary of the Royal Society; and by him communicated to Mr. Lavoisier, who immediately repeated the experiments, and with great address and ingenuity, applied the discovery to his theory; and not only surmounted the difficulties now mentioned, but by inverting the experiment, and resolving the water into its constituent parts, he gave his principles an influence almost unbounded, explaining almost all the phenomena of active nature. It is here, much more than in the first conception of the theory of combustion, that the penetration, the inventive genius, and the sound judgment of Mr. Lavoisier are most conspicuous. The precise logic, to which he endeavoured always to adhere, would have preserved Lavoisier from many errors, into which *his followers*, in all parts of Europe, have frequently fallen,—misled by precipitant and overweening notions of their own knowledge. The composition and decomposition of water affords a mode of explanation susceptible of so many forms, according to the fancy and *the wishes* of the employer, that there is scarcely a phenomenon of which a specious explanation may not be given in more ways than one.

Dr. Black says most justly, therefore, that science has cause greatly to deplore the death of that eminent philosopher. He always expressed a high opinion of Mr. Lavoisier's genius and sound sense; but was much displeased with the authoritative manner in which the junto of chemists at Paris announced every thing, treating all doubt or hesitation about the justness of their opinions, as marks of the want of common sense.

But, perhaps, Dr. Black was not a competent judge of the matter. In the course of his own discoveries, he was satisfied with the justness of his view of the subject. And he found himself able to communicate his knowledge to his students by means of very plain arguments, and the most familiar and simple experiments. He despised the parade of multiplying expements and argument. But he employed, with becoming acknowledgment of his obligation, the experiments furnished him

by Mr. Watt and other friends, in further confirmation of his doctrines. Having sufficiently instructed his students, he had no farther care; and was contented with that reputation which he enjoyed without struggle, and which he was conscious of deserving.

But Mr. Lavoisier was in a very different situation. He saw that he was about to operate a complete revolution through the whole extent of chemical science. He could not but foresee doubt and opposition on all hands. Confident of victory (after his happy employment of Mr. Cavendish's discoveries), the prospect was very flattering. I may perhaps add to this the genius and character of his nation. This is scarcely left in my choice,—for, almost at the first, the doctrines of Lavoisier were preached by the associated chemists as the system of *French chemistry*. Mr. Fourcroy, Monge, De Morveau, and others, repeatedly give it this name, with some exultation. It was propagated as a public concern; and even propagated in the way in which that nation always chooses to act,—by address, and with authority. Every thing pertaining to the system was treated in council, and all the leading experiments were documented by committees of the academy of sciences. To accomplish this purpose more effectually, they published the *Annales de Chymie* in concert: and they formed a new language, with the pretext indeed of improving science, but, in reality, that every thing might be forgotten which did not originate in France. A Swiss gentleman, affectionately attached to Dr. Black, was in Paris at the time, viz. 1787, and wrote to him in these words: "*L'objet qui occupe les chymistes surtout à present, c'est la nouvelle Nomenclature. Il paroit qu'on veut par lá donner le coup de grace au pauvre phlogistique; quant a l'air fixe, il faut qu'elle devienne l'acide carbonique*," &c. The writer had surely caught the patriotic flame; otherwise he would have recollected that it could not amuse his friend to learn that his discovery, which had led the way, must vanish with the rest. The plan was the same with that of Fabre d'Eglantine with his new calendar; and the

principle was that of Rabaud,—" *il faut tout detruire,—oui,—tout detruire,—parce qu'il faut tout recréer**."

Dr. Black disliked this way of proceeding, so unlike science and philosophy. He disliked the avowed principle of the nomenclature, thinking it more likely to corrupt science than to promote it: and he began to write some observations on it, but he soon desisted.

Some time after this, he had more reason to be displeased, and even to be offended. Mr. Lavoisier saw that his theory of combustion depended on the doctrine of latent heat; and was extremely anxious to obtain Dr. Black's acquiescence. In the course of 1789, Dr. Black received two letters from the Marquis de Condorcet, full of respect for his " *illustre confrére*," (Dr. Black having not long before been elected associé etranger de l'Academie des Sciences). In October 1789, Mr. Lavoisier wrote to him in these words: " C'est un des plus zélés admirateurs de la profondeur de votre genie, et des importantes revolutions que vos decouvertes ont occasionné dans la chymie, qui profite de l'occasion du voyage de Mr. B. à Edinbourg," &c.

Learning, by the return of this gentleman, that Dr. Black thought well of his theory, and had introduced it into his lectures, he wrote to him again in July 14th, 1790, as follows:

" J' apprends avec une joie inexprimable, que vous voulez bien attacher quelque merite aux idées que j'ai professé le premier contre la doctrine do phlogistique. Plus confiant dans vos idées que dans les miennes propres, accoutumé a vous regarder comme mon maitre, j'etois en defiance contre moi même (*credat Judæus Apella*) tant que je me suis ecarté, sans votre aveu,

* It is not undeserving of remark, that not only does this principle or aim of the new nomenclature greatly resemble that of the new calendar, and the new measures of France, but that also several of this chemical convention were also assistants, officially, to Fabre d'Eglantine in his project. La Place was in a high department of public business. Monge was a minister of state, and ere this, had signed the death-warrant of his sovereign. Meunier was a general officer. Morveau was a commissary of the convention; and persecuted with the most cruel virulence the noblesse of his province, who had twice paid his debts, and given him 24,000 livres to enable him to prosecute his chemical inquiries. He was the chief agent in framing the nomenclature. Hassenfratz, the publisher of the nomenclature, and of the symbols which he had contrived, was also high in office, and most active in all the projects of Robespierre. It is not, therefore, on light grounds that I have assigned the same motive to the nomenclature and to the calendar.—EDITOR.

de la route que vous avez si glorieusement suivie. Votre approbation, Monsieur, dissipe mes inquietudes, et me donne un nouveau courage. Je ne serai content jusqù a ce que les circonstances me permettent de vous aller porter moi même le temoignage de mon admiration, et de me ranger au nombre des vos disciples. La revolution qui s'opere en France devant naturellement rendre inutile une partie de ceux attachés à l'ancien administration, il est possible que je jouisse du plaisir de la liberté: et le premier usage que j'en ferai, sera de voyager, et surtout en Angleterre, et à Edinbourg, pour vous y voir; pour vous entendre, et profiter de vos leçons, et de vos conseils."

Dr. Black wrote him a very plain, candid, and unadorned letter in answer, expressing his acquiescence in his system. Mr. Lavoisier answers this by praising, in the highest terms, the elegance of the style, the profoundness of the philosophy, &c. &c. and begs leave to insert the letter in the *Annales de Chymie*. Dr. Black, who had been in very low spirits when he wrote that letter, and was much dissatisfied with its feebleness, was disgusted with what he now conceived to be artful flattery; and refused to grant the request. Yet his letter appeared in that work before his refusal could reach Paris.

This wheedling, in order to extort from Dr. Black an acquiescence, on which he put a high value, for the influence which it would have on the minds of others, was surely unworthy of Lavoisier. Dr. Black was not only disgusted with the flattery, but seriously offended with its insincerity; and with a sort of insult on his common sense, by the supposition that he could be so wheedled, by a man whose publications never expressed the smallest deference for his opinions. For, by this time, Dr. Black had read Mr. Lavoisier's *Elements of Chemistry*, and the various dissertations by him and Mr. De la Place, published in the *Memoirs of the Academy*. His name is not once mentioned, even in the dissertations on the measures of heat, where his doctrine of latent heat is delivered and employed as the result of Mr. Lavoisier's own meditations. Nor is he named in those passages of the earlier dissertations, where the characters and properties of fixed air, and of the mild and caustic alkalis, are treated of. All appears to be the train of Mr. Lavoisier's own thoughts, for which he was indebted to no man. Such incon-

sistency with the deference expressed in the above cited letters, provoked Dr. Black to such a degree, that he resumed his critique on the nomenclature, and began to express his dissatisfaction with some parts of the theory, and his utter disapprobation of the unscientific and bullying manner in which the French chemists were trying to force their system on the world. But, by this time, his health had become so delicate, that the least intensity of study not only fatigued him, but made him seriously ill, and forced him to give it up. I saw him but seldom at this time, being then in very bad health myself; but had this information from Dr. Hutton, who shared all his thoughts. It was at this time that he gave up his intention of making a considerable change in the arrangement of his lectures, and that he expressed himself, as I have related, at the end of the introduction to the particular doctrines of chemistry. But still, notwithstanding the contempt which he expressed for the folly of a man who had tried, by fulsome and insincere flattery, to obtain what he had given him unasked, by teaching all his doctrines, Dr. Black considered the death of Lavoisier as a great loss to the science*. He expected much from his penetration and sound sense: and he considered him as the only person who could keep his followers right, by checking their precipitant manner of proceeding.

Professor Lichtenberg, of Gottingen, a man of extensive and accurate knowledge in every department of natural science, gives an entertaining and instructive account of the introduction of these doctrines into Germany. It is to be found in his preface to the edition 1794, of *Erxleben's Introduction to Natural Philosophy;* as also in the *Literary Magazine* of Gotha. Great hesitation, doubt, and objections, were to be expected in Germany, the native soil of chemistry, and the resort of all who wished to perfect themselves in mineralogy. The new doctrines were even received with aversion and disgust. This, he says,

* This ornament of France fell a sacrifice to the ambition of the very men whom he had associated with him in his labours and honours. They were all persons in office, or national representatives, and, in that character, gave their consent (to say the least of it) to his sentence of death. But he was rich, and loyal,—they were——and——

was chiefly owing to the character of the nation from whence they came. The Germans, who had been accustomed to consider themselves as the chemical teachers of Europe, could not bear to hear the opinions of their master, Stahl, treated with contempt; to be told by Frenchmen, living among them for instruction, that the principles of Stahl were such as no man could embrace who had a spark of common sense; to be told, in letters from France, that the principle of Stahl was a *mera qualitas;* a *mera contemplatio*, a fancy of the brain, which disgraced any man who entertained it for a minute; and to have it added, with saucy politeness, *dulci requiescat in pace!* But what most provoked them, was the pitiful triumphs of victory in which the French chemists indulged themselves. He says, that when the association had finished their experiments on the composition and decomposition of water, which filled up all the gaps of the system, they had a solemn meeting in Paris, in which Madame Lavoisier, in the habit of a priestess, burned on an altar Stahl's *Chemiæ dogmaticæ et Experimentalis Fundamenta*, solemn music playing a *requiem*. And he remarks, that if Newton had been capable of such a childish triumph over the vortices of Des Cartes, he could never be supposed the man who wrote the *Principia*. I might add, that if Newton or Black had so exulted over Des Cartes and Meyer, their countrymen would have concluded that they were out of their senses. But at Paris every thing becomes a mode, and must be *fêté*. Dr. Black's nice sense of propriety made the intriguing conduct and arrogant assumption of all merit by the French chemists extremely offensive to him; and probably made him so minutely careful to place in full view all the labours and discoveries of the British and Swedish chemists, particularly those of Cavendish and Scheele, which supplied the great facts on which the ingenious doctrine of Lavoisier is established.—I flatter myself that this statement of facts, and these reflections, will not be thought improper or unimportant.

We shall now proceed to take a nearer view of the different kinds of the inflammable substances.

The most remarkable inflammable substances may be arranged under seven titles, which are these:

1. Inflammble air.
2. Phosphorus.
3. Sulphur.
4. Charcoal.
5. Spirit of wine.
6. Oils.
7. Bitumens.

Of these, the first four may be called SIMPLE INFLAMMABLES; because we have not been able to resolve them into substances more simple. Ardent spirits, oils, and bitumens, are very easily resolvable, and are vastly complex.

I.—INFLAMMABLE AIR.

THE first in this order, the *gas pingue* of Van Helmont, the substance which has been long known by the name of INFLAMMABLE AIR, is certainly the most subtile and most highly inflammable of all the bodies that belong to this class. The peculiar phenomena and consequences of its inflammation, as well as what was observed in combining it with other bodies, caused it to be considered by some authors, of the first rank among chemists, as the true phlogiston of the chemists, or as totally made up of their principle of inflammability. This opinion of it was formed by Mr. Cavendish, and by Mr. Kirwan, who published his thoughts on this subject in the Philosophical Transactions for the year 1782; and, after that time, in a separate volume. And Dr. Priestley had nearly the same opinion of it. But, since that time, Mr. Kirwan has abandon-

ed the supposition of a phlogiston in the inflammable substances.

This inflammable substance has been known a long time. Indeed, it must have been known as early as any considerable progress was made in the knowledge of nature and chemistry. Van Helmont calls it *gas pingue*. It is not always precisely the same. There are great varieties of it, occasioned by impurities or admixture: and some of these are found in almost all that is obtained already formed by nature. But it may be also produced, or extricated from different substances artificially, by a variety of chemical operations.

It is frequently met with in mines, especially in those of coal; and renders the working of them extremely dangerous. It is called by the miners the *fire-damp*, or *wild-fire*. It is also extricated or produced from animal and vegetable substances, when these are decompounded and destroyed by fire or putrefaction. And hence it is that there is a small quantity of it mixed with the black mud of putrid ditches and marshes in summer, which mud is composed of the putrid remains of vegetables and animals. If a stick be thrust down to the bottom of such ditches, and the mud be stirred, a number of air-bubbles rise to the surface of the water, and a candle being held near it at the same time, the air will take fire, and give a momentary flash. Or it may be collected in inverted glasses filled with the water, and may be afterwards fired. This was first discovered by the celebrated Dr. Franklin*. The knowledge of that kind of it which occurs in coal mines, must have been as early as the art of mining coal.

In those coal mines which are infested with it, it is observed to issue from crevices of the strata in the subterranean chambers of the mine, in form of a vapour or aëreal fluid, which, mixing with the air of the mine, is said to produce some de-

* Van Helmont mentions this, and adds, "Stercoraceus flatus, per flammam candelæ transmissus, transvolando accenditur; ac flammam diversicolorem, instar iridis exprimit." (*De Flatibus*, § 49.)

It is even produced by some living plants. The *Dictamnus Fraxnella* emits it from its flowers in such abundance in a calm evening, that it may be set on fire by a candle, nay, take fire of itself.

gree of misty appearance in it. And, when it is not very abundant, it does not communicate any unwholesome quality to that air.

The greatest danger attending it proceeds from its high degree of inflammability; the smallest flame, as that of a candle, being sufficient for firing the largest quantities of it, with a violent explosion. And, unfortunately, in those places, no work can be done without artificial light. In some mines they are obliged to work by the dull light produced by a piece of flint rubbing against the circumference of a steel wheel, which is jagged like a file. When it happens unfortunately that considerable quantities take fire, the inflammation of it is as rapid and violent as that of gunpowder. And it produces an explosion almost like thunder, and which is attended with most dreadful effects. In some cases, the whole works of the mine are demolished, and numbers of miners killed, and sometimes blown up, with heavy machinery, to a considerable height in the atmosphere. These shocking effects are produced by the great expansion which the flame occasions in the air and vapour that is mixed with it. The inflammable air itself does not expand in the act of inflammation, but, on the contrary, collapses into very small bulk. But it is then mixed with the vapour of water, and with azotic gas, both of which it expands, and forces them along the long and narrow chambers of the mine; and sweeps every thing along with it, just as the firing of gunpowder accelerates a bullet along the barrel of a musket.

In some mines, in which the sources of this vapour are but scanty, and in which it requires a long time before a considerable quantity is collected, they preserve themselves from danger by firing it frequently, and therefore, by small quantity at a time. They observe the places in which it collects, which are always over their heads, or in the hollows of the roof of their subterraneous workings, it being the rarest or lightest of all fluids that we know. When pure, it is but one-fifteenth of the weight of an equal bulk of common air. At stated times they set fire to it with a candle fastened to the end of a long stick, or tied to the middle of a long string, the two ends of which are held and drawn by two men at a distance from the spot.

But there are some coal mines in which the sources of it are too abundant to be easily managed in this manner. In these they have recourse to another method, by which it is constantly carried off and destroyed, namely, by having wooden trunks or pipes conducted along the roof of the workings, (so the chambers of a mine are named) with branches carefully leading to all the places where this air most copiously gathers. All these trunks meet at the bottom of a shaft; and from thence a great trunk is carried up, to the surface, in a corner of the shaft, where it enters into a small chamber having a tall chimney. A fire is kept in this chamber, and air is supplied to it only from this trunk. The warmth of the chamber and chimney produces a current: and thus the air is collected from all parts of the mine. When the inflammable air is very copious, it is said to burn at the top of the trunk, and produce heat enough, without any more fuel, for maintaining a continual flame and current.

There are several places on the Continent, particularly in Italy, where a vapour of this kind breaks out at the surface of the earth, and is liable to take fire, producing a lambent flame. In England there is an example or two, recorded in the Philosophical Transactions. In Persia, there is a small district, where the inhabitants collect it into one place by means of covered gutters, and there setting fire to it, use it for dressing their victuals, and even for lighting their huts. I doubt much that these are exaggerated accounts; for this extremely rare fluid gives so little heat, that its flame scarcely will scorch the hand; and the light is proportionably feeble. When it rises through the water of wells in bubbles, they burst at the surface: and when they are very copious, so that while one is burning another rises close by it, then a candle being applied, flame catches at the surface, and continues with a crackling noise. In the burning well at Chittagong, in India, it takes fire of itself after having been extinguished by dashing pailfuls of water in it.

Besides these examples, where it is formed by nature, I said that it is also very frequently produced from different substances artificially, by a variety of chemical operations.

The examples of this are too many to admit of my enume-

rating them all here*. I shall for the present mention only one simple process by which this gas is produced in a high degree of purity. We need only to mix some of the strong sulphuric acid with about eight times its weight of water, and throw into the mixture some very clean iron filings, equal in weight to half of the sulphuric acid. The iron is dissolved with ebullition and heat: and a great quantity of this aëreal inflammable substance arises from the solution, and may be collected in vessels filled with water, and inverted into a vessel of water.

This has been long known to the chemists: and it was usual with them, when they had occasion to dissolve iron in the sulphuric acid, to amuse themselves by firing this vapour, to make it give explosions, or burn in different ways.

But no other experiments were made to investigate its nature in other respects, until after I had made the experiments on quicklime, and on fixed air, which I have already described to you.

I had then the curiosity to try whether this gas was attracted by alkaline substances, in the same manner as fixed air is attracted by them; and I satisfied myself that it was not. I was also accustomed to exhibit to my pupils the different manner in which it burns when pure or when mixed with air. When it issues pure, in a continued stream, from a pipe, a candle applied to the jet will kindle it: and it will continue to burn quietly as fast as it issues;—but not till it is out of the pipe, because it burns only where it is in contact with vital air. But, if the vessel from which it issues contain vital or atmospheric air also, mixed all over with the inflammable air, then a candle

* We must, however, carefully distinguish the inflammable air of which Dr. Black is now speaking, from a vast multitude of inflammable vapours which nature and art produce. Oils, vinous spirits, and many other inflammable substances, can be changed into vapour by heat; and the vapours are inflammable, of course. But we are now speaking of a *peculiar substance*, which we have never been able to decompound, and therefore assume as a simple substance. This, when pure, is always the same, in whatever way we procure it. The other inflammable and incondensible airs are not simple, but yield, by burning, carbonic acid gas.—EDITOR.

applied to the mouth will fire the whole in an instant, with an explosion that will burst the vessel, if not very strong.

The Honourable Mr. Cavendish, some time after, (anno 1766) published in the Philosophical Transactions, experiments on this and other kinds of air; by some of which he ascertained, with great ingenuity and exactness, the density of different airs or gases, compared with that of common air. He found that the gas we are now speaking of, has a surprising degree of rarity. It weighs less than the one-tenth part of the weight of an equal bulk of common air. Therefore, if you would keep it in an open vessel for any immediate experiment, you must keep the mouth of the vessel down, and the bottom uppermost. If you fire it in this situation in a tall glass, and immediately turn it up, the inflammable air rises in a beautiful burning column.

As soon as this discovery of its great levity was published, it pointed out an obvious consequence, which immediately occurred to me,—that if a quantity of gas could be confined in a vessel, or other containing matter that was exceedingly thin and light, the gas and vessel together might form a mass lighter than an equal bulk of common air, and which would rise in the atmosphere, as cork does in water. I therefore thought of providing a vessel or envelope for this purpose; and that which first occurred to me was either the allantoïs or the amnion of a calf, which I procured. But not getting it ready soon enough to shew the experiment at the time I intended it, I did not exhibit it; but mentioned it in my lectures as a thing which might be found practicable, though I did not see that it could be applied to any use. I did not imagine that the same idea would have been improved to such a degree as it was afterwards in France. All the world has been amused with their air-balloons, which they soon made of such a monstrous size as to lift very heavy weights to a great height in the air*. Of these balloons two kinds have been made use of in their experiments.

* It is worthy of notice, that Dr. Mayhow, in his dissertation *de spiritu nitro-aëreo*, describes experiments which have certainly been made with oxygen gas. He also gives very plain hints of balloons filled with a substance much lighter than air, which he says was known to him.—Editor.

Mr. Mongolfier, a paper-maker at Lyons, first thought of making a balloon so light as to float in the air, merely by burning shreds of paper or straw under the mouth of a great globe of paper or thin linen. Having succeeded, he made another so large as even to carry up a considerable weight; and, in order to keep it afloat, he hung under it a choffer, in which the fuel was renewed by the persons who were carried up by it. He made others of 40 feet diameter, and 70 feet high, which carried six or seven persons.

When accounts of this contrivance reached Paris, the inhabitants of which are keen for amusement, Mr. Charles, an intelligent chemist, immediately recollected the immense superiority of inflammable gas for a project of this kind; and readily found men of fortune and pleasure to contribute to the great expense of such entertainment, which in several cases amounted to more than 500*l*. His balloons were made of a thin but strong silk, made air-tight by varnish: and they were filled with gas produced from iron dissolved in vitriolic acid,—but so far from pure, that it was not more than seven times lighter than common air. Indeed, this is as much as should be reckoned on; because the iron employed is generally rubbish, rusty, and even cast iron, which produce much fixed air. His balloons were much smaller than Mongolfier's, but rose to a very great height, sometimes almost three miles.

Since, in order merely to float, the weight of the balloon and air must not exceed that of common air, there is a minimum of size, depending on the weight of a square foot of the covering. The smallest balloon of thin post paper, that will merely float, is seven inches in diameter. Strong post paper must not be less than thirteen inches. Oiled silk will float, if two feet ten inches,—and oiled linen, if four feet six inches. An oiled linen balloon, of nineteen feet diameter, will lift a weight of 250 pounds a mile high. And other sizes will lift nearly in the proportion of the cubes of the diameters, when they are large.

These experiments gave rise to a number of projects for performing voyages with such machines; though it must have appeared evident to any person who understood their nature, and

considered it well, that they were totally unfit to be applied to any such purpose.

That air balloons cannot be applicable to the purpose of making voyages, or of traversing the air in any direction that we please, is evident, by these reasons:

1*st*, We cannot find a power that will be sufficient for moving such bulky masses through the air, and that can be lifted up by them. The force of one man, or of any number of men which the balloon can lift, is very far from sufficient for moving it with the requisite velocity for performing voyages, even in a perfectly calm air. And if there be the least of a contrary wind, they could not move it an inch in the proposed direction. All this is true, even supposing that the whole force of those men could be employed or exerted in order to move it. But how are we to employ or exert this whole force, when the balloon is suspended in mid air? Had the men some fixed immoveable body, towards which they could draw the balloon with ropes, or from which they could push it with poles, their whole force might be exerted. But they have nothing to push it from, except the empty air, (as it is styled by the poets) a fluid so rare, that it gives very little resistance. And the force of the men would be mostly expended in moving their own limbs and the instruments, whether oars or wings, with which they should attempt to beat or to push that air. When a boat is impelled through the waters by men and oars, the oars are applied to a medium, which, though fluid and yielding, yet gives incomparably more resistance and power to the stroke of the oar, than air. It is more than 800 times as dense as air. And besides, the boat is formed for moving through the water with the least resistance possible. The two machines cannot be compared together.

Some again have thought of the example of ships, which can be made to go in different directions with the same wind, by setting their sails obliquely to the wind in different positions. And they thought that some sort of sails might be applicable to a balloon. But here again the case is totally different. A ship has a hold of the water by her bottom and hull while she is impelled by the wind. And the form of the vessel disposes it to

glide easily through the water with the prow foremost, but to be difficultly moved with the broad side. In consequence of this, it is made to sail in many different directions with the same wind. The balloon has no hold of any thing whatever, but the air or the wind itself. It is, therefore, carried along by that air, as a feather would be; and has as little power to resist the action of the air on it as a feather has.

2*dly*, Beside all these, there is still another and an insuperable reason against the possibility of using balloons to make voyages, and to command their motion and direction. They must necessarily be made of very thin materials, and of the most flimsy construction, that they may be sufficiently light. Now, supposing we could apply a power to them that could move them with sufficient velocity, they could not support the impulse and resistance of the air against them while they moved through it. They would immediately be torn in pieces.

In the common manner of using them, when no attempt is made to direct or modify their motion, they are secure from this accident, being then carried along by the wind as a feather would be; so that although they are moved sometimes with great velocity, they are not exposed to any violent impulse of the air on any one side of them more than another. They move as fast as the air itself, and the persons who are in them feel as if they were becalmed.

3*dly*, They cannot remain suspended in the atmosphere for any considerable time.

4*thly*, Another inconvenience, and even danger to which balloons are exposed, is a whirlwind, which they sometimes raise, and by which some of them have been agitated, with great danger to the aëronauts.

They only use to which they have been found applicable, is one which occurred to me, and which I have occasionally mentioned ever since they were contrived, viz. for reconnoitering the position and strength of an enemy's encampment, and posts, in the art of war. It has been common to ascend steeples and rising grounds for this purpose. But in calm weather, a balloon, secured with a rope, can easily be made to rise to many times the height of a steeple.

Let us now return to the examination of inflammable air.

Another remarkable property of inflammable air, is its high degree of inflammability*.

The flame of this gas, in its unconfined state in common air, is extremely weak, as is reasonable to expect from a fluid so very rare, that a cubic foot weighs only 37 grains. The best way of observing it in this situation, is to blow up a soap bubble with it, and fire it with a candle. A more showy way is to fill with it a tall glass, having a movable bottom. It must be held with the bottom uppermost, otherwise the gas will soon disperse by its great levity. Holding the glass upright, and a candle a little way above it, (about twice the height of the glass) remove the bottom suddenly; and the gas, pushed up by the air below, will rise and meet with the candle, and form a beautiful column of lambent flame not hot enough to singe the finest down. It burns with a brighter flame at the mouth of a pipe; because it is denser there, especially if strongly pressed out, by squeezing the bladder which contains it.

It burns with more vivacity in vital air: but the difference is not so remarkable as one should expect. Yet, on reflection, we must be sensible that so small a quantity of inflammable matter must be completely and instantaneously inflamed, even in common air, with which it readily mixes.

The examination of the phenomena which accompany the in-

* It catches fire by the smallest spark. The most trifling electric spark is sufficient. But it seems as if the mere elevation of its temperature is not enough; for it is very difficult to fire it by passing it through a red hot tube, or by blowing it against a lump of ignited, but uninflamed matter. Even in the cases where we succeed, I am doubtful whether it is not by a spark of inflammable matter in the act of composition, that it is kindled. For I observe, that when the purest that I could obtain, by dissolving a metal in muriatic acid, is kindled at the end of a tube, from which it issues in a stream, the dull flame with which it burns has in the very middle a continual train of brighter ruddy sparks, which not only rush straight forward, but frequently split and dart sideways, with a momentary brilliancy, like the sparks of brandishing iron. I suspect that these are scorifications and explosions. These may be effected by the contact of a red hot tube, and will fire the gas. We know, without being able to explain it, that the action of the electrical spark is of the same kind. It seems to be only a comparative security which the light from flint and steel gives to the miners. Yet I confess that I have not been able to fire it in this way.—EDITOR.

flammation of it in vital air has been productive of such extensive consequences, and has so enlarged our knowledge of the chemical operations of nature, that I think it necessary to give you an historical account of it, and of the contributions which different authors have made by its means to the general stock of knowledge.

Dr. Priestley's examination of the gaseous fluids had exhibited a great number of concrete substances brought into an aëreal form, contrary to all our former conceptions of things. But this particular gas occasioned a discovery still more unlooked for. A substance which had been considered as an element, not only in the very dawn of natural philosophy, but which had maintained the character undisputed by the most acute and penetrating chemists of this most inquisitive age, is now found to be a compounded substance, and its ingredients fairly put into our hands.

Dr. Priestley was occupied with the examination of inflammable air, and tried the effect of almost every substance on it. He also tried the effect of the electrical shock and spark. As he expected, he found that it was expanded by it; but could not be inflamed by it in close vessels, unless mixed with common air. In this state it fired with a violent explosion. He was particularly surprised at the great diminution of bulk,—finding that a mixture of one part of inflammable air, and two of common air, might be made to contract into half the bulk, and that it was now phlogisticated air. Having already discovered the vital air, he fired a mixture of these, and found that when two parts of inflammable air and one of vital air were exploded together, it collapsed into almost nothing, or nearly the whole disappeared. Mr. Warltire, who assisted in these experiments observed that the inside of the vessel in which the deflagration had been made, was always moistened with dew. Dr. Priestley naturally ascribed this to moisture, which probably adhered to the airs employed; as they were always produced in processes in which water in some form or other was present. These experiments were made about the year 1782.

My friend Mr. Watt had taken great interest in these experiments of Dr. Priestley's; and communicated his opinion con-

cerning them to Mr. De Luc, in a letter dated April 1783. This letter is, in part, a transcript of one written some months before to Dr. Priestley, with a desire that it should be communicated to the Royal Society. In this he declares his opinion, that the water observed in these experiments arose from the combination of the two airs; and says, that water is the compound of dephlogisticated or vital air, and inflammable air, deprived of their latent heats; and that dephlogisticated air is water deprived of its phlogiston (i. e. of the inflammable air) in an aëreal form, that is, saturated with the matter of light and heat. Dr. Priestley did not communicate this to the Society, because (he says) some experiments which he had made since he saw Mr. Watt, were directly contrary to this opinion.

Dr. Priestley's experiments excited the attention of the Honourable Mr. H. Cavendish; and recalled to his mind his own observation of the moisture in the vessels in which he had exploded these two airs. These experiments had been begun in the summer 1781; and were continued from time to time, along with those by which he had discovered the composition of the nitrous acid. He immediately set about repeating the explosion of dephlogisticated and inflammable airs by the electrical spark. And in May 1783, he found that when six parts by weight of pure dephlogisticated air were exploded with one of inflammable air, they disappeared entirely; and that the result was a quantity of pure water, equal in weight to the airs employed. The utmost care had been taken to free the airs made use of, by making them pass through the dry muriat of lime. The vessel burst in several of his experiments; because, in the instant of explosion, the vapour of the produced water was expanded by the heat extricated from the airs. Much of this heat, to be sure, was expended in giving these the vaporous form, or supplying it with latent heat. But the vessel was instantaneously heated, shewing that the heat contained in the two airs more than sufficed for this purpose. These experiments were published in the Philosophical Transactions for 1784.

Such curious experiments, and so interesting a result, could not remain a secret, had such a thing been intended. But there was no such intention. Mr. Blagden, secretary of the Royal

Society, went to Paris in June 1783; and communicated these experiments of Mr. Cavendish to Mr. Lavoisier, and his associates, De la Place, Meunier, Monge, &c. knowing that they were much interested in their result, which was so intimately connected with the new theory which Mr. Lavoisier was then establishing.

Accordingly, Mr. Lavoisier, who saw the immense consequence of this discovery to his theory, immediately set about repeating the experiment of composing water by the combination of the two airs; and in September 1783, with the assistance of Mr. Meunier, effected the composition in a way that admitted no doubt. Instead of effecting it by the explosion of a few grains of gas, which is all that a manageable vessel of glass can contain, he did it by admitting two fine streams, one of each gas, into a balloon, through two tubes leading from large magazines of gas, and having their points so near to each other that the streams mixed immediately. The gases were supplied *in the due proportion* by regulated pressures of water on the gases in the magazines. While the pipes were thus delivering the due proportion of gas, it was fired by an electric spark, and the flame continued as long as the gases continued to be supplied. In this manner, very great quantities of gas were inflamed, so that the unavoidable errors in the ultimate measurement bore a very small proportion to the whole. At the end of the operation, there was commonly a remainder of carbonic acid and of azote, from which it is almost impossible to free the gases completely.

The result of this capital experiment was perfectly conformable to that of Mr. Cavendish. When the exact proportion of gases was attained, the result was water slightly acidulated. This proportion was fourteen parts by weight of inflammable air, and eighty-six of vital air.

Mr. Monge made a similar experiment at Mezieres, in June 1783, with the same result, and (he says) without having heard of the experiments of Mr. Cavendish, or those of Lavoisier and Meunier. The vital air employed weighed five ounces five drachms twelve grains: and it left thirty-five grains of water in the muriat of lime through which it passed. The inflammable air weighed six drachms thirty grains, and left forty-four grains of water. Therefore the quantities which really burned were—

	oz.	dr.	gr.
Vital air	5	4	49
Inflammable air		5	58
	6	2	35
Mixture remaining unburnt .		6	24
Quantity of gases compounded .	5	4	11
Water produced	5	4	41

This excess of thirty grains must be ascribed to errors in the estimation and weighing of the different articles. The water was not perfectly pure, but contained five grains of nitrous acid in each ounce.

Some time after, in 1798, Mr. Seguin again repeated this experiment, expending 25582 cubic inches, or nearly two hogsheads of inflammable air, and 12457 of vital air. The first weighed 1039$\frac{1}{3}$ grains, and the second 6210, amounting to 7249$\frac{1}{3}$ grains. And the water obtained amounted to 7245 grains, which is nearly 5944 grains English troy, about three-fourths of an English wine pint. No greater loss than four grains, in an experiment of this kind, is an exactness of which one has no idea. I doubt not, however, as this relation is a formal report from the Academy of Sciences, but that the experiment was very accurately performed, and the result extremely satisfactory.

Another experiment still was made by Le Fevre de Geneau, in which 35085 inches of oxygenous gas, and 74967 of inflammable gas were burned, weighing two pounds three ounces and sixty-four grains, (French *poids de marc*): and two pounds three ounces and thirty-three grains of water were obtained, containing twenty-seven grains of nitrous acid. Still more trials were made by Von Hauch, employing 3000 and 5000 inches, also with 1600 and 3000. The aim of so many laborious and expensive trials was, to hit the proportion of gases so exactly that the water should be pure;—but it was always contaminated with nitrous acid. This valuable information, however, was obtained from it,—that it was indifferent what acids had been employed for obtaining either of the gases. *Nitrous acid only* was found in the water.

A very candid and intelligent account is given of all the discoveries relating to the inflammation of these two gases in the translator's preface to the second edition of Fourcroy's Chemistry.

Mr. Cavendish, the original author of these experiments, and of the doctrine deduced from them, concluded that water is a compounded substance, and that its constituent parts are vital air and phlogiston, viz. inflammable air. For at that time Mr. Cavendish was of opinion that inflammable air is the true phlogiston of the chemists.

But, although Mr. Cavendish is the undoubted author of this decisive experiment, and, with Mr. Watt, is also the author of the important doctrine of the composition of water, Mr. Lavoisier has the still greater merit of seeing this proposition *in all its importance*. *This* incited him to undertake these laborious and expensive experiments, which confirmed those of Mr. Cavendish beyond a doubt. And he had also the sagacity to perceive *immediately*, that by means of this proposition, he should extricate his great system from difficulties and objections which I think would otherwise have been unsurmountable; and even to convert them into strong arguments in its favour, and make them the means of extending it to chemical facts, and to the great operations of nature, which seem otherwise inexplicable.

Thus excited, Mr. Lavoisier was not contented with having demonstrated that the explosion of vital and inflammable airs produce pure water: but, in September 1783, with the assistance of Mr. de la Place, he confirmed this demonstration of the composition of water by decomposing it, and producing its ingredients in a separate state. I shall therefore relate to you Mr. Lavoisier's experiments on this subject, and the manner in which he reasoned from them.

His first experiment consisted in simply putting some clean filings of the purest iron into distilled water, which filled a jar standing in the same water. After standing some days, a quantity of pure inflammable air is found collected in the top of the jar, and the iron is found corroded and black; and when carefully dried, weighs more than before, and if ex-

posed to heat in a retort, affords vital air. The iron, says he, attracts the oxygen of the water, and the inflammable air is set at liberty.

The second experiment is more remarkable. A small glass retort, having a very long neck, and holding an ounce or two of water, is so placed that this neck passes through a choffer of live coal, by which it is maintained red hot, while the water in the retort is made to boil gently. The vapour is collected and condensed in a proper pneumatic apparatus. It is found to be pure water, and precisely equal in weight to the water boiled off.

But, having put into the neck of the retort 28 grains of pure charcoal, and repeated the distillation, he found that the charcoal had vanished; and that the water collected in the receiver was $86\frac{4}{10}$ grains less than the water which had quitted the retort, which was $113\frac{7}{10}$ grains. But he found in the pneumatic vessel connected with the retort and receiver, 100 grains of carbonic acid, and 12 of inflammable air. Here, therefore, it appears that the carbone had attracted the oxygen of the water, and thus decomposed it. The quantity of the carbonic acid was determined by passing the whole elastic matter obtained through milk of lime, which absorbed it. Now 100 grains of carbonic acid had been long before proved, by his experiments, to contain 72 grains of oxygen. This quantity of oxygen, combined with $13\frac{7}{10}$ grains of inflammable air, would compose $85\frac{7}{10}$ grains of water. There appeared, therefore, a deficiency of $1\frac{7}{10}$ grains of inflammable air.

In a third experiment, he placed, instead of the charcoal, 274 grains of fine soft iron wire, loosely coiled. At the end of the operation, he found the iron changed into black iron scales, such as are found to fly from iron in forging, and 85 grains heavier than before. In the receiver he found 15 grains of pure inflammable air; and there was a loss of 100 grains of water. Now 85 grains of vital air, when united by inflammation with 15 grains of inflammable air, should compose very nearly 100 grains of water.

The conclusion from these experiments is so evident, that it is needless to go through it minutely. I have not used the pre-

cise numbers which occurred in Mr. Lavoisier's experiments, but such numbers in *the very same proportions*, as enable you to make the calculations without any trouble. Mr. Lavoisier and his associates give the name HYDROGEN to the ponderable basis of inflammable air, (which they call HYDROGENOUS GAS); because, when combined with oxygen it composes water.

Notwithstanding this body of evidence, some chemists, unable to relinquish their habits of explaining every thing by phlogiston, have made many observations upon and objections to these experiments. And when they could not gainsay the facts, they endeavoured to explain them by different suppositions. But I confess that I think their explanations infinitely embarrassed and hypothetical. There has since appeared, long after the date of these experiments, a proof of a very different kind.

Messrs. Van Troostwyck and Dieman, of Haerlem, produced electric sparks under water by the discharge of a square foot of coated glass between two balls of gold. At every spark, a small bubble of air was formed between the balls, which ascended through the water, and occupied the upper part of the tube that contained it. The air thus collecting, caused the surface of the water gradually to subside. At last, it sunk so as to be below the uppermost of the two gold balls. The next spark, therefore, was not under water, but in the air. The very first spark that was made in these circumstances, exploded the whole air which had been collected. When this did not burst the tube, (which it sometimes did), the water immediately filled it to the very top, the whole air having vanished. Here is a decomposition, and subsequent recomposition of water, which I see no way of gainsaying*.

* If further proof be still wanted, the wonderful effects of galvanism supply them in abundance. Mr. Woolaston also has greatly improved the method of the Dutch Philosophers, by availing himself of the well known property of fine points, by which they promote the transference of electricity; (a property happily explained by Mr. Cavendish, in the 61st volume of the Philosophical Transactions). By employing a very small shred of fine gold-leaf, all coated with sealing-wax, except the very extremity formed by breaking it across, he so constipated the stream by which the electric fluid is supposed to flow in or out, that a very middling machine, without coated glass, produces a continual decomposition.—EDITOR.

By the help of this discovery of the composition of water, Mr. Lavoisier easily explains the production of inflammable air during the solution of iron in diluted sulphuric acid, which, you may remember, I told you was the best process for obtaining it pure. While the sulphuric acid dissolves the iron, and divides it into parts inconceivably minute, it puts it into a condition for more powerfully attracting the oxygenous principle of the water. It attracts some of it, and thus leaves disengaged hydrogen, which assumes the form of inflammable air*. Lavoisier remarks that we do not obtain inflammable air, but sulphur, or sulphurous acid, when the sulphuric acid is concentrated. It must be largely diluted. Here the dissolving iron, having plenty of water to act upon, attracts oxygen more easily from it than from the acid. It is certain that it unites with oxygen on this occasion; for if we separate it from the acid, we find it in fact combined with oxygen, and can obtain this from it again.

Thus, you will now understand the opinion which at present prevails concerning the nature of water, and of this highly inflammable substance, and the consequences of inflaming it.

We may now further remark with regard to inflammable air, that it is at present considered as one of the simple or elementary bodies in nature. I mean, however, the *basis* of it, called *hydrogen* by the French chemists; for the inflammable air itself, namely, *hydrogen gas*, is considered as a compound of that basis, and the matter of heat. What appearance and properties that basis would have, were it deprived of its latent heat and elastic form, and quite separated from all other matter, we cannot tell. But it is supposed to be an elementary principle in the composition of a great number of natural bodies; particu-

* I do not see how its attraction for oxygen is increased. The iron is certainly, by this doctrine, combined with oxygen derived from the sulphuric acid,—a compound of oxygen and sulphur. How can this increase its attraction for oxygen already combined with hydrogen? The first action of the iron is generally supposed by the French chemists to be exerted on the water. And they suppose that the sulphuric acid acts only on the compound already formed of iron and oxygen. This may perhaps assist, by removing the iron already saturated with the oxygen taken from the water: but there is still a difficulty,—to be noticed afterwards.—EDITOR.

larly, it is an ingredient in all animal and vegetable substances. The attention of chemists was much directed to this object by some most ingenious experiments and reasonings of Mr. Lavoisier and Mr. Berthollet: and it is now pretty generally received as a position fully demonstrated, "that nothing is to be found in the bodies of plants and animals, except the four kinds of gas which we have discovered, namely, hydrogenous, carbonic, oxygenous, and azotic; and a small quantity of earthy and saline matter." And these substances, hydrogen, carbon, oxygen, and azote, are supposed to exist in the plant or animal in various states of composition, forming solids and fluids, in which these simple substances do not exhibit their peculiar properties, by reason of their composition. The chemists of the new school further hold, that the union by which these substances exist as ingredients in the distinctive solids and fluids of organised bodies, is but slight; so that it readily gives way to changes of temperature, and to the vital functions of the plant or animal; and that this is the cause of those fermentations and corruptions which we observe in them all. By these mutual actions of the sensible ingredients, these ultimate simples change their partners, (so to speak), and become ingredients of new compounds, uniting by pairs or triplets, in consequence of a change produced in their former attractions,—a change occasioned by a change of temperature, or by the living powers of the plant or animal.

When we maturely reflect on the subject, we see that the opinion has a great degree of probability, and that an inconceivable variety of appearances may fairly result from this seemingly very simple constitution of things. The theory here aimed at is most magnificent and comprehensive, embracing almost all the chemical phenomena of nature. And it even promises some introduction to the knowledge of those mysterious functions of vegetable and animal life, by which plants and animals assimilate, or convert into their own peculiar substances, the various materials which serve them for food and nourishment; so that even air, and light, and heat, become part of their composition. But it is at the same time very evident, that the most scrupulous caution is necessary in all our disquisitions on this subject,

and the utmost moderation in our theories. The combinations of pairs and triplets, in a collection of five ingredients, are so numerous, that it is in our power to bring out any ultimate compound we please, by properly selecting the order of succession of their mutual actions.

I shall give you one example of this manner of proceeding, which seems to meet with general approbation; and will give you a pretty clear notion of the kind of reasoning employed in the French school. This is the explanation given of the composition and formation of the volatile alkali. (*See Note* 41, *at the end of the Volume.*)

All the volatile alkali that we know is produced from animal and vegetable substances, or substances derived from these, by the action of heat, or by putrefaction. Yet we cannot discover it to be present in the substances from which it is thus obtained (*ex. gr.* in silk, animal jelly, &c.) before the action of great heat, or before putrefaction.

We have long had reason to believe that volatile alkali is a compound substance, and contains inflammable matter. The deflagration of nitrous ammoniac, and of all the ammoniacal salts with nitre, put this past doubt. Putrid steams, when copiously produced, are generally alkaline. They are always inflammable: and it is not till the putrefaction, accompanied by such steams, has proceeded a certain length, that the alkaline smell is perceived. It becomes gradually more sensible and less fœtid.

Mr. Berthollet observed that the muscular fibre, when fresh, gave out a great quantity of azotic gas, if digested with nitric acid; but if so treated when in a putrid state, it gave none, but gave inflammable air and volatile alkali. He was induced by this to think that the ammonia, which appears in this process of putrefaction, arises from a combination of the azotic gas and the inflammable air, in the instant of their extrication from the compounds from which they were disengaged. He supposed that ammonia is composed of inflammable air and azotic gas, or of the hydrogenous and azotic gases.

This opinion appeared to Mr. Berthollet almost demonstrated, by the effect produced on volatile alkali by the muriatic acid surcharged with oxygen. Although the liquid alkali was per-

fectly caustic, the mixture produced a considerable effervescence. But the gas which escaped was not carbonic acid, but pure azotic gas : this, being a simple substance, must have existed in the materials. The acid contains none ; it therefore made a part of the alkali. In the mean time, the acid became ordinary muriatic acid,—its redundant oxygen had disappeared,—it had combined with the hydrogen of the alkali, and formed water.

This opinion explains, and is confirmed by, many observations of different chemists before this conjecture of Berthollet; and, in the first place, some very remarkable experiments by Dr. Priestley, in which he shewed that inflammable air had the properties of other inflammable bodies, but with circumstances that were characteristic. Thus, we know that minium, or red lead, is converted into lead by making it red hot, in contact with oils and other inflammable liquids and solids. In like manner, it is converted into lead, if heated by a burning-glass, when exposed in a vessel filled with inflammable air. In this experiment, the inside of the vessel is covered with dew, which trickles down the sides, and proves to be pure water. The inflammable air is almost completely absorbed.

But it is also converted into lead, if treated in the same manner, in a vessel filled with pure caustic volatile alkali. But in this experiment, there is a great remainder of unabsorbed gas. Dr. Priestley expected to find this nearly pure vital air,—the lead having (according to his theory) absorbed all the phlogiston of the alkali. He was astonished to find it, on the contrary, highly phlogisticated ; that is, nearly pure azotic gas.

Mr. Berthollet explains these two experiments in a very satisfactory manner. Minium contains (as we shall learn in due time) a quantity of oxygen. This, uniting with the hydrogen in the first experiment, produces the water which Dr. Priestley observed; and the hydrogen disappeared. But, in the second experiment, the azote, which is a simple substance, and must have existed in some of the ingredients, but cannot be demonstrated in minium carefully prepared, must have come from the ammonia, and must have been one of its ingredients. The other is, in all probability, hydrogen ; for it is a simple substance, and it is yielded by putrid muscle when digested with nitric acid;

which putrid muscle also yields volatile alkali. It yields volatile alkali only when it ceases to yield disengaged azote, the putrefactive process having combined it with the hydrogen.

This is the general theory, founded on a very few experiments indeed, but these abundantly simple. They are not, perhaps, decisive. But this theory gathers strength by attending to a number of more complex facts, and taking along with us the two discoveries of Mr. Cavendish,—the composition of water, and that of the nitrous acid, as propositions fully demonstrated.

1. Our newspapers inform us that the French chemists procured saltpetre for the army, by blowing alkaline gas, and even putrid steams, through red hot substances which readily yield oxygen. We know that such steams yield both inflammable air and azotic gas. The last of these seizes part of the oxygen presented to it, and forms nitrous acid; while another part combines with the inflammable air, and composes water, which dilutes the acid. It seems to be for such reasons that putrescent substances are useful in nitre beds, and that the nitre first obtained is frequently nitrous ammoniac.

We often find the older chemists expressing their surprise at the strong smell of volatile alkali from the mixture of substances which contain none. Thus, iron or copper filings, when dissolved in strong nitrous acid, often emit the smell of volatile alkali, instead of the offensive smell generally emitted from this mixture. The metal may be supposed to decompose the water: and the hydrogen, uniting with the azote (now redundant in the nitrous gas in consequence of the dissolution of some metal by the acid) will form ammonia.

Dr. Austin, who had early formed the same opinion of volatile alkali, narrates, in the Philosophical Transactions for 1788, several facts of the same kind. The following is one of the most simple, and is very constant:—Put a small quantity of iron filings, very pure and clean, into a phial containing azotic, gas, having previously wetted the filings with pure water. The gas will be quickly absorbed, and signs of ammonia will appear. The smell becomes very distinct,—test-paper becomes green,—paper dipped in the solution of copper in muriatic acid, will be-

come blue ;—these are all marks of ammonia. All this will happen, but more slowly, in common air, which contains azote in abundance. The process is obvious. We know that the iron decomposes the water which wets it,—the disengaged hydrogen combines with the azote. For the same reasons, we smell volatile alkali in a mixture of iron filings, sulphur, and water. It would seem, however, that in all these experiments one or both of the gases must be catched by the other in its nascent state, in the very act of its extrication. Dr. Austin could not combine them when already in the form of a gas. *(See Note 42. at the end of the Volume.)*

On the other hand, facts have frequently occurred which are best explained by the decomposition of volatile alkali. Mr. Milner, by blowing alkaline gas through red hot manganese, which yields oxygen in great abundance, produced nitrous acid, as the French did. Also, the muriatic acid, taken in a state in which it is overcharged with oxygen, being blown through, or made to mix with alkaline gas, (ammonia) produces water and azotic gas. The oxygen seizes the hydrogen of the alkali, and forms water: and the azote is disengaged. In general, when ammonia is forced to bear a red heat, in contact with substances which readily yield oxygen, we obtain azote and water. If they strongly attract azote, we obtain inflammable air.

Such are the facts which seem to establish Mr. Berthollet's opinion of the composition of volatile alkali. He imagines it to consist of one part of hydrogen, and four parts (by weight) of azotic gas nearly.

The union of inflammable with vital air came in our way in considering the effect of heat on inflammable air. Its importance has occasioned me to take up a good deal of time with it. I now proceed to consider how inflammable air is affected by mixture with other substances.

It has little disposition to mix with pure water. It does, however, mix in a small proportion ; and gives it a very nauseous smell. It is this that offends so much when water is thrown on red hot coals. In its pure gaseous state, it is by no means offensive, although rather unpleasant. I speak of the pure hydrogen gas, obtained from iron or zinc, dissolving in the mine-

ral acid. This is distinguishable, by its great levity, from that obtained from vegetable and animal substances. When its weight is more than one-thirteenth of that of common air, it is impure, and has various smells (all bad), according to the sources from which it was obtained, or the mixture it holds in solution. All of them are considerably heavier than the one now under consideration. They generally emit a brighter flame. The inflammable air from marshes is usually called the *heavy inflammable air*. Another produced from charcoal has some remarkable properties, particularly its operation on living animals who respire it. It is called *hydrocarbonat*, and will be noticed very soon. It is reasonable to doubt whether these inflammable gases have any thing in common with hydrogen besides their inflammability. Yet all compose water by deflagration with oxygen. Therefore they contain some common substance.

Hydrogenous gas loses much of its inflammability by frequent agitation with water; and gives it a bad smell.

It has little action on the alkaline salts. Mr. Lavoisier was once disposed to consider it as the alkaline principle: and I observe that Chaptal, and others, have still a leaning to this opinion. This gas combined with quicklime is supposed to form potash, and soda when mixed with magnesia*. But I see very little to support this notion.

Its action on the acid salts is much more distinct. If a little strong sulphuric acid be heated in the bottom of a very narrow and tall glass, which swells out at the other end like a pear,—and if, in this state, inflammable air be blown through it by a long pipe from a bladder, they unite very readily. The hydrogen from the gas unites with the oxygen of the acid,—and they form water. The acid, deprived of its due proportion of oxygen, becomes redundant in sulphur, which is manifest by its suffocating fumes: and even sulphur in powder will sometimes collect in the wide part of the glass. When the acid is concentrated as much as possible, and made to boil before the inflammable air pass through it, it acts in another way. Instead of

* See a letter from Van Mons in the *Annales de Chymie*, of which an extract is given in *Nicholson's Philosophical Journal*, IV. 334.—EDITOR.

abstracting the oxygen, and combining with it, it combines with some of the sulphur; and comes off in form of an abominably fœtid gas, which will be considered afterwards by the name of *hepatic gas*, or *hydrosulphuret*, only noticing at present that it preserves in some measure the chemical relations of an acid. When passed through an alkaline solution, it forms a sort of neutral salt, having a disgusting fœtor and taste. But,

Nitric acid also absorbs this gas very readily. We can see at once what must be the effect of an acid which yields oxygen so readily,—it becomes ruddy and fuming; because water is formed of part of its oxygen, and the nitrogen or azote is now predominant.

This mixture gives me the first opportunity of confirming the discovery of the composition of nitrous acid by Mr. Cavendish, which I mentioned when giving you an account of the gases discovered by different chemists, after the publication of my dissertation on fixed air and quicklime. I considered it as abundantly proved by that experiment of Mr. Cavendish. But it has been proved since that time by many experiments, in which the two ingredients, oxygen and azote, are separated. None exhibit this more clearly than the mixture of nitrous acid, or nitrous salts, with inflammable substances. Inflammable air is the first and most simple of them, at least in its chemical relations.

When a long continued stream of inflammable air is made to pass though nitric acid, we obtain (in a pneumatic apparatus) the gas which Priestley calls *nitrous air*, which is colourless at last, though ruddy in the beginning, and has no acidity, nor changes the colour of test paper, and is scarcely absorbed by water. This gas, when mixed with vital air, (oxygenous gas), collapses with it into nitrous acid. Here then is a proof that vital air is one of its component parts. The inflammable air had united with a part of the oxygen that is more easily detached from the perfect acid, and the gas which came from it is therefore deficient in it; so deficient as not to be acid. But when oxygen is presented to it, it is combined, and we have again nitrous acid. In the mean time, the nitric or perfect acid

is become fuming, and also weaker, or diluted, by the water that is formed by the inflammable and vital air.

It is to be particularly remarked in this experiment, that although the gas produced is clear, and nearly colourless, and vital air is the same, yet these two, on mixing, form, for a few seconds, a thick ruddy cloud: and a very sensible heat is produced by their condensation into nitrous acid*.

If the experiment be made with common air, in the place of oxygenous gas, we still produce nitrous acid, and have the ruddy cloud: however, the two airs do not vanish, but leave a considerable residuum of azotic gas. The reason of this is now obvious. The nitrous air combines only with the oxygen of the atmospheric air, and leaves the azote. It was no part of the nitric acid employed in the experiment. We now also see the cause or origin of those red fumes which appear in most experiments with the nitrous acid. They are formed during the combination of nitrous air with the vital portion of common air.

This experiment is therefore instructive. But it is extremely tedious, because the quantity of matter in a reasonable bulk of inflammable air is so very minute. We shall have much better examples as we proceed.

Its relations to the other acids, to the compound salts, and to the earths, have been but little examined as yet. We are now to be occupied with the other inflammable substances; and shall consider the relation of it to each. Some are very remarkable.

II.—PHOSPHORUS.

The next sort of inflammable substances we proposed to describe are those named Phosphori. The principal species of these is commonly named the Phosphorus of Urine, on account of its having been prepared formerly from urine.

* These ruddy fumes are most evidently vesicular, and some of the vesicles very large.—Editor.

When pure and newly prepared, it is semitransparent; and by its degree of cohesion bears some resemblance to white bees wax. It makes nearly the same resistance to a knife in cutting it: and it melts with a heat even inferior to that of melting wax, coinciding rather with the heat of the human body.

It may be melted with this heat safely, if immersed in water, and covered by it from the contact of air; or even without water, provided the glass vessel containing it be of a small size, and closed up, to prevent the renewal of the air in it.

In a small retort, with a suitable receiver closely luted to it, this phosphorus can both be melted, and by an increase of the heat to the lowest degree of ignition, can be converted into vapour, and thus made to pass over into the receiver, which being kept cool, the phosphorus quickly congeals in it, and is in the same state as before. It is sometimes subjected to this sort of distillation in order to purify it.

But, in all such operations with it, we must be very careful that no fresh air be admitted into the vessels until they be perfectly cold again: and, even then, the moment the receiver is separated from the retort, it ought to be filled with cold water.

This precaution is necessary, on account of the extraordinary propensity of this substance to be inflamed by the action of fresh air, especially if it be in the least warm, or exposed to the air, with an extensive surface of communication with it. And, when it takes fire, it burns with amazing rapidity and violence. It is therefore proper to be cautious in handling it; as the warmth of the fingers may set it on fire.

The low degree of heat at which it takes fire shews the extraordinary inflammability of this substance; and is the foundation of many of its remarkable properties, and of some of the tricks that are played with it, such as setting paper on fire by rubbing the paper*. We may kindle tow, which conceals a lit-

* This is done by previously drawing a strong line with a piece of phosphorus on a piece of stiff and rough paper, such as cartridge paper, laid upon some very cold body during the friction. The warmth of the fingers being sufficient to set phosphorus on fire while it is so hard rubbed, it must be wrapped two or three times round in a piece of wet paper. In order to shew the trick, the paper is folded upon the stroke, and briskly rubbed very hard one part upon the other. The phosphorus that was left upon it is generally sufficient to set it on fire.

tle bit of it, and is loosely wrapped round a phial, by pouring hot water into the phial, or by mixing in it two cold liquors which grow hot by mixing. Another trick is to light a candle by touching a glass of cold water. The glass has a minute bit of phosphorus stuck on its edge. The showman pours cold water into it, blows out the candle, and while the wick is still hot, he touches the phosphorus with it, which instantly takes fire. With this phosphorus also are made what are called phosphoric matches. These philosophical toys are slender wax tapers, having an atom of phosphorus at the end : and each must be kept in a glass tube hermetically sealed. It is warmed by putting that end into the mouth,—then broken, and the taper suddenly drawn out. It generally takes fire. They are costly, offensive by their vile smell, and very childish.

During the rapid inflammation of the phosphorus, it is quickly changed into a saline substance, which is no longer inflammable in the same degree, and which is thrown out of the flame or burning vapour in the form of a thick white smoke. A part of this smoke is dispersed in the air, and unavoidably lost. But a considerable part of it is immediately condensed on the surface of the vessel, in the form of a saline crust, which has a strong attraction for the humidity of the air, and is very soon liquefied by it, forming with it an acid liquor.

Although this acid matter, when first produced, is no longer inflammable in the same degree as the phosphorus, it still retains a small degree of inflammability. This we learn when we expose it to a stronger heat, such as that of red hot iron. Then, after glowing a little, it becomes, at last, a white or transparent saline substance, which has lost all remainder of inflammability, and is a perfect acid.

The properties of this acid were first investigated by Mr. Margraaf of Berlin, and published in the Transactions of the Royal Academy there, and since, in his *Opuscula*, which have been translated from the German into the French language. The compounds which it forms with different substances are also described by M. Fourcroy.

Mr. Margraaf made it return to the state of phosphorus, by mixing it well with charcoal powder, and exposing this mixture

in earthen retorts to a violent heat in the way of distillation, with the proper precautions for preventing the phosphorus from taking fire in the receivers.

His opinion of the conversion of the phosphorus into an acid by inflammation was the same with that of other chemists at that time; namely, that it happened in consequence of abstracting the phlogiston. And yet he particularly remarks, that the quantity of the acid which he collected by burning it gradually, or by small bits in succession, greatly exceeded the quantity of the phosphorus.

This fact has been more exactly ascertained since that time by the experiments of Mr. Lavoisier, and others. And many instructive discoveries have been made by means of the inflammation of phosphorus, and its conversion into an acid. It is peculiarly fitted for being useful in investigations relating to combustion. Sulphur and inflammable air are equally simple and effective. But the compounds which they make by inflammation are so volatile, or offensive, or troublesome, that they are almost unmanageable. Here it is quite otherwise. This pointed it out to Scheele and Lavoisier as the fittest substance for ascertaining the change produced on air by combustion. No volatile matter from the phosphorus will in any way taint it. It is now well known, that when it is burned in a limited quantity of atmospherical air, the vital part of the air, or the oxygen gas, is expended and disappears, without any formation of carbonic acid. And when burned in pure oxygen gas, it burns with amazing brightness and violence, and the whole of the gas is absorbed and disappears.

The burning of phosphorus in oxygen gas was first tried by Dr. Scheele. But the same experiment was afterwards repeated by Mr. Lavoisier, with larger quantities of the phosphorus, and with the most careful attention to every circumstance which could affect the conclusion to be drawn from it.

Scheele put his bit of phosphorus into a phial filled with oxygen gas; closed the mouth of the phial with a cork; and then warming the phial, he thus kindled the phosphorus. When the inflammation was finished, and the phial was cool again, he plunged it into water, and drew out the cork under water. The

water was suddenly pressed into it by the atmosphere, and filled the phial perfectly full, or very near it. He therefore concluded that the oxygen gas had united with the phlogiston of the phosphorus, so as to form with it heat and light, which had passed through the glass.

But Mr. Lavoisier, performing a similar experiment, took the precaution to weigh the glass with what it contained immediately before the inflammation of the phosphorus. Weighing it again, after the inflammation, and before it was opened, he found it was precisely of the same weight. Afterwards, examining as exactly as possible the weight of the acid into which the phosphorus was changed, he found that it exceeded the weight of the phosphorus consumed, by a quantity exactly equal to the weight of the gas which had disappeared. It was therefore evident that the gas was now changed, by the loss of its latent heat, into a dense matter, which made up the greater part of the weight of the acid. One part of phosphorus absorbs in this way a litte more than $1\frac{1}{2}$ parts, by weight, of the oxygen gas. The acid is made up of the phosphorus and oxygen, in the proportion of 100 to 154*.

The change of phosphorus into an acid is, therefore, frequently named the OXYDATION of phosphorus. And other similar changes of other inflammable substances are also called OXYDATIONS†.

* This experiment must be considered as one of the most convincing proofs of the doctrine of the French chemists. Whatever notion we have of the phosphoric acid, it is plain that the phosphorus itself enters into its composition; for the phosphorus disappears, and we have the acid in its stead. It can never be said, therefore, that phosphorus consists of the phosphoric acid and phlogiston; for phosphoric acid consists of phosphorus, and something besides: These are irreconcilable.—EDITOR.

† It is rather an unlucky term, chosen in the heat of discovery, and before Mr. Cavendish had discovered the composition of water. Had this been known, it is not likely that a person of Mr. Lavoisier's general knowledge and good sense would have included the formation of water in the list of acidifications. Most of his followers were less sensible of the violence done to common language. Perhaps they even liked a diction which will cause the uninitiated to stare. We see this very plainly in the phraseology of some of them, who are fond of using the term combustion in cases where a plain man can see nothing like it. What he would call combustion, they call oxyda-

Since these discoveries were made, Mr. Pelletier, another French chemist, who has distinguished himself by many instructive experiments relating to phosphorus and the process for preparing it, contrived a process for oxydating phosphorus, which appears to be very effectual, and very well fitted for preventing the loss of any part of the acid.

He melts the phosphorus under water, in a cylindrical glass vessel, and then throws into it oxygen gas, by very small quantities at a time, through a glass tube, connected with a bladder, containing the gas. Every little addition of the oxygen gas kindles that part of the phosphorus with which it comes in contact, and is absorbed by it. That part of the phosphorus is thus changed into acid, and dissolved by the water: and thus the whole of it can be thus oxydated, or changed into acid, which is dissolved by the water.

Another process or experiment, founded on the same discoveries, may also be mentioned here. It is an experiment by which we learn the proportion of oxygen gas contained in atmospherical air. *The eudiometer of phosphorus*, or method for learning exactly, by the use of phosphorus, the proportion of oxygen gas contained in atmospherical air, contrived by Seguin and Lavoisier. *Annales de Chymie, tom.* ix. *p.* 301.

Get a glass tube about one inch in diameter, closed above and widened below, and about seven or eight inches long. Fill it with quicksilver; and invert it into a cistern of the same fluid. Throw up or introduce into it a little bit of phosphorus, and approach a burning coal to the upper end of the tube, to warm and melt the phosphorus by blowing on the coal. Then, having measured a proper quantity of the air to be tried, throw it up by small portions at once, each of which will cause the phosphorus to burn, and will thus consume or saturate some of it, and in so doing will be saturated, and changed into acid, in as far as it consists of oxygenous gas. When it is all thrown up,

tion: and what he would call oxydation they call combustion. The formation of water is an *oxydation of hydrogen:* but the formation of nitrous acid is the *combustion of azote.* There is little science in this, but abundance of vanity.—EDITOR.

warm the tube again, to be sure that the oxygen gas shall be completely expended or saturated. Lastly, let it cool; and transfer the air into another tube which is graduated for measuring exactly the bulk of the remaining air. This will shew the quantity of the oxygen gas which it originally contained. A glass funnel, having the extremity of its tube closed up, may serve very well in place of the above apparatus.

These are the most remarkable particulars of the properties of phosphorus with respect to heat, and the manner in which it is inflamed and changed into phosphoric acid.

It has also a quality, upon which have been founded many of the curious experiments and surprising tricks that have been performed with it. This quality of it appears when it is exposed to the air in an extended surface, but in degrees of heat inferior to that necessary for its bright inflammation. It then emits a pale light, visible in the dark only. We do this very effectually by drawing lines with phosphorus on strong white paper.

When we view the paper in day light, the light of the phosphorus is not perceived, in consequence of its weakness: but a white smoke is seen to arise from it. A small solid mass of phosphorus continues to emit this pale light and smoke a surprisingly long time. Mr. Boyle relates that a bit of phosphorus, weighing only three grains, continued to emit this weak light fifteen days and nights before it was exhausted.

From the consequences observed, when a bit of the phosphorus is thus exposed on a plate of glass a little inclined, we find reason to be satisfied, that this luminous state of it is only a state of very slow inflammation. It is gradually converted into an acid, which attracting humidity from the air, forms an acid liquor, much the same with that formed by the bright and violent inflammation of the phosphorus; only that it is not quite so perfect an acid. It is still somewhat deficient of the proper quantity of oxygen. This trickles down along the glass, and may be thus collected.

One of the processes for converting phosphorus into an acid is founded on this property. The phosphorus, formed into small cylindrical pieces, is put into a glass funnel, the throat of

which is slightly stopped with a pebble or a bit of glass, to prevent the descent of the phosphorus into the pipe. A phial is then placed under the funnel, and the whole apparatus set in a moderately cool place. Thus the acid of the phosphorus, in proportion as it is formed, drops into the phial. But we must take care that the place in which the apparatus stands, be sufficiently cool. A small increase of the heat of the air has great effect in accelerating the process: and if it be much accelerated, the phosphorus becomes warm by the very oxydation, and there is danger of its taking fire, and burning with violence. Scheele discovered that even the weakest lumination of the phosphorus is attended with the production of some perceptible heat, discoverable by a thermometer. But when the process I speak of is rightly conducted, this heat being weak and slowly produced, it is carried off by the surrounding air, so that it never is accumulated in such quantity as to dispose the phosphorus to be rapidly inflamed.

We come now to consider phosphorus in mixture with other bodies. Being a substance of recent discovery, its chemical relations have not yet been thoroughly examined. Many of those we know are very remarkable. Mr. Margraaf, to whom we are indebted for the knowledge of the chemical nature of this substance, has made these combinations with his usual judgment and accuracy.

A drachm of phosphorus was distilled by him with an ounce and a half of sulphuric acid, giving at last a violent heat. A few grains of phosphorus remained, mixed with a spongy white mass, which deliquesced in the air. The liquor which distilled was thickish, and a little milky. Both liquors contained a mixture of sulphuric and phosphoric acids.

A drachm of phosphorus was distilled with an ounce of strong nitric acid. As soon as it was dropped into the acid, blood red fumes were disengaged, which made him fit on the receiver in a hurry. The solution went on with great vehemence and heat: and in a short time the greatest part of the nitrous acid came over, without applying any fire to the retort. At last the phosphorus yet remaining took fire, and burst the retort with great noise.

The union of the oxygen and azote in the nitric acid is so weak, that scarcely any body which attracts oxygen can be presented to the acid which will not overcome their union and decompose the acid. The azote, or rather nitrous gas, escapes and produces those red fumes, by uniting with the atmospheric air. The latent heat of the oxygen, as it is contained in the nitric acid, greatly exceeding what is necessary for the acid of phosphorus, emerges and produces heat enough to inflame the remaining phosphorus.

But, by another way of conducting the process, it is very manageable. Put strong nitric acid into a tubulated retort fitted with a receiver. Have ready a quantity of phosphorus cut into very small pieces: drop in one, and immediately stop the hole. The phosphorus will dissolve very quickly, and will produce heat. When all is cool, drop in another bit; and continue this till the last bit dissolves and seems to saturate the acid. Now apply heat: and the nitric acid will distil over in fiery fumes, and leave nearly pure phosphoric acid in the retort.

This mixture also gives us a pretty phenomenon. Put about half an ounce of strong nitric acid into a small and thin flask with a narrow mouth. Drop in a bit of phosphorus like a large pea. There is an effervescence, or rather an explosion, during which a slender column of flame is darted out of the glass along with the vapours and drops of acid. Care must be taken so to regulate the quantity to the size of the orifice, that the vessel do not burst; and to have it of such a shape, that few drops of acid may come out.

This is the next opportunity given us for examining the composition of nitrous acid: and it is incomparably better than the last with inflammable air. Accordingly, all the phenomena are the same in kind, but much more remarkable. The production of the phosphoric acid, in the same quantity precisely as if it had been produced by inflaming the phosphorus, shews evidently that oxygen constitutes a great portion of nitric acid. The gas which escapes is the same as when inflammable air is employed, provided that the combination be slowly effected. If rapidly, much phosphorus is volatilized, and taints the gas, sometimes even making it inflammable. The fumes are blood

red, while they mix with common air or with oxygen: and nitrous acid is produced by the union. If all access of air be prevented, the gas is colourless, and without acidity. By comparing the gain to the phosphorus, with the oxygen necessary for forming nitric acid with the gas, Lavoisier found that the proportion of oxygen and azote in the gas, is that of 68 to 32 nearly. It requires about 24 parts (in bulk) of common air to saturate 11 parts of this gas, and form with it nitrous acid. In this mixture, the whole nitrous gas disappears, and a fourth part of the common air; so that 35 cubic inches, after mixture, will only occupy 18 inches. This is azotic gas.

That the red vapours are true nitrous acid, appears from an experiment of Dr. Priestley. Hang in the glass a piece of sal ammoniac. When the red fumes are over, a snowy powder settles all over the vessel, which is imperfect nitrous ammoniac.

The nitrous gas may be decomposed, and the composition of nitrous acid completely demonstrated, by filling a jar with nitrous gas, and putting into it a quantity of *hepar sulphuris*. This will immediately attract the oxygen remaining in the gas, and leave the other ingredient alone. This is found, by this experiment, to be pure azotic gas.

We may surely now assume the composition of the nitrous acid as a thing as firmly established as any doctrine in chemistry. You will recollect, that, in order to answer an immediate purpose, I mentioned the precious experiment of Mr. Cavendish, in which he found, that when seven parts of vital air were deflagrated with three of phlogisticated air, or azotic gas, the whole collapsed into pure nitrous acid. But I did not at that time assume this constitution of the acid as a fixed point; because I was not then in a condition to shew you how the acid might be separated or resolved into those its constituent parts. I was unable to do this, because you were unacquainted with the substances whose properties and manner of action were to operate this decomposition. Enough of these have now occurred: and I have given you most distinct examples of the fact. More will yet occur as we proceed; and some of them perhaps still more perspicuous. But we have enough: and it will be

agreeable now to meet with the others, as phenomena which are explained by this principle now in our possession.

The muriatic acid did not appear to Mr. Margraaf to act at all on the phosphorus, which did not dissolve. At the end, indeed, of the distillation, the phosphorus also came over, but without any remarkable change.

The pure or caustic fixed alkalis may be combined with phosphorus, or can be made to dissolve it, as they dissolve sulphur, and indeed all the inflammable substances in the humid way. In consequence of this combination, an inflammable gas, extremely fœtid, smelling like rotten fish, is produced, which takes fire the moment it comes in contact with atmospherical air; and which therefore exposes the vessels to the risk of being burst by its explosions.

This gas is undoubtedly produced from a small portion of the water decompounded by the dissolved phosphorus. It is the hydrogen in its form of gas; and as fast as it is produced, it dissolves and volatilizes a small portion of the phosphorus itself, and from this receives the quality of spontaneous inflammability*. This small portion of the phosphorus, however, is very slightly united with the hydrogen; for it is deposited or separated, if the gas be kept for some time confined with water. It gradually deposits the phosphorus on the sides of the vessel; loses its spontaneous inflammability; and is changed into common inflammable air or hydrogen. The same gas is produced by quicklime. *(See Note 43. at the end of the Volume.)*

By these experiments, you will perceive that phosphorus is one of the most easily inflammable bodies that we know; that

* Is the series of operations here stated very satisfactorily established? I cannot help considering this experiment, and those which are analogous to it in the treatment of sulphur with alkaline substances, as examples of that gratuitous employment of the decomposition of water, which the followers of Lavoisier indulge in with so little circumspection or moderation. All depends on the *order* in which the different actions succeed each other. I think that phosphorus and sulphur, and perhaps, charcoal, afford a probable opportunity of settling the point, by means of a previous determination of their simple affinities. This is not in our power, perhaps, in the more complicated substances of animals and vegetables.—EDITOR.

it has a strong propensity to take fire, and to be inflamed; or, in other words, that it has a strong attraction for oxygen. A very ingenious and instructive experiment has lately been founded on this strong attraction, or has been contrived in consequence of it. It has been a great desideratum among the chemists to decompound the carbonic acid; that is, to contrive some way by which the carbone or coal may be separated from the oxygenous gas or vital air, which is now held to be its other ingredient. This has been attempted with very flattering appearances of success by Mr. Smithson Tenant. You have an account of it in the Philosophical Transactions, vol. 81. part ii. I shall give you a brief account of it.

Mr. Tenant put a small bit of phosphorus into a glass tube that was shut at one end; and then put over it marble reduced to a fine powder. He shut the other end, but loosely, that the common air expanded by heat, might escape; and yet so that the free circulation of air, which might kindle the phosphorus, should not take place. He heated this apparatus red hot for a few minutes. When all was cold, he broke the tube, and found therein a black powder, which consisted of coal, phosphorated lime, and phosphorus mixed with quicklime. When the phosphorated lime was separated by solution in an acid, and filtration, and the phosphorus by sublimation, the coaly matter that remained did not appear to differ from vegetable coal in any respect. Mr. Tenant explains the experiment by saying that the coal is separated from the oxygen, although it has a stronger attraction for it than the phosphorus has, in consequence of the sum of the attractions of the phosphorus for oxygen, and the phosphoric acid for quick-lime.

Dr. Pearson observing that the compounds of phosphoric acid and the fixed alkalis could not be made to yield phosphorus by treating them in contact with charcoal in a red heat, while the calcareous phosphat yields it with great readiness, thought that the fossil alkali would be a better intermedium than calcareous earth, for operating the decomposition effected by Mr. Tenant. He therefore employed, with perfect success, a mixture of two parts of phosphorus, and eight of carbonat of soda, cleared of its water of crystallization. The process was similar to Mr.

Tenant's, and very easy. The rationale of these processes is by no means obvious. But the production of carbone, and this in due quantity, completes the theory of carbonic acid. A letter of Dr. Pearson to Hassenfratz, and some observations by Fourcroy, which accompany it in the 18th volume of the *Annales de Chymie*, deserve perusal.

Phosphorus will also combine, though loosely, with the caustic volatile alkali; and produces a gas with an abominable smell. This gas also takes fire in the air; and, which is remarkable, deposits the greatest part of the phosphorus in the flash. Indeed, in all these gases, containing phosphorus volatilized by hydrogen, the union seems exceedingly slight. They all decompose by long keeping, even in corked phials. Westrumb says that they deposit the phosphorus, even in phials hermetically sealed. That the phosphorus is not inflamed in these experiments, but deposited, appears singular at first view, seeing that it is so very inflammable. But when we consider the extreme rarity of the gas, and reflect that the inflammation even of this rare gas, which takes place by the mere contact of air, is probably the low inflammation, in which phosphorus itself only shines without ordinary combustion, we shall be sensible that the complete inflammation of the phosphorus is not to be expected.

These are some of the most remarkable qualities and relations of this inflammable substance. It is also capable of being combined with some of the other inflammables*, and with the metals; and forms singular compounds, which shall be noticed hereafter.

The acid which it affords is also now become one of the important objects of chemistry. It is fixed and vitrifiable. With the fossil alkali it forms a salt, now used in medicine, and recommended by Dr. Pearson by the name of SODA PHOSPHORATA.

* Indeed all the inflammable substances are susceptible of a perfect admixture: and this has, in many cases, some appearance of a chemical combination,—the compounds having certain general properties which do not belong to the ingredients, at least in the same degree. They are, in general, more fusible, volatile, and inflammable, than should be expected from the ingredients: and they are more disposed to union with another inflammable substance.
EDITOR.

A process for preparing this neutral salt is given in a new edition of the Edinburgh Pharmacopœia*.

* *Process for Soda Phosphorata, communicated by Dr. Pearson.*

Take bone ashes: Those to be had at the hartshorn manufactures are commonly used, and ground to a coarse powder, in the state they are in for manure, and as sold for about a shilling a bushel—ten pounds.

Pour on them, in an earthen, or iron pan, oil of vitriol, of specific gravity about 1800—six pounds.

Stir the mixture well, and add to it gradually rain or river water—nine pounds.

Stir the whole well together, and set the mixture to digest in a sand heat of about 130°, for two or three days. Then add to this mixture nine pounds more of very hot water, and pour it on a filtre of coarse linen cloth, upon which pour boiling water till it passes through with little acid taste. Let the filtrated liquors, all mixed together, stand for the sediment to fall. Decant the clear liquor, and evaporate to about nine pints. Filtrate, to separate the selenite precipitated in boiling, and evaporate again to seven pints. Cool the liquor, and separate more selenite. Heat the liquor in an earthen vessel, and add pure crystallized fossil alkali, dissolved in $1\frac{1}{2}$ its weight of water, until the effervescence ceases. Filtre the saline liquor hot, into a shallow vessel, and let it crystallize three or four days. Decant the remaining liquor from the crystals: and if it be acid, neutralize it again with the solution of fossil alkali, and evaporate again and crystallize; repeating these operations, until a liquor remain which will not give any more crystals, either by evaporation or addition of more alkali.

Shorter Process, but with more waste of phosphoric acid.

Add as much water to a mixture of sulphuric acid and bone ashes, as will reduce it to a thin paste, which must be put into a coarse thick hempen bag, tied up close at the mouth. Then press and moisten it with water repeatedly, until the whole, or greatest part of the acid liquor is extracted. The turbid acid liquor must be purified from the selenite, by decantation and filtration. And if the quantity of this liquor be more than six pints, reduce it to that quantity by evaporation: and saturate, as before described, with a solution of fossil alkali.

The quantity of phosphorated soda should be at least equal to the weight of the alkali, and about five-sixths of that of the bone ashes; so that the above quantities should yield above $8\frac{1}{2}$ pounds of the salt.

This salt is liable to be contaminated with Glauber's salt, or superabundant alkali, which are distinguishable in it by the taste. Pure soda phosphorata has a slight taste of marine salt. The bone ashes sometimes contain more, sometimes less acid, and the fossil alkali is often impure.

The surest way to succeed, is to be careful that the sulphuric acid be rather too little for decompounding the whole of the bone ashes, than that there should be too much of it. In the above process this is attended to.

When the acid is completely freed from phosphorus, and may therefore have the distinctive name, PHOSPHORIC ACID, it forms with the alkalis, salts, which crystallize with great difficulty. But, when it retains some phosphorescence and volatility, in which state we may call it PHOSPHOROUS ACID, these compounds crystallize very well.

With calcareous earth it forms a substance insoluble in water, resembling, in all respects, the earth of bones.

Origin and Preparation of Phosphorus.

THE first process, by which phosphorus was obtained in its pure state, appears to have been an accidental discovery in 1669, (*Leibnitz de Invent. Phosph. Miscell. Berol.* 1.) by Brandt, a merchant in Hamburg, who was employed in experiments on urine, in the hopes of making gold; and it remained in his hands, or in the hands of a few others, who acquired the knowledge of it, but concealed it from the public for a long time after. It was brought to England by a Dr. Kraft. At last, some hints relating to it were published in the Philosophical Transactions, No. 196, by Mr. Boyle, who had practised Kraft's process with some degree of success. Meantime, Kunkle, a chemist in Dresden, by dint of labour, discovered an effectual process, which he published, and claimed the invention. A full description of a better process appeared afterwards in the Memoirs of the Royal Academy of Sciences at Paris, for the year 1737, in consequence of the purchase of the secret from a chemist who was possessed of it. All this is detailed very distinctly by Mr. Macquer, in his Dictionary of Chemistry. The urine was evaporated to a dry extract or coaly matter. Then some of the salts were separated from this extract by water: and the remaining matter was distilled with a violent heat in earthen retorts.

Although some phosphorus may be produced by this process, it is far from being a good one. Some parts of it are actually very detrimental, or diminish the quantity of phosphorus which

might be obtained from the materials: and the process is exceedingly troublesome and hazardous. The best management of the process, and the manner in which the phosphorus is actually produced by it, were never understood until Mr. Margraaf applied himself to the study of it, and published his experiments in the Berlin Transactions. By them it appears that the production of phosphorus from urine depends upon a salt contained in the urine, and which had been observed in it before, but not sufficiently examined. Dr. Boerhaave takes notice of it, and calls it the essential salt of urine. Mr. Margraaf collected a quantity of this salt, and examined it. He found it ammoniacal, or containing a volatile alkali in its composition. It is a mixed neutral, composed of a peculiar acid, combined partly with each of the fixed alkalis, and partly with ammonia. With charcoal dust this salt gave a larger yield of phosphorus than ever had been obtained from any other materials. And the remains of the urine from which this salt had been extracted, gave hardly any sensible quantity of phosphorus. Mr. Margraaf also shewed, by a train of experiments, that the phosphorus is changed by inflammation into an acid, now named the phosphoric acid; which acid can again be changed into phosphorus. This cleared up the whole matter, and gave reason to be assured, that the salt just now mentioned contains this very acid.

In consequence of these discoveries, Mr. Margraaf contrived some improvements of the process for preparing phosphorus from urine; by which improvements the operation was facilitated, and the quantity of phosphorus much increased.

This process of Margraaf's continued to be the best, until Mr. Scheele of Sweden, in company with Mr. Gahn, another eminent chemist, taught us one still better. The two gentlemen just mentioned have saved us the trouble of evaporating urine, by discovering that the acid of phosphorus is contained in the bones of animals; and when combined with the calcareous earth, forms their basis, or their most solid and fixed matter,—that is, the white earthy-like matter which remains of them after all their inflammable matter is consumed; in short, what is usually called *the earth of bones*. The process these

gentlemen propose for extracting the acid from this matter, was a little complicated. A more simple one has been discovered since that time. We need only to mix with the bone ashes some sulphuric acid and water, &c.—*(Vide first part of the process for sodo phosphorata, in the Pharmacopœia Edinensis).*

But the phosphoric acid may be extracted by other processes, as 1*mo*, By applying the mild volatile alkali, or carbonat of ammonia, to the bone ash reduced to fine powder. (N. B. The double exchange will probably happen best in a cold place).

2*do*, By applying sulphat of ammonia, dissolved in water, to the bone ashes.

Since these discoveries have been made, the production of this inflammable substance is a much easier operation than it was formerly. Mr. Pelletier, at Paris, has sometimes made 60 ounces of it at once; and in one year he made upwards of 300 pounds of it. (*Journ. de Phys.* 1785. Jul.). The only nicety is in the choice of the vessels, and management of the condensation, which must be so contrived as to allow a very great quantity of gases produced during the operation to escape. These gases seem to arise from the water of the acid, and its action on the charcoal and the phosphorus nearly formed. It acts on these substances in the form of vapour, therefore in the most extensive surface possible, and furnished with great store of heat. With the charcoal it forms inflammable air of the heavy kind, as we shall learn afterwards: and with the phosphorus it forms a gas which takes fire when it comes in contact with the external air. This immediately kindles the inflammable air, which issues along with it: and the whole produces a bright flame. The gases are not formed in an equable manner, but by sudden paroxysms, or explosions, which frequently burst the vessels. Mr. Hellot found it necessary to have a hole in the receiver, lightly stopped with a wooden peg, which was blown out when the vapours became too elastic. Other chemists had a tube, which communicated with the receiver, and had its mouth immersed. A small quantity of generated phosphorus was saved in this way.

Having thus learned how phosphorus may be obtained pure, we are curious to learn how its acid comes into the composition of animal bodies; for phosphorus must surely be added to the list of simples which the French chemists allot to the formation of animal and vegetable substances. There is reason to think that it is introduced into them from the vegetable substances by which animals are ultimately nourished. Margraaf obtained phosphorus from the charcoal of wheat, rye, and other nutritive vegetable substances. Whence these receive it, is a question not so easily answered. It may be produced in them by the powers of vegetation. For we know that there is in vegetables a power to combine their elements together in different ways, so as to generate productions which would not otherwise be formed. Oil, sugar, &c. are manifestly formed in the vessels, or organs of plants, of materials which before were of a quite different nature*.

But a quantity of this acid has also been found in some fossil substances; for example, in the green ore of lead. There is also a bed of stone in Spain, in the province of Estramadura, and district of Truxillo, near Lagrosana, which contains this acid united to calcareous earth, as copiously as the earth of bones does. This was discovered by Mr. Bowle, and communicated to the French Academy by Mr. Proust. It forms very extensive strata, resting on quartz; is of a white colour, and fibrous texture, not so hard as to strike fire with steel, but hard enough for building. It is so employed for houses and inclosures. Thrown into the fire, it burns faintly, with a pretty, green light, which it keeps for some time after being taken out

* We must, as yet, suppose that the phosphorus exists in the soil, and is taken up by the vegetative functions of the plant; for we have no authority to say that it is a substance composed of more simple ingredients. But further, as those plants now mentioned will grow and thrive in pounded glass moistened with distilled water, enjoying at the same time the benefit of air and light, we must, if they yield this salt when so raised, look for phosphorus in these sources. This leads to very nice speculations. I found it, in very great quantity, in a piece of fine coral rock from Port Royal, in Jamaica; and am inclined to think that all corallines contain it; and that, by a proper treatment, they may be rendered true phosphori, like the Bononian stone, without the sulphur employed in that preparation.—EDITOR.

of the fire. A fossil of the same kind was discovered by Werner at Lunenberg in Saxony, and at Slackenwald in Bohemia, crystallized in hexahedral prisms, and in plates, generally mixed with fluor, spar, lithomarga, and steatites, but rarely with quartz. The pure specimens are called APATIT by the German fossilists; and they say that it contains $\frac{9}{20}$ths of phosphoric acid.

I think that a stone, forming thin white strata, near the Giant's Causeway in Ireland, is of this nature: and perhaps the *lapis suillus*, and other fœtid marbles are so*.

III.—SULPHUR.

THIS is the next inflammable body in the order in which I proposed to consider them. Its common appearance is toofamiliar to need any description. When held in the warm hand, we feel it crackle, and even hear it. This is a real splitting: and the same thing is observed in the large crystals of saltpetre, and some other salts. It smells when rubbed, and becomes highly electric.

Several of its properties have already been occasionally noticed. It has long been an object of great attention by the chemists; and has acted the chief part in all their explanations of phenomena. It was considered as the first principle of metallization, and of every species of combustion. It has now sunk to the condition of a simple ordinary chemical substance, of vast extent indeed, existing in an endless variety of bodies, but deprived of all its former pre-eminence.

Sulphur melts and evaporates without change, in very mode-

* It may be advisable to observe with some care the vegetation of the Spanish district now mentioned. If this stratum of phosphat crops out on the surface, it is not improbable that its rubbish will affect the vegetation. Experiments should be tried with plants raised on powder of this stone, especially of such plants as are superficial. It is most probable that plants so raised will take up some phosphoric acid, or phosphorus. If they do not, the origin of it in plants and animals is not a little mysterious: and speculations on this subject seem to open a door to much research, which may greatly affect our current theories.—EDITOR.

rate heats; but with some peculiarities that are worth mentioning. When heated to 170° of Fahrenheit's thermometer, it begins to evaporate: and we feel a very disagreeable suffocating smell. This, long continued in open air, produces a considerable change in it, which we shall not consider at present. In close vessels, there is no such change: but at 185° or 190° it begins to melt; and before 220° it is fluid. If the heat be quickly increased, it loses its fluidity, and becomes firm, and of a deeper colour. It regains its fluidity, if we reduce the temperature: and this may be repeated at pleasure in close vessels, if the changes of heat be not too slow: otherwise it begins to evaporate so copiously, that we cannot apply heat in sufficient plenty suddenly to raise its temperature. These peculiarities were first observed by the eminent naturalist, Fontana.

If, after being quite melted, we let it cool, it congeals in a crystalline form, but so confusedly, that we cannot easily define the shape of the crystals, further than that they are slender interlaced fibres. If a great mass be kept fluid below, while it fixes at the surface, the crystallization there is much more distinct. If melted sulphur be poured into water, the congealed mass has a considerable pliancy: but this does not last.

When heated in open air above 300°, it takes fire, and burns with a very weak blue flame. By this inflammation it is totally changed; and from being a solid, mild, tasteless substance, now becomes a fluid immensely corrosive, and in the highest degree acid, being now what you are well acquainted with by the name of *vitriolic* or *sulphuric acid*.

When this acid is treated in a red heat, and in contact with an inflammable body, it is changed into sulphur: and any inflammable body, whatever will answer, if it can be made to bear the heat. Even inflammable air will do.

Hence it was inferred by Dr. Stahl, that there was a principle common to all inflammables, and the cause of their inflammability,—the PHLOGISTON. Hence it was inferred that sulphur consisted of the peculiar acid now spoken of, and phlogiston; and that this phlogiston was expelled during inflammation, but restored to the acid by any inflammable body, in consequence of a greater attraction for the acid.

But no person ever saw this phlogiston in a separate state, or could prove that there was such a thing in sulphur. Mr. Lavoisier first obliged the chemists to attend to a thing which they had either overlooked, or accounted for in an unwarrantable manner,—namely, that the weight of the acid is vastly greater than that of the brimstone from which it is produced. From eight grains of sulphur we can produce twenty-six of vitriolic acid: part of this indeed is water, collected from the atmosphere, but by no means the whole. Moreover, he found that in burning, the sulphur absorbed and attached to itself a great quantity of the pure part of the air. And at last, he found, by careful measurement, that it absorbed a quantity exactly equal to the augmentation of its weight by inflammation: and he gave good reasons,—reasons which have at last been acquiesced in, that this air is the cause of the acidity of vitriolic acid,—he therefore called it *oxygen*.

Sulphur, therefore, is now considered as a simple substance: and sulphuric acid is a compound of sulphur and oxygen: and in this light I shall continue to consider it.

At the temperature of 140°, or 150°, sulphur begins to attract oxygen sensibly: and if the heat be increased to 180°, or 190°, the combination becomes pretty rapid, accompanied by a faint light: and if this be long continued, the sulphur will be converted into acid, in the form of suffocating steams. But the heat is insensible; at least, it is so weak, that the inflammability of the sulphur in gunpowder will be completely destroyed without setting fire to the charcoal, and the powder is now quite useless. This is similar to what happens in phosphorus and many other inflammable substances. It is an imperfect, or rather a slow inflammation, which shall be noticed more particularly in the sequel.

When sulphur is evaporated in close vessels, it sublimes into a fine dust or powder, called *flowers of sulphur*. They are fine crystals, generally a little acid, by reason of the air which filled the vessels. This acidity may be removed by washing the flowers in water.

I come now to consider the properties of sulphur discoverable by mixing it with other bodies.

Sulphur unites readily with the fixed alkalis, as you have already seen, especially when they are caustic: and this combination is effected both in the dry and the humid way. It combines also with all the alkaline earths, and the compounds are called SULPHURETS. It can also be combined with volatile alkali. It then forms a volatile hepar, called also *volatile tincture of sulphur*. This combination of sulphur with volatile alkali is produced by mixing together two parts of the muriat of ammonia, two parts of lime, and one part of sulphur, and distilling the mixture briskly. The sulphuret does not begin to form till towards the end of the operation; the lime immediately detaching the ammonia in its pure state. This volatile hepar is mixed, but not compounded with the pure volatile alkali. It may be separated, and will even crystallize.

The propensity which sulphur has, when thus combined with alkaline substances, and dissolved in water, to absorb oxygen more quickly and easily than when it is pure, was formerly noticed. In its pure or separate state, or even when combined with alkaline substances, *viâ siccâ*, it does not attract oxygen, except when it is heated to such a degree as to make it melt and begin to evaporate. Then indeed its union with oxygen begins to take place, or it enters into a state of imperfect inflammation. But, when united with alkaline salts or earths, and at the same time dissolved in water, it gradually attracts oxygen from the air to which it is exposed; and is thus changed into sulphuric acid, without needing the assistance of heat. You doubtless recollect examples of this when I was considering the different kinds of gas, and the experiments by which Scheele and Lavoisier demonstrated the composition of atmospheric air.

There cannot be a doubt but that this increase of its disposition to attract oxygen proceeds from the change induced upon its cohesive attraction by the alkali.

Many of the foreign chemists explain this in another way. Sulphur, say they, attracts oxygenous gas so weakly in low heats, that it cannot take it from the air in that form. But being mixed with alkali, this prevents the first approach to saturation of the sulphur with oxygen, by its attraction for the nascent sulphuric acid, with which it instantly unites and forms a sulphat.

This is carried off by the water, and leaves the rest of the sulphur equally ready for combination.

The attraction of sulphur for alkaline substances is not very strong. It may be separated by any acid, even the carbonic; and in the moment of this separation, the mixture emits a gas or elastic fluid. If the acid be poured on a dry hepar sulphuris in powder, the copious escape of this hepatic gas occasions a brisk effervescence, although the hepar has been prepared with a caustic alkali.

This hepatic gas has very singular properties.

1*mo*, It has an intolerably offensive smell, which is commonly said to resemble the smell of rotten eggs. Indeed, the vapour coming from an egg when boiled, whether fresh or rotten, contains this gas, and blackens silver, &c. like it. If a bit of hepar sulphuris, a boiled egg, or a piece of newly manufactured horn, be shut up in a cupboard, all the silver in it will be stained almost black in a few days. A few hours will stain it brown.

2*do*, It can be condensed into a sort of oily-like matter by intense cold, as appears from experiments of Mr. Monge, narrated by Fourcroy in his *Preliminary Discourse*, *page* xxxi.—*Kerr's edition*, 1788.

3*tio*, In its elastic or vaporous state, it is highly inflammable; and burns something like hydrogen gas, but not so rapidly: and while it burns, a small quantity of sulphur is separated from it. The sulphur also undergoes a slight degree of inflammation, and is in part changed into sulphurous acid. This gas is much heavier than the hydrogenous. It unites with alkalis, in the same manner as the hepar from which it was produced; and is separated without decomposition by an acid, provided that acid do not too readily part with some oxygen.

The nature of it was not understood, until the late improvements were made in our science by the study of gases or elastic fluids. It is now considered as an hydrogen gas, holding a small quantity of sulphur combined with it. (*See Note* 44, *at the end of the Volume*).

The inferior degree of rarity, or of elasticity and volatility, which it has, when compared with pure hydrogen gas, proceeds

from the sulphur which it contains. The sulphur, by its attraction for the hydrogen gas, diminishes its volatility; and therefore renders it a denser or heavier fluid, and disposes it also to be condensed by a great degree of cold: and, probably from the same cause, it derives an aptitude to be condensed or absorbed by water, to which it communicates its own detestable odour. Hence the smell of sulphurous mineral waters, and the deposition of sulphur observed at many such springs.

If such water, however, be exposed to the air, or put into bottles, without using every possible precaution to prevent the escape of the elastic matter, a part of the gas evaporates, or is lost. And it leaves behind in the water a part of the sulphur which was united with it. This renders the water milky, and is deposited by it. Hence the sulphur deposited by some famous mineral springs. This happens in consequence of the great volatility of the hydrogen gas, which makes it evaporate, carrying away with it a part only of the less volatile sulphur*.

Such water is also made to deposit the sulphur immediately, by adding to it a small quantity of very strong nitrous acid. And the sulphurous acid produces the same effect. But neither the sulphuric acid, nor the muriatic in its ordinary state, have any power to precipitate the sulphur: and even the nitric has but little of this power.

It is supposed that the strong nitrous acid and the sulphurous acid act by a loose and separable oxygen, which unites with the hydrogen, and changes it into water. The sulphur, when alone, not being soluble in water, must therefore make its appearance in an undissolved state. But I cannot understand why the sulphuric and the nitric do not produce the same effect. *(See Note 45. at the end of the Volume.)*

Several of these experiments were first made by Professor Bergmann, and also by Scheele. Bergmann was the first who explained by them the nature of many of the mineral waters, called *sulphurous waters*.

* Is it not more probable that this decomposition of the gas, and precipitation of the sulphur, is effected by the oxygen in the air? This was Scheele's eudiometer; and is perhaps superior to any other.—EDITOR.

They have the odour, and the other properties, more or less, of an artificial compound of water with this gas. This will be exhibited again hereafter, when we describe the mineral waters.

The authors who have thrown the most light on the formation of this gas, are a little society of chemical philosophers in Holland, Messrs. Von Deiman, Troostwyck, and others, who have published a volume or two of their experiments on different subjects. Their doctrine on this subject may also be seen in the 14th volume of the *Annales de Chymie*, page 294.

According to these gentlemen, a small portion of the dissolved sulphur acts on a small portion of the water, so as to take its oxygen from it. The separated hydrogen of that small portion of the water does not immediately assume the form of a gas; but is joined to the remaining unchanged sulphuret, attaching itself to it by an attraction for both the sulphur and the fixed alkali. But when we add an acid to saturate the alkali, the separated hydrogen has nothing left with it but the sulphur, the attraction of which is not sufficient for entirely repressing its volatility. It therefore assumes the form of gas, aided in this by the heat produced or extricated by the action of the acid and alkali on one another. And while it assumes the form of gas, it volatilizes a part of the sulphur, which is combined with the gas thus produced*.

This hydrogenous sulphuret has already come before us, while we were considering sulphur in its connection with the alkaline substances.

We come next in order to consider its relation to the acids. Its relation to the sulphuric acid is already known.

We may foresee what will be the effect of mixing sulphur with the nitric acid. It must be very similar to that of a mix-

* This explanation seems both gratuitous and embarrassed. We assume, without warrant, that water is decomposed, and is afterwards recompounded. In the *Ann. de Chymie*, *vol.* 14. *p.* 311. the hepar sulphuris is supposed to decompound the water, not of itself, but by help of an acid, whose caloric forms a hepatic gas with the hydrogen and part of the sulphur. But here the decomposition of the oxygen becomes still more mysterious: and we cannot see why the hydrogen, which at first detached the caloric from an acid, should afterwards let it go, and again unite with the acid, and compose water.—EDITOR.

ture of phosphorus with it. Accordingly, if we pour on a quantity of sulphur twenty times its weight of nitric acid, and distil it, we shall obtain sulphuric acid double the weight of the sulphur. This arises from the very loose and separable state of the oxygen in nitric acid. For the same reason, this change may be produced by the oxygenated marine acid.

You all know that melted nitre forms the sulphuric acid with rapidity and vehemence, by deflagrating it with sulphur: for we have in the crucible a sal polychrest, or sulphat of potash.

Phosphorus can be combined with sulphur in the way of fusion and sublimation, in a retort and receiver. Margraaf formed a compound of this kind, in which the attraction of both these inflammable substances for oxygen appears to have been more powerful than when in their separate state. The compound took fire, and burned with violence, whenever it was exposed to the air*. The chemical combination of these highly inflammable substances produced this effect probably by a diminution of their cohesive attraction.

Natural History of Sulphur.

SULPHUR is to be found in all the kingdoms, as they are called, of nature. It is formed by the decomposition both of animals and vegetables. The fœtor of animal excrements is found to arise from hepatic gas. A considerable quantity of sulphur was collected in cleaning an old common sewer at Paris. (*See Chaptal, tom.* i. *p.* 91.) The same gas is found in all putrid collections of decaying vegetables. The pit in which flax is steeped, year after year, impregnates the clay around it to such

* I rather think that Margraaf's account of it indicates less inflammability. It inflamed with some difficulty, he says, by friction, giving a yellow light. A dry heat, equal to that of boiling water, caused it to burn with violence, giving a strong smell of hepar sulphuris. It swelled in water, imbibing much of it, and rendered the water acid and sulphurous. The water, into which it dropped in the distillation, effervesced violently with alkalis.

This is a very curious and somewhat puzzling experiment. Whence did the acid come, and what was it? Did the compound decompose the water, and become oxydated?—EDITOR.

a degree, that it burns with a blue suffocating smoke. Nay, sulphur is found in the juices of some plants, particularly the *rumices* or *docks*.

But it is most abundant in the mineral kingdom. And there it is generally in a state of combination, chiefly with metals. The ores of most metals contain it. But the ore or mineral substance, most remarkable for the quantity of sulphur which it contains, is the PYRITES, in which the sulphur is combined with iron or copper,—chiefly, however, and oftenest, with iron. This compound is of metallic opacity and lustre, and a pale brassy colour. It is found in entire veins, or sometimes in separate masses. It generally is so found among coal. Relics of animal and vegetable substances are frequently found completely penetrated with it, and, as it were, changed into pyrites. In the island of Sheppey, and other parts of Kent, such specimens are very abundant; particularly vast quantities of the *cornu ammonis*, some of them of enormous size. What is curious, the shell only is penetrated with pyrites: and its hollows are filled with sand-stone or other common matters. Pyrites is also found very frequently crystallized. The cubical brass-like crystals in common slate are the purest specimens of iron pyrites that I know. But there is a vast variety of other forms, many of them very beautiful, adhering to almost all ores and spars in metallic countries. These crystals are commonly the most showy parts of a fossilist's cabinet.

It is only from the richest pyrites that sulphur is now extracted. Such as give less than one-fifth of their weight, are not worth the labour and expence; but are long roasted in open heaps, to drive away the sulphur, and reduce the pyrites into a state fit for smelting for its metal. In some of these heaps, cavities are left in proper places, into which the sulphur, which evaporates or melts from the rest of the heap, is directed, and there collected.

Very rich pyrites are treated for their sulphur by a rude kind of distillation. The retorts are nothing but conical earthen pipes, about four feet long, ten inches wide at one end, and two at the other, and open at both ends. The furnace is an oblong space between two walls three feet asunder, having several holes

in the roof for the smoke, and also a row of holes in the floor, to admit air to maintain the fire. The conical pipes lie across this gallery, the wall on one side having holes ten inches wide, and the opposite wall having as many two inches wide. Thus the pipe fits both holes, and is made tight with lute. It lies with a small descent towards the narrow end, which projects three or four inches; and a rude receiver is there joined to it. The lumps of pyrites are put in at the wide end: and when the pipe is full, that end is shut up by a round tile luted into it. The narrow end of the pipe is also plugged with a bit of tile shaped like a star. This allows the melted or vaporized sulphur to get out, but keeps in the lumps of pyrites. The space round the pipes being filled with fuel, the fire is kindled, and kept at a moderate heat, by opening or shutting the holes in the roof. The sulphur melts and evaporates, and runs into the vessels under the small end of the pipes: and when no more runs, the tile is taken out of the wide end, and the effete pyrites are raked out, and fresh put in immediately; so that the work is not interrupted. The pyrites taken out still retain sulphur. This is driven away by roasting them in a heap: and then the remainder is smelted for its metal.

But the greatest part of the sulphur used in Europe is obtained much more easily. It is found in vast abundance, ready formed, in the volcanic countries, particularly at Solfatara in Italy. It is undoubtedly produced in those countries in the same way that we produce it by art. The subterranean fires are occasioned chiefly by the decomposition of the matrices of sulphur; and they act on them in the same way as the fires in our laboratories, causing the sulphur to fly off in vapours through every fissure and cavity. It sublimes into those cavities, and collects in vast quantities, so as even to break down by its own weight. The vapours even penetrate upwards to the very surface, impregnating even the soil, so that the very earth taken up with the spade will yield sulphur. In the cavities, and adhering to the stones and rubbish, it is often found pure and crystallized,—sometimes transparent. This is called *sulphur vivum*. But it is generally foul, like what is obtained from the pyrites.

Crude sulphur is contaminated by earthy matters diffused in it, and also by metals which are in some measure united to it. It is purified by melting, and keeping for some time fluid; by which means the impurities subside, and the pure sulphur is raked off, and poured into moulds, which form it into the little rolls in which we commonly see it.

It is also purified more completely by sublimation. For this purpose, a furnace, holding a pot, in which the sulphur is melted, is built at one end of a room, which is shut on all sides, and has the walls, ceiling, and floor, covered with lead or a proper cement. The sulphur rises from the pot in steams, which are condensed on the walls, ceiling, and floor, in the form of fine dust, called FLOWERS OF BRIMSTONE. These are sometimes a little acid, owing to the air which originally filled the room, the oxygen of which decomposes some of the sulphur. They must be cleared from it by washing before the sulphur can be used for all purposes of medicine.

The medicinal preparations of sulphur are not many. It is combined with quicklime, in the moist way, forming a calcareous hepar, which we have paid sufficient attention to already. But this is only a previous step for the preparation of LAC SULPHURIS, by precipitating the sulphur with any acid. The muriatic is the one prescribed in the London Pharmacopœia for this purpose.

Sulphur is also combined with some oils, to compose BALSAMS OF SULPHUR,—nauseous medicines, having a most offensive fœtor, occasioned by the emanation of an inflammable gas.

The chief preparation from sulphur, and it is a very important one, is its acid. This can be obtained only by inflammation; for we need not speak of the process of distilling a great quantity of nitric acid from sulphur. This, indeed, gives the acid, but in a way vastly too expensive. In the ordinary way of burning sulphur, the acid is obtained in a volatile suffocating form. It is an acid vapour, holding, but very slightly, a considerable portion of sulphur in solution, and a great quantity of water, collected from the atmosphere. It is what we named *sulphurous acid*. That this is its nature and composition, is

proved by distilling vitriolic acid, into which a bit of sulphur, or almost any inflammable substance, has been put. If we expose some of this volatile acid to vital air, under a glass, it will absorb it in a minute, gain weight, and lose entirely its volatility and suffocating fumes, becoming *sulphuric acid.* This is not altogether by saturating the redundant sulphur, for some of it is precipitated.

Sulphurous acid is scarcely acid to the taste; also its chemical relations, as an acid, are exceedingly weak, so that almost any acid will detach it from an alkali. It has distinguishing properties; particulary that of quickly discharging vegetable colours. The suffocating vapour of burning brimstone will make a red rose white in a few minutes. It is employed for whitening woollen, and silk, and linen goods. This volatile acid could not be obtained in a tangible form, were it not for the moisture diffused through the air; and it is this alone which makes it liquid in the old process. This process was to burn sulphur with a small flame, under a large glass bell, kept cool by a wet cloth. The acid formed on its inside; and thence it dropped into a funnel. This produced the *spiritus sulphuris per campanam*, now called sulphurous acid, to denote its redundancy in sulphur.

To obtain sulphuric acid free from these suffocating fumes, we need only expose the sulphurous acid to the air. The redundant sulphur partly attaches to itself more oxygen, and partly is lost, perhaps by precipitation in the air.

The manufacture of sulphuric acid, in the state in which it is required in chemistry and the arts, is a very difficult process; and a very lucrative manufacture to those who are possessed of the secret. It is, as yet, in very few hands. This much is known of it, that the sulphur is kept burning in a pot, set on a small furnace, built at one end of a chamber which is closed on all sides, and lined and floored with lead. Water is kept on the floor, to aid the condensation of the acid vapours. Nitre is employed, mixed with the sulphur, before inflammation. This maintains the combustion, which otherwise would soon cease, because the sulphur quickly absorbs the oxygen of the air that fills the chamber in which it is burned, and its vapours

condensed. The remaining azote, and the acid vapours already produced, soon put an end to the inflammation. The nitre maintains it by supplying oxygen. But nitre is a very costly article: and no more can be afforded than what just keeps up the inflammation. Even with this help, a great many nice contrivances are practised in the great manufactures of Great Britain, (which country alone, as yet, possesses the secret) to keep up the inflammation: and, after all, the acid is loaded with much redundant sulphur, and is very weak, because much water was employed for condensing the vapours. It must therefore be concentrated. This would be a simple operation with sulphuric acid, which is much more fixed than water. We needed only to evaporate the superfluous water. But here it is difficult, partly because the volatile steams contain sulphur, which would be lost, and partly because, in a very diluted acid, the water will carry off much acid. It is concentrated by a distillation in great retorts, several times repeated, in a way which would be tedious to describe, but which a little reflection on the properties of the substances will suggest to you. Attempts have been made to supply oxygen in this part of the process by means of manganese, a mineral of low price, which contains much of it very loosely combined. The acid must be dephlegmated till it acquire a specific gravity almost twice as great as that of water. It must be at least 1,6 or 1,7 before it is fit for dissolving indigo for the dyers.

When fully saturated with oxygen, it seems to contain seven-tenths of sulphur, and three-tenths of oxygen.

NOTES AND OBSERVATIONS.

BY THE EDITOR.

[*Note* 26. *p.* 8.]

THERE are among Dr. Black's papers several sketches of an arrangement of the chemical substances, with a view to make the consideration of them more synthetical and systematic. One of them, in which he has made many changes and corrections, begins with water, and goes on in this manner:

" Water....Margraaf's experiments....silex, foreign to it....
" Dr. Austin, with iron filings....inflammable air....ignifying
" air....Cavendish....water....nitrous acid....nitrous air, or choke-
" damp....acids."

I think that I perceive the connections by which this may be made a skeleton of chemical philosophy. There is another paper, in which the properties of nitric acid are gradually developed and applied, so as to terminate in the establishment of the anti-phlogistic system, in a very familiar and easy manner.

I recollect a conversation which I had with Dr. Black, and Dr. James Hutton, soon after the appearance of Mr. Lavoisier's sketch of a scientific arrangement of chemical objects. I was telling him how highly I was pleased with that arrangement, on account of the happy train of synthetic deduction which it enabled Mr. Lavoisier to carry through the whole of the chemical history of bodies.....

" This," said Dr. Black, " is the very thing I dislike it for. " Chemistry is not yet a science. We are very far from the " knowledge of first principles. We should avoid every thing

" that has the pretensions of a full system. The whole of chemical " science should, as yet, be analytical, like Newton's Optics: " and we should obtain the connecting principle, in the form " of a general law, at the very end of our induction, as the " reward of our labour. You blamed, and, in my opinion, justly, " De La Grange's *Mechanique Analytique*, for being the very " opposite to a real analytical process;....for adopting as the " fundamental proposition, as a first principle, a theorem which " in fact is nothing more than a sagacious observation of an " universal fact, discoverable indeed in every mechanical phe- " nomenon; but still not a principle, but the mathematical and " not the physical result of all our inductions. This is not a " fundamental theorem, fit for instructing a novice in the science, " but for adepts alone. The case is the same in chemistry.

" But this is not the greatest fault in the arrangement which " sets out from the constitution of the atmosphere. In order " to get the proofs on which the validity of this first principle " must entirely rest, we must fall to work with a number of " complex, very complex substances, of which we know nothing, " and whose modes of action are among the most mysterious " things in chemistry: and the conclusions which we must " draw, require a steadiness and contention of thought which " very few possess,....which a beginner in philosophical investi- " gation cannot possibly possess. It is by no means fair to " appeal to a Lavoisier, a Cavendish, or a Berthollet, or other " great chemist, for the clearness of the evidence. They are " not the proper judges. Lay it before a sensible metallurgist, " ignorant of chemistry. Ask this man whether he sees the " incontrovertible force of the proof. When I take the matter " in this light, I affirm that, even to a philosopher, the proofs " of the fundamental propositions which have been acquiesced " in by the authors of this arrangement, are very scanty, very " slight, and very refined. This is a fault in a system published " for the instruction of the ignorant; and, in the present day, " it is a very great fault. There is just now a rage for system,* " ....for complete systems. We have got such a high conceit of

* Much of what follows is taken from an introductory lecture with which Dr. Black was accustomed to begin his course.

" our knowledge, that we cannot be pleased with a system which " acknowledges any imperfection : it must not leave one open " link : it must not leave any thing unexplained. And I see it " always happens that if the application of a system to the " explanation of phenomena be very comprehensive, leaving " no blanks, and if the explanation have some feasibility, this " catches the fancy,....it dazzles the understanding. Nay, we " think it impossible that a principle that is false can tally with " so many phenomena. This seeming coincidence is considered " as a proof of its validity: and we are no longer solicitous " about the *direct* proofs adduced in the beginning. I have often " heard such arguments for what I knew to be great nonsense. " This kind of authority accruing to a theory from its specious " and extensive application to phenomena, is always bad: and, " with mere beginners in philosophy, it is doing them an irre- " parable hurt. It nourishes that itch for theory ; and it makes " them unsolicitous about the first foundations of it. Thus it " forms in their minds the worst of all philosophical habits.

" I am resolved to go on in a very different way. I subscribe " to almost all Mr. Lavoisier's doctrines : and I will teach them " all. And I affirm that I shall teach them with an impression " of their truth which his method can never make. My students " shall get all these doctrines piece-meal;....every one of them " by steps which shall be quite easy and confident, because they " shall be acquainted with every substance before I employ its " phenomena as proofs. Each of Mr. Lavoisier's doctrines " shall arise in course, as a small and obvious addition to the " properties of some substance already known. Then I shall " carry the student back, and shew him that the influence of our " new discovery extends also to those substances which we " had been considering before. Thus, all the doctrines will be " had easily, familiarly, and with confidence in their truth.

" I even think that this method will be more pleasant,....the " novelties, or reformations, being, by this method, distributed " over the whole course. And it will have yet another advan- " tage. It will make the student acquainted with the chemistry " of former years, which is far from being unworthy of the " attention of a philosopher. Newton, Stahl, Margraaf, Cramer, " Scheele, Bergmann, were geniuses not below the common

" level. But the person who learns chemistry by Lavoisier's " scheme may remain ignorant of all that was done by former " chemists, and unable to read their excellent writings.

" I do not find that my old arrangement needs much change; " some I will make,....chiefly in the order in which I treat the " inflammable substances and the metals."

Such was very nearly the manner in which my excellent preceptor expressed his sentiments and intentions on the occasion that I mentioned above, and at several other times. I cannot but think that he had much reason for what he said. The proofs which were acquiesced in at that time were very scanty indeed, and very refined, unless they were deduced from known properties of substances, which can be familiar only to an adept in chemistry. And the dashing boldness with which the chemists applied them to the most complicated phenomena, and the authority with which our acquiescence was demanded, were disgusting; particularly to a man of Dr. Black's scrupulous caution, which scarcely ever allowed him to hazard a conjecture. The public has great reason to regret that this sagacious philosopher, and faithful follower of Newton's steps, did not live to put the finishing hand to the arrangement of facts on which chemical science should be rested.

Dr. Black's feeble constitution, and low state of health for several years before his decease, put this out of his power. The close thinking which such a task required, not only fatigued him, but greatly deranged his health: and he was always obliged to give it over. He employed himself, however, from time to time, in making small changes in the arrangement of the articles of his course. In the last conversation I had with him on chemical subjects, he told me that he was about to make a general revision of his treatment of the metallic substances, in order to put into a more regular and connected form the way of considering each metal in different stages of oxydation. It does not appear that he had proceeded far in this revision.

I regret also that no distinct notes are to be found respecting the difficulties which Dr. Black found in the antiphlogistic system of chemistry. He remarked, in some of his annual courses of lectures, that Mr. Lavoisier's system did not explain the light which is so characteristic of combustion; and said

that some very judicious observations on this subject were to be found in Lubbock's inaugural dissertation, *de Principio Sorbili*, which also professes to give a theory of combustion and acidification.

[*Note* 27. *p.* 13.]

There are innumerable facts which shew that common air is contained in fluids, chemically, but slightly combined. When water is gradually heated in a glass vessel, or is put under an air-pump receiver, and the pressure of the atmosphere on its surface is removed, innumerable bubbles are formed all over it, and rise to the top. If, on the other hand, the water be put into a condensing apparatus, and be agitated for a long while with air violently compressed, we shall observe, that as soon as we open the cock, and let out the condensed air, air-bubbles will form in the water in the same manner, and rise up and escape. If the water, and the air which come out in the first experiment, occupy the whole phial, the air being now collected in one mass at the top, the water will reabsorb it all after some time.

This evident mixture of air and water is perfectly transparent: and it appears by Mr. Canton's experiments, that it is no more compressible than water purged of all air. The air, therefore, is not in its elastic state. It is chemically combined.

In those experiments, the air bubbles form most copiously on the sides of the vessel, or on any body immersed in the water. Part of this probably was adhering to those solids. This, however, is not certain from this appearance alone, because the superior attraction of the water and the glass should detach the air dissolved in the water contiguous to the glass sooner than in any other place. But it is in part owing to air adhering to the glass: For when we drive out the air from the mercury in the upper end of a barometer by boiling, and then bring the same mercury in contact with a part of the tube farther down, we shall obtain more air from it. This must have adhered to the tube. I have also found that I could obtain a much greater quantity of air by boiling, or the air-pump, from water into which I had thrown a quantity of powdered glass. It is very probable, therefore, that a very considerable portion of the air which escapes from a solution of salt in water, proceeds from the salt, and had

[*Note* 28. *p.* 15.]

The general appearance of a clouded atmosphere is extremely agreeable to this theory. It generally consists of extensive strata of clouds, of no great thickness, separated by strata of clear air, of much greater thickness. The under surfaces of the clouds are pretty even. This is precisely what should happen. One great stratum of air, coming from one quarter of the heavens, glides over another, coming perhaps from another quarter. These, having a relative motion, rub as it were on each other, and mix a little way into each other, producing a precipitation, that is, a fleecy cloud. But the interior parts of the strata of air which do not mix, remain clear. This constitution agrees also finely with the electrical phenomena of the atmosphere, giving an extensive conducting coating to the strata of air which are in opposite states of electricity. A thunder clap is soon succeeded by another, in the same place, because it only restores the electric equilibrium in a certain, perhaps small, thickness in the clear strata of air: and the opposite electricities still remaining in the rest of the stratum, soon enable the coatings to give another discharge. It is like the residuum shock from glass that is coated only in spots. When an irregular wind tosses the strata, and jumbles them together, then we see great roundish clouds of a vast thickness vertically. These clouds are probably clear within, and only superficially opaque, viz. in the touching boundaries of the masses of air so jumbled, &c.

[*Note* 29. *p.* 27.]

It is not very clear in what case we have a proof of a greater, and in what of a lesser attraction in the crystallization of a salt. It is true, the salt is let fall by the water; and one attraction, or principle of union, has prevailed over another. But, since a saline crystal is a compound of salt and water, the formation of a crystal is rather the evidence of a prevailing attraction between the salt and water. Why it takes place at a particular proportion of the ingredients, seems owing to the same cause as the regular forms which

the crystals assume. It was observed on a former occasion, that the form of solidity required the attracting forces to be different in different directions, and perhaps in the different parts of the particle; so that two particles of a crystal may tend to unite in one way rather than in another. Suppose a particle of a saline crystal to consist of one particle of salt, and one of water, and suppose that they unite because the particles of water attract those of salt more strongly than the particles of salt attract one another; the consequence of this must be, that two such particles, floating in the water, cannot unite indifferently. They will approach each other so that the saline ingredient of the one will apply itself, in preference, to the watery ingredient of the other. For similar reasons, even the two ingredients of a particle will unite in a particular manner. In short, their manner of coming together will resemble the manner in which magnets floating on quicksilver will come together. Polarity seems to be as good a term as any for expressing this affectation of a particular position or attitude. We have no authority for saying that the figure of a crystal must resemble that of the primitive atom, although it undoubtedly depends much on that figure; because that must greatly influence the inequality of the corpuscular attraction in different directions and different points of the particle. It is plain, and we see it in magnets, that this inequality must increase as we come nearer to the particle. This seems to be the effect of abstracting the water of the solution. When this is done to a certain degree, the polarity begins to operate; and then the attracting points of the particles bring them briskly together. It is not, therefore, a superior strength, but a certain modification of the corpuscular force which produces the crystallization.

[*Note* 30. *p.* 31.]

Mr. Lowitz, of the Imperial Academy of Sciences in Petersburgh, has made some considerable improvement in the crystallization of salts. He makes the solution very warm: and when it is almost ready to shoot into crystals, he puts into it a small crystal. The crystallization instantly begins, [illegible] producing beautiful crystals.

As the brine becomes weaker, it begins to act on the crystal put in, and dissolves it. He puts in another, which renews the crystallization,...and repeats this till all that will separate is crystallized. The crystallization is more beautiful the more slowly we allow the brine to cool. It should therefore be set in a tub of hot water. He obtained fine crystals in this way, even from the most deliquescent salts; and succeeded with some that never had been crystallized before.

Mr. Lowitz, in the practice of this method, made an observation that is extremely curious, and peculiarly serviceable in this method of separating salts of different kinds. Reflecting on Mr. Beaumé's having obtained pure crystals from a muddy solution, he thought it not improbable that a salt, in crystallizing, rejected any thing which did not correspond with its own manner of going together; and therefore that a crystal of saltpetre would not affect a solution of Glauber's salt. He found it so upon trial. He then concluded that in a mixture of different salts, a crystal of one of them would induce the crystallization only upon its own kind. He dissolved two ounces of saltpetre, and three ounces of Glauber's salt, in five ounces of water almost boiling hot. He divided the brine into three phials: and into one he put a crystal of nitre, into another a crystal of Glauber's salt. His expectations were completely answered. Nitre alone crystallized in the first; and Glauber salt in the second; and a mixture in the third. Taking out these crystals, he then put into the remaining solutions a bit of the salt which had not crystallized. This immediately induced the crystallization.

This observation is equally important to the artist and to the philosopher. It greatly aids the practical chemist in this troublesome process: and it is most instructive to the philosophical chemist. It is not explained by the simple notion of things of one kind going together, of nitre uniting with nitre, and borax with borax; for this is not the operation. It is that nitre induces water to unite in the way of crystallization only with nitre: and borax disposes it to unite only with borax. I think it one of the strongest confirmations of the operation of those peculiar modifications or compositions of corpuscular attraction, which I have called *polarity*.

[*Note* 31. *p.* 85.]

Dr. Robert Hooke had published his theory of combustion in his *Micrographia*, in 1664, (page 103), in which he expressly says that combustion is nothing but the solution of the combustible body in this nitrous spirit, which constituted the greatest part of our air. And in his *Lampas*, published in 1676, he again gives his theory at length; and observes that it had been very well received eleven years before by the learned at Oxford, and adopted by them in their writings, evidently alluding to Mayhow's work. It does not appear, however, that Hooke had evinced, by direct experiments, the presence of this air in nitre; but that he had inferred it from the fact that air was necessary for the burning of all inflammables; and that nitre enabled any inflammable to burn without air, and must therefore have supplied it in the very act of combustion. We must acknowledge the justness of his inference, and admit him as the real original author of this theory of combustion. Mayhow is not more explicit; and certainly had never made any chemical experiments with the air obtained from nitre, which he seems to call the *nitro-aëreal* spirit. Had he tried it as the supporter of flame, the phenomena are so remarkable, that they would have been minutely described. Even in his explanation of combustion by this spirit, he is extremely obscure: and it is impossible to decide whether his explanation is upon chemical principles, or by motion and mechanism. Dr. Hooke, on the contrary, is most simple and perspicuous in his theory, which is purely chemical. And when he explains the phenomena of flame, he does it with as much precision and philosophical propriety as can be conceived. Indeed, there is no where to be met with so accurate a description and explanation of the flame of oil or spirits, as is to be seen in Hooke's *Lampas*, page 5, &c. His numerous writings on many parts of natural philosophy give him many occasions of applying this theory; and it is therefore most strange that it should have been so entirely forgotten. As he promised to bring his theory into better form, and undoubtedly made many notes on the subject, I am persuaded that some of them will yet be found in that chest of papers

which was delivered by his friend Mr. Waller to the Royal Society.

[*Note* 32. *p.* 90.]

A groove eight lines wide, four deep, and 386 feet long, was filled with good powder. It employed thirty-three seconds in burning from one end to the other. It was filled again, and then covered with deal boards, simply laid on it. Ten feet of the covering weighed one pound. The train now burnt from end to end in seven and a half seconds; so much was it expedited by this slight pressure, which obliged the flame to blow through among the grains. It made no sensible noise. I was within a quarter of a mile of a magazine of 350 barrels of gunpowder, in a large tent. It caught fire and blew up. The explosion did not last above a second, and was prodigiously loud. The barrels were the only confinement in this case, yet sufficient for making the explosion almost instantaneous.

The composition just now described by Dr. Black does not fire till all is fluid,....therefore all in the same state,.... and therefore all fires at once. The first expansion of this composition appears to be immensely greater than that of gunpowder. Half an ounce fired on an ordinary parlour fire-shovel will generally beat the place where it lay into a hollow. Half an ounce of gunpowder fired on a card, or even a bit of stiff paper, will not tear it. Yet pulvis fulminans, when inclosed in the chamber of a musket, and exploded with a ball lying above it will impel it with very little force. This shews that the expansive force of the elastic matter produced in the explosion diminishes much more by an increase of bulk than in the case of gunpowder.

[*Note* 33. *p.* 122.]

In a bundle, marked "old notes, excerpts, &c." I find some experiments on this salt, which deserve some notice. Dr. Black seems to aim at the best process for preparing it for medical purposes by sublimation. He was aiming at the same thing with the salt called *acetous ammoniac*; and is

surprised that he can prepare the latter very easily, but that the nitrous ammoniac could not be condensed, although its ingredients are not nearly so volatile as those of the other.

In one experiment with a dry nitrous ammoniac, which he had prepared himself by mixing colourless nitrous acid with the purest volatile alkali, the vapours were incoercible *in part:* and what did condense was almost pure water, greatly exceeding in quantity what could be supposed necessary for the crystals of the salt. He was obliged to give a passage to the incondensible vapours. He tried whether they were inflammable, by presenting a bit of lighted paper to the hole in the luting. It did not take fire, but it made the paper burn with prodigious violence. He thought, from this circumstance, that it was the nitrous acid. But, putting alkaline air into the receiver, he did not find it condense more readily, nor produce a nitre. Putting lime-water into the receiver, he found no precipitation, when he used the pure salt prepared by himself: but employed some gotten in the shop of Mr. Hill, (which I mention, because it shews the date of the experiment to be previous to 1766) he had precipitate. He attributes this to impure alkali, containing inflammable matter. He says, that although the incoercible fumes filled the laboratory, the effect on his breathing and sensations was *very far from being unpleasant.* He suspects that the acid suffers some decomposition; and again wonders at the quantity of water obtained. With some particular view, he had mixed with the salt thrice its weight of finely pounded glass. In three succeeding trials, the mixture detonated, and burst the vessels, although the heat was not much above that of boiling water.

These experiments tally, in many particulars, with those in the judicious analysis of this salt by Mr. Davy of the Royal Institution. Dr Black has had some experience of the wonderful effects of the *gaseous oxyd of azote*, or *nitrous oxyd*, which have given so much amusement of late, and from which such mighty medical consequences are expected by some physicians. This subject will come before us some time hence.

[*Note* 34. *p.* 148.]

Dr. Black highly approved of a systematic nomenclature; and thought the French one extremely ingenious; and that its many barbarisms and philosophical incongruities should be overlooked, as something unavoidable, or that they should be corrected. Accordingly he occupied himself a good deal on this subject; but his notes are so imperfect, and, I may say, *undecided*, that I could not make any use of them. He disapproved, however, exceedingly of the entire substitution of this for all other denominations of chemical substances; and affirmed that proper names, where they can be had, should on all occasions be preferred. The employment of the scientific names only gives an appearance of knowledge without the reality of science. It is merely an abbreviation of language. There is the same necessity of learning that the muriat of soda is common sea salt as that sea salt is the muriat of soda. Without the last, indeed, you are not a chemist; but without the first, your chemistry is of no use. He was, therefore, for retaining all the old names that were, strictly speaking, proper names; such are, kali, muria, soda, natrum, nitrum. He thought air as good a name as gas, and combustion as chemical a phenomenon as oxygenation.

A determination to be the founder of a system and a sect of philosophers seems to have seduced Mr. Lavoisier, and made him acquiesce in measures which may be called violent and unbecoming. As for the *imitatores*, *servum pecus*, they hesitated at no incongruity with common language and sentiment; and rather had a pride in it, as a mark of their authority over the opinions of other men. What can be more absurd than to give the name oxygenation to the formation of tasteless water or charcoal, or of combustion to phenomena where neither heat nor light are observed? No knowledge whatever is acquired by the exclusive use of this nomenclature: and it has introduced into chemistry the same licentious dialectic that the Aristotelian metaphysics introduced into the schools of philosophy, and will produce the same bigotry and the same ignorance. It gives the appearance of research to mere technical language: and many pages of modern systems of chemistry "are but the naming of their tools."....HUDIBRAS.

Not only no acquisition is made of knowledge, but if the theory be erroneous in any circumstance, (and what philosopher will say that this is impossible ?) the error must inseparably adhere to every name, and every phrase, and every opinion.

But all this is only the licence of literary ambition and vanity. The same principles, and the very same men, formed this nomenclature and the new kalendar and metrical system of the French. But these inconveniences are not essential to a good systematic nomenclature. Had all the proper names been retained, and had a becoming deference been paid to ordinary language and sentiment, the nomenclature would have been much more intelligible,....would be free from paradox,....and Mr. Lavoisier's well deserved honours would have been fully secured to him. Newton still stands at the head of philosophers, although they still speak of the sun's path round the heavens, and retain the old astronomical language. But Newton had no such ambition ; nor did the Royal Society furnish such a *legion of honour* as Mr. Lavoisier found among his countrymen.

[*Note 35. p.* 188.]

I must mention here that it was discovered by Mr. Milner in 1787, that if this alkali be made to pass through a red hot tube, along with vital air, (oxygenous gas) we obtain nitrous acid. The experiment was this: He put a quantity of a substance called manganese (much employed in glazing the coarser black earthen wares) into a gun barrel, and making this red hot, he sent this alkaline gas through it. It is well known that the manganese yields only oxygen gas by this treatment. I am informed that the French, availing themselves of this discovery, procured saltpetre for their military operations, by passing common air (which contains oxygenous gas) through vapours which contain this alkaline gas. It appears, however, in this, and in many other instances of such mixtures of gases, that the combination cannot be effected, unless one or other of the gases be mixed in the very act of its formation. The gases themselves, in many instances, will not mix, even when red hot, when completely formed. This alkali also combines with sulphur, forming a gas of a most abominable smell.

[*Note* 36. *p.* 208.]

The word was first employed by Van Helmont, and particularly to express the vapour which escaped from liquors in the vinous fermentation. He ascribes to this gas the effects of the Grotto del Cane, in Italy, so named from the number of dogs killed in that cavern by breathing it. With a skill and justness that is surprising, he explains many changes which happen in animal substances by the extrication of gases. He says that those gases, into which many bodies are completely resolved, do not exist in them in an elastic, but in a liquid, or even a concrete and solid form. He gives them the general name gas; but distinguishes several kinds, such as gas silvestre, (an epithet borrowed from Paracelsus,) flammeum, ventosum, pingue, &c. By gas, then, we are to understand a perfectly invisible elastic fluid, that can be contained in a vessel, which expands by heat and contracts by cold, but is not condensed by cold into a liquid or solid, as the vapours of water or of camphor. It is proper to add the first character, to distinguish gases from fire, light, and the supposed elastic atmosphere of magnetic and electric bodies. Some chemists would except respirable air from the gases, and consider them as all distinct from air. But it is not improper to employ gas as the object of chemical examination, and to call them airs, when we examine them mechanically.

[*Note* 37. *p.* 250.]

It is indeed a very improper denomination, on the principle by which it is pretended that the French nomenclature is regulated. It neither follows the rule adopted for the simple substances, nor that for those of a second order. It is not distinctive. For almost every aëreal fluid, except the oxygenous gas, is azotic, *i. e.* extinguishes the life of the warm blooded animals. Moreover, knowing the wonderful augmentation which the respiration of the nitrous oxyd makes in the vivacity and energy of animals, it seems extremely incongruous to call its chief ingredient azote. Lavoisier intended another name for it. Some experiments of Berthollet had made him hope to

establish it as the alkaline principle, as vital air was assumed by him as the acid principle, and thus to embrace, in one proposition, the whole round of chemistry. But Mr. Cavendish's experiments put an end to this, seeing that it *must* be adopted as the *distinctive* ingredient of the nitrous acid. Yet he would not call it nitrogen, because it was discovered to be also one of the two ingredients of volatile alkali. He gave this reason, and some hint of this little history, to Mr. De Luc, in conversation. But Mr. De Luc could not extract more out of him, though few enquirers are more pertinacious. Perhaps Lavoisier's hopes of making it the alkaline principle were not yet extinguished.

[*Note* 38. *p.* 252.]

It is not improbable that electricity has something to do here. The light of the electrical spark, visible in a great extent of air between the discharging balls, is, I think, the indication of some chemical action going on in the whole of that extent; indeed, on the principles of the new chemistry, it cannot be any thing else. There is no such thing as the transference of something luminous from the one body to the other. There is a decomposition of oxygenous gas taking place wherever we see the light. It seems to be simultaneous: but it is successive and amazingly rapid. There is a smell accompanying all electrical experiments. This smell is also a strong indication of some chemical action. But this is very distinct, or peculiar, and has no resemblance to the smell in any process with the nitrous acid. I suspect, therefore, that electricity acts otherwise than merely by exciting a great heat. Great heat will produce a combination of oxygenous and azotic gases, if either of them be taken in its nascent state, *i. e.* in the very act of its extrication; but not when they are completely formed. This may arise from the constituent parts of the completely formed gas. When nitrous acid is decomposed by detonation, much light and heat are disengaged. It may happen, that, in the formation of these gases, the mutual attraction between them may be very great, while both or either of them are unprovided with the heat or light required for their gaseous form, but may be much weaker when they are furnished with it. This will even be analogous to

the greatest part of chemical combinations. The effect of electricity may be to discharge part of this heat and light from the air in which it is seen. But, on the whole, there are several phenomena in the relations of azotic gas which are not easily reconciled with our present notions, and even affect considerably the whole system of Lavoisier.*

I may here mention another peculiarity of this gas. It communicates the green fæcula to plants growing in the dark, which would otherwise be white. This appears from a series of experiments by Sennebier.

[*Note* 39. *p.* 263.]

The order of composition expressed by this termination *et*, (*etum*, in Latin), has not been yet explained by Dr. Black. It means, in the French nomenclature, the combination of a radical, such as sulphur, carbon, phosphorus, &c. with any substance except oxygen, without an intermedium. Thus, we have the *sulphuret of potash*, the *carburet of iron*, the *hydrogenous phosphoret*, &c. But when the same radical substance is combined with potash by the intervention of oxygen, the compound is then a sulphat of potash, or a sulphite of the same, according as the proportion of oxygen is great or small.

The sulphat of potash is not, however, considered as a compound of these ingredients, but as a compound of potash united with sulphuric acid which is occasionally considered as a substance *sui generis*, having affinities and properties truly distinctive, in which the properties of its ingredients, sulphur and oxygen, are in some measure dormant. This was undoubtedly the way in which Mr. Lavoisier considered these things. I apprehend that this is the only accurate idea that can be had of a true chemical combination; and that there is no such thing as a compound of three ingredients, in which the primary properties of

* Many chemists of eminence imagine that its radical part is the same with that of oxygenous gas; and that the difference in its chemical qualities proceeds from a difference in the proportion of caloric combined with it. Others imagine that it has not caloric combined with it, but the matter of light. But these are all conjectures.

each are immediately efficient. Such compounds, however, are frequently spoken of by the new chemists, especially in their attempts to point out the procedure of nature in the fermentations.....vinous, acetous, and putrefactive. But I know no substance in which the ingredients exert the same combining energies as if they were all separate. They take this method, because it gives them a vastly greater latitude in their explanations. But once this liberty is taken, you will scarcely see two chemists explain the phenomenon in the same way. Had the political ambition of those whom Lavoisier associated with himself in his labours and honour, suffered him to remain at their head, he would have saved his followers from many embarrassments in which they have involved themselves by this manner of proceeding.

[*Note* 40. *p.* 350.]

I cannot omit mentioning in this place, that my colleague, Dr. Daniel Rutherford, read, in the year 1775, to the Philosophical Society of Edinburg, a dissertation on nitre and nitrous acid, in which this doctrine is more than hinted at or surmised. By a series of judiciously contrived experiments, he obtained a great quantity of vital air from nitric acid; about one-third of that quantity from the sulphuric acid, as contained in alum; and a small quantity (and this very variable and uncertain) from the muriatic acid. The manner in which it came off from the compounds, in various circumstances, led him to think that the different quantities obtained did not arise from the different proportions in which it was contained in those acids, but merely in the different forces with which it was retained. He therefore concluded that vital air was contained in all acids; and thought it likely that it was a *necessary* ingredient of an acid; and, seeing that it was the *only* substance found, as yet, in them all, he thought it not unlikely that it was *by this that they were acid:* and he points out a course of experiments which seems adapted to the decision of this question. I was appointed to make a report on this dissertation; and I recollect stating as an objection to Dr. Rutherford's opinion, "that it would lay him under the "necessity of supposing that vitriolic acid was a compound of sulphur and vital air," which I could not but think an

absurdity. So near were we at that time to the knowledge of the nature of the acids!

[*Note* 41. *p.* 379.]

Dr. Black's notes, from which he was accustomed to lecture on this subject, for the last four years of his teaching, are extremely imperfect; and consist of nothing more than references to experiments by Priestley, Austin, Milner, Berthollet, and an intimation that the French chemists practised a certain process to procure saltpetre for the army, and here and there a slight thread of reasoning from the experiments. I think that I have found out all the experiments to which he refers, and I have put them down in the order in which they stand in the notes: but I confess that unless I greatly exceed any authority derived from the manuscript, I cannot give that clearness that will satisfy a cautious mind. Nor can I adhere to the rule laid down in the beginning of this chemical history, namely, to employ in argument no substance of which the properties have not been previously discussed. I have availed myself of the notes taken by a young gentleman who attended the two last courses of Dr. Black's lectures, so that I presume that what I have inserted in this place does not differ much from what he delivered.

[*Note* 42. *p.* 381.]

It must be confessed, that the evidence for this composition of ammonia is in a great measure hypothetical, even when the composition of water and of nitrous acid is fully acquiesced in: and the followers of Lavoisier differ much among themselves in the ways in which they explain the phenomena which are adduced as arguments. Having a number of substances before us, which exert mutual actions, it is plain that we can match or pair them in a variety of ways, and may select that double exchange which suits our purpose. We do not, in many cases, see clearly why either azotic or hydrogenous gas is not *always* produced. Mr. Berthollet obtained azotic gas, and Dr. Priestley obtained hydrogenous gas from ammonia by the electric spark. Ni-

trous ammoniac does not always yield azotic gas and water, but another gas considerably different. We ask what becomes of the hydrogenous gas in Mr. Berthollet's experiment? It is said that the mercury is always covered by a film of mercury combined with oxygen; and that this is detached by the hydrogenous gas and water formed. It is also said that nitrous acid was formed in Dr. Priestley's experiment: but there is no proof of this offered. It is an assumption *on the authority of a previous theory;* and this, without having ascertained the elective attraction which that theory necessarily supposes. The same gratuitous procedure is observable in many explanations given by the followers of Mr. Lavoisier, in all cases where they employ the decomposition of water. They have not ascertained, by experiments instituted on purpose, the double exchanges that are possible among the substances employed. I can point out instances which cannot both be possible: and yet I see both employed.

[*Note* 43. *p.* 394.]

Two ounces of slaked lime, and one drachm of phosphorus cut into very small bits, are made into a soft paste, which must be hastily put into a small earthen retort, having a swan neck tube luted into its neck. This is introduced into the ordinary pneumatic apparatus, as it is called, and heat is cautiously applied, on account of the explosions which frequently happen. The gas soon comes over, and continues to distil for a great while. This quantity of materials will yield three English quarts of gas.

If a quantity of it be let up through water into the air, it gives a bright flash, and a fine ring of white smoke rises from it. This combination was made by Dr. Raymond.....*Ann. de Chym.* x.

Dr. Pearson at London lately made an experiment, which shews still more distinctly the nature and hydrogenous origin of this gas. He combined phosphorus with quicklime, and put the compound into water. While it slowly penetrates, and partly dissolves it, a small part of the water is gradually decompounded; the dissolved phosphorus attracting its

oxygen, and allowing the hydrogen to escape: and this is collected in the upper part of the apparatus in its ordinary form, containing (but not always, nor in equal quantity) a small portion of phosphorus. The gas, accordingly, will not always kindle by simple contact with atmospheric air. It rarely fails to kindle in pure vital air: and in all cases it kindles by any spark. The inference is plain.

This combination of phosphorus and alkaline substances, is in many respects similar to the combination of sulphur with these salts, and like it, produces a hepatic gas, having similar properties. This experiment of Dr. Pearson illustrates all these hepatic phenomena.

[*Note* 44. *p.* 406.]

The proofs of this not being adduced in Dr. Black's manuscript, and its properties being remarkable, and chiefly because the mode of its formation is one of the complicated applications of the new theories, it seems necessary to mention some of the more direct and simple arguments.

Dr. Higgins, by passing the steam of water over melting sulphur, produced sulphurous acid and hydrogenous gas.

Mr. Gingembre, bringing the focus of the sun's rays through a large lense on a piece of sulphur inclosed with mercury in inflammable air, produced this gas in perfection.

Dr. Priestley, by passing a stream of inflammable air through strong vitriolic acid boiling hot, produced this hepatic gas.

Dry hepar sulphuris, made with caustic alkali or lime, when treated in a retort with great heat, does not afford this gas, but sulphur: but if it be moistened, or have been prepared in the humid way, it yields hepatic gas in great abundance. Dr. Austin precipitated sulphur from it by the electric spark. The remainder was inflammable air, of the light kind.

[*Note* 45. *p.* 407.]

This observation of Dr. Black's is very just: and the language of the French chemists in explaining these phe-

nomena is a proof that they proceed without distinct notions of the subject. Fourcroy, for example, says, " L'acide sul- " phureux decompose le gaz hydrogene sulphuré, en sepa- " rant le soufre ; parceque l'oxygene, en partie libre dans " cet acide, se porte facilement sur l'hydrogene de ce gaz. " L'acide sulphurique ne produit pas le meme effet." *Supp. p.* 76. Now, surely in their theory, the sulphurous acid has no " *oxygene en partie libre*"....on the contrary it has *souffre en partie libre.* I may say the same thing of the nitrous or fuming acid. He says in the same page, that the dephlogisticated marine acid (acide muriatique oxygenée) decomposes this hepatic gas. Here I grant the " oxygene en partie libre." Surely in as far as the decomposition depends on oxygen, the operation of the sulphurous and nitrous acids should be the reverse of that of the oxygenated muriatic acid. In truth, this decomposition embarrasses those chemists: and they differ exceedingly in the way in which they conceive it to be effected. Fourcroy, and the Dutch chemists, of whom Dr. Black speaks in the next paragraph, do it in one way: and in the *Annales de Chymie*, vol. 14. page 313, we have quite a different account of the procedure. Gren, a German chemist of great reputation, is of opinion that the theory is imperfect without another substance which he calls *firematter:* and with the help of this he solves all the phenomena very easily and elegantly. But there is no end to substitutions founded on such fancies as this. It is like the æthers and other invisible fluids, which the mechanicians have introduced, because their explanations by impulsion cannot go on without them. Before we can proceed with safety in those explanations which employ the decomposition of water, a series of experiments should be made for ascertaining the elective attractions of the radicals of the gases, with a precision equal to what we have attained with the most familiar substances. Till this be done, we may form ingenious conjectures concerning the hidden operations of nature in bodies of a complicated nature: but we gain no consistent knowledge. The followers of Lavoisier, grasping at every thing, find no difficulty of giving what may be called a *narration* of this internal procedure, taking the com-

binations and decompositions in such order as suits their purpose: and this is contrived so as to terminate in the ultimate combination which we all observe. This is not a very difficult task, even when we limit our combinations to two substances, and produce them by simple affinities. If we take compounds of three ingredients, as in the present case, and employ double affinities, our means of accomplishing the *desired* end are increased prodigiously; and there is nothing that can escape us. The new phraseology is so significant, that every epithet indicates an operation; so that our explanation has great appearance of a real knowledge of the facts. But that all this is little better than conjecture, and very precipitated and unwarranted conclusions, appears from this,....that two eminent chemists, explaining the same ostensible phenomenon, and employing the same agents, give quite a different *story*, merely by taking a different order of succession in the steps of the internal procedure. They therefore employ quite different combinations and decompositions. This cannot be, if the affinities of the substances, when in the same situations, be constant. Lavoisier has rarely taken much liberty this way. But his more zealous followers set no bounds to their theories.

END OF THE NOTES TO VOL. II.

PRINTED BY B. GRAVES,
No. 40, North Fourth-street.