A

SYSTEM

OF

CHEMISTRY,

IN FOUR VOLUMES.

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VOLUME THIRD.

A
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CHEMISTRY.

BOOK III.

OF AFFINITY.

THE term *affinity* appears to have been first introduced into Chemistry by Dr. Hooke, and it has gradually come into general use; because an appropriate term was considered as necessary to distinguish chemical attractions from *gravitation, cohesion,* and *adhesion.*

The term affinity as at present used signifies the power by which the ultimate particles of bodies are made to unite together, and kept united. When two substances have the property of uniting chemically, they are said to *have an affinity for each other.* Thus *sulphuric acid* has an affinity for *potash* and for *lime,* and nitric acid has an affinity for magnesia. Sometimes bodies unite whenever they are placed in contact; this is the case with oxygen and deutoxide of azote, and with acetic acid and soda. But frequently they require for union a certain increase of temperature or liquidity. Thus oxygen and hydrogen gases may be mixed together at the common temperature of the atmosphere without uniting; but when the temperature is raised to redness they unite with great violence. Zinc and copper may be left in contact without uniting; but when they are brought into fusion they readily combine and form brass. Tartaric acid and bicarbonate of soda, both in crystals, may be pounded together without acting on each

Book III. other; but when the mixture is thrown into water the acid unites with the alkali and expels the carbonic acid.

Newton was the first person that gave a satisfactory explanation of the nature of affinity. Since his time the subject has accasionally attracted the attention of chemists. But the philosphers to whom we lie under the greatest obligations for the light which they have thrown on this difficult department of Chemistry are Bergman, Berthollet, Richter, Dalton, Davy, and Berzelius.

As no complete theory of affinity can be exhibited at present, it will be requisite in this *book* to detail the general doctrines of Chemistry as far as they have been hitherto ascertained; that we may omit no part of the subject I shall divide the *book* into five chapters. In the *first* I shall consider the nature of *affinity* in general; in the *second* I shall treat of *gases;* in the *third* of *Liquids;* in the *fourth* of *Solids;* and in the *fifth* of *Decomposition.*

CHAP. I.

OF AFFINITY IN GENERAL.

Chap. I.   1. ALL the great bodies which constitute the solar system are urged towards each other by a force which preserves them in their orbits and regulates their motions. This Attraction, force has received the name of *attraction.* Its nature is unknown: whether it be inherent in these bodies themselves, or the consequence of some foreign agent, are questions altogether beyond the reach of philosophy, because we have no method of deciding the point. One would be more inclined to the first supposition than to the other, as we can conceive no foreign agent sufficient to explain the planetary motions unless an intelligent one; and, for any thing which we know to the contrary, it was as easy for the Creator to have bestowed on the planets the power of acting on each other at a distance, as the power of being acted on, and receiving motion from other substances.

Universal.   2. Sir Isaac Newton demonstrated, that this planetary attraction is the same with *gravitation,* or that force by

which a heavy body is urged towards the earth; that it is possessed, not only by the planets as wholes, but by all their component parts also; that it is mutual; that it extends to indefinite distances; and that all bodies, as far as is known, are possessed of it.

3. When two bodies are brought within a certain distance, they adhere together, and require a considerable force to separate them. This is the case, for instance, with two polished pieces of marble or glass. When a piece of metal, or indeed almost any body whatever, is plunged into water and drawn out again, its surface is moistened, that is to say, part of the water adheres to it. When a rod of gold is plunged into mercury, it comes out stained indelibly of a white colour, because it retains and carries with it a portion of the mercury. Hence it is evident that there is a force which urges these bodies towards each other and keeps them together; consequently there is an attraction between them. Bodies, therefore, are not only attracted towards the earth and the planetary bodies, but towards each other. The nature of this attraction cannot be assigned any more than that of gravitation; but its existence is equally certain, as far at least as regards by far the greater number of bodies.

4. In all cases we find the particles of matter united together in masses; differing indeed from each other in magnitude, but containing all of them a great number of particles. These particles remain united, and cannot be separated without the application of a considerable force; they are kept together therefore by a force which urges them towards each other, since it opposes their separation. Consequently this force is an *attraction*.

Thus we see that there is a certain unknown force which urges bodies towards each other; a force which acts not only upon large masses of matter, as the sun and the planets, but upon the smaller component parts of these bodies, and even upon the particles of which these bodies are composed. Attraction, therefore, as far as we know, extends to all matter, and exists mutually between all matter. It is not annihilated at how great a distance soever we may suppose bodies to be placed from each other, neither does it disappear, though they be placed ever so near each other. The nature of this attraction, or the cause which produces it,

Book III. is altogether unknown; but its existence is demonstrated by all the phenomena of nature.

Ascribed to impulsion, 5. This attraction was long accounted for by supposing that there existed a certain unknown substance which impelled all bodies towards each other; a hypothesis to which philosophers had recourse, from an opinion long admitted as a first principle, " that no body can act where it is not;" as if it were more difficult to conceive why a change is produced in a body by another which is placed at a great distance, than why it is produced by one which is situated at a small distance. It is not only impossible to explain the

But without out reason; phenomena of attraction by impulsion, but it is as difficult to conceive how bodies should be urged towards each other by the action of an external substance, as how they should be urged towards each other by a power inherent in themselves. The fact is, that we can neither comprehend the one nor the other; nor can any reason be assigned why the Almighty might not as easily bestow upon matter power of acting upon matter at a distance, as the power of being acted upon and changed by matter in actual contact.

But farther, we have no reason for supposing that bodies are ever in any case actually in contact. For all bodies are diminished in bulk by cold, that is to say, their particles are brought nearer to each other, which would be impossible, unless they had been at some distance before the application of the cold. Almost all bodies are diminished in bulk by pressure, and consequently their particles are brought nearer each other; and the diminution of bulk is always proportional to the pressure. Newton has shown that it required a force of many pounds to bring two glasses within the 800th part of an inch of each other; that a much greater was necessary to diminish that distance; and that no pressure whatever was capable of diminishing it beyond a certain point. Consequently there is a force which opposes the actual contact of bodies; a force which increases inversely as some power or function of the distance, and which no power whatever is capable of overcoming. Boscovich has demonstrated, that a body in motion communicates part of its motion to another body before it actually reaches it. Hence we may conclude that, as far as we know, there is no such thing as actual con-

tact in nature, and that bodies of course always act upon each other at a distance. Even impulsion, therefore, or pressure, is an instance of bodies acting on each other at a distance, and therefore is no better explanation of attraction than the supposition that it is an inherent power. We must therefore be satisfied with considering attraction as an unknown power, by which all bodies are urged towards each other. It is a power which acts constantly and uniformly in all times and places, and which is always diminishing the distance between bodies, unless when they are prevented from approaching each other by some other force equally powerful.

6. The change which attraction produces on bodies is a diminution of their distance. Now the distances of bodies from each other are of two kinds; either too small to be perceived by our senses, or great enough to be easily perceived and estimated. In the first case, the change of distance produced by attraction must be insensible; in the second case it must be visible. Hence the attractions of bodies, as far as regards us, naturally divide themselves into two classes: 1. Those which act at sensible distances; 2. Those which act at insensible distances. The first class obviously applies to bodies in masses of sensible magnitude; the second class must be confined to the particles of bodies, because they alone are at insensible distances from each other.

7. It has been demonstrated, that the intensity of the first class of attractions varies with the mass and the distance of the attracting bodies. It increases with the mass of these bodies, but diminishes as the distance between them increases. Hence we see that in this class of attractions every particle of the attracting bodies acts, since the sum of the attracting force is always proportional to the number of particles in the attracting bodies. Why it diminishes as the distance increases, it is impossible to say; but the fact is certain, and is almost incompatible with the supposition of impulsion as the cause of attraction. The rate of variation has been demonstrated to be inversely as the square of the distance in all cases of attraction belonging to the first class.

8. The attractions belonging to the first class must be as numerous as there are bodies situated at sensible distances; but it has been ascertained that they may be all reduced to

Book III. three different kinds; namely, 1. Gravitation; 2. Electricity; 3. Magnetism. The first of these has been shown by Newton to belong to all matter, as far as we have an opportunity of examining, and therefore to be universal. The other two are partial, being confined to certain sets of bodies, while the rest of matter is destitute of them; for it is well known that all bodies are not electric, and that scarcely any bodies are magnetic, except iron, cobalt, nickel, and chromium.

The intensity of these three attractions increases as the mass of the attracting bodies, and diminishes as the square of the distance increases. The first extends to the greatest distance at which bodies are known to be separated from each other. How far electricity extends has not been ascertained; but magnetism extends at least as far as the semidiameter of the earth. All bodies possess gravity; but it has been supposed that the other two attractions are confined to two or three subtile fluids, which constitute a part of all those bodies which exhibit the attractions of electricity or magnetism. This may be so; but it has not, and scarcely can be demonstrated.

9. The absolute force of these attractions in given bodies can only be measured by the force necessary to counteract the effect of these attractions, or by the space which given bodies, acted on merely by these attractions, traverse in a given time. If we compare the different bodies acted on by gravitation, we shall find that the absolute force of their gravitation towards each other is in all cases the same, provided their distances from each other and their mass be the same; but this is by no means the case with electrical and magnetic bodies. In them the forces by which they are attracted towards each other, called electricity and magnetism, are exceedingly various, even when the mass and the distance are the same. Sometimes these forces disappear almost entirely; at other times they are exceedingly intense. Gravity, therefore, is a force inherent in bodies; electricity and magnetism not so: a circumstance which renders the opinion of their depending upon peculiar fluids exceedingly probable. If we compare the absolute force of these three powers with each other, it would appear that the intensity of the two last, every thing else being equal, is greater than that of the first; but their relative intensity

cannot be compared, and is therefore unknown. Hence it
follows that these different attractions, though they follow
the same laws of variation, are not the same in kind.

10. The attractions between bodies at insensible distances,
and which of course are confined to the particles of matter,
have been distinguished by the name of *affinity*, while the
term *attraction* has been more commonly confined to cases
of sensible distance. Now the particles of matter are of
two kinds, either *homogeneous* or *heterogeneous*. By homo-
geneous particles, I mean particles which compose the ·
same body; thus all particles of iron are homogeneous.
By heterogeneous particles are meant those which compose
different bodies; thus a particle of iron and a particle of
lead are heterogeneous.

Homogeneous affinity urges the homogeneous particles
towards each other, and keeps them at insensible distances
from each other; and consequently is the cause why bodies
almost always exist united together, so as to constitute
masses of sensible magnitude. This affinity is usually de-
noted by the term *cohesion*, and sometimes by *adhesion* when
the surfaces of bodies are only referred to. Homogeneous
affinity is nearly universal; as far as is known, caloric and
light only are destitute of it

Heterogeneous affinity urges heterogeneous particles to-
wards each other, and keeps them at insensible distances
from each other, and of course is the cause of the formation
of new integrant particles composed of a certain number
of heterogeneous particles. ' These new integrant particles
afterwards unite by cohesion, and form masses of com-
pound bodies. Thus an integrant particle of water is com-
posed of particles of hydrogen and oxygen, urged towards
each other, and kept at an insensible distance by hetero-
geneous affinity; and a mass of water is composed of an
indefinite number of integrant particles of that fluid, urged
towards each other by homogeneous affinity. Heterogene-
ous affinity is universal, as far as is known; that is to say,
there is no body whose particles are not attracted by the
particles of some other body; but whether the particles of
all bodies have an affinity for the particles of all other
bodies, is a point which we have no means of ascertaining.
It is, however, exceedingly probable, and has been generally

Book III. taken for granted; though it is certainly assuming more than even analogy can warrant.

11. Chemists at first supposed that when two heterogeneous bodies united together and formed a third body, the two constituents themselves were entirely destroyed. Thus when sulphuric acid and potash are mixed together, both the acid and the alkali disappear, and a salt formerly distinguished by the name of *vitriolated tartar* is formed. The sulphuric acid and the potash were both conceived to be destroyed, and the vitriolated tartar to be formed out of their *ruins*.

Mayow's explanation of union. This opinion was refuted by Mayow, in 1677, in the fourteenth chapter of his treatise *de Sal-nitro, et Spiritu nitro-aereo*. Sal ammoniac, he observed, is a compound of muriatic acid and ammonia, and, as a proof that neither the acid nor the alkali in this compound are destroyed, he showed that either of them might be again recovered at pleasure. When the sal ammoniac was treated with potash the ammonia was separated, and when it was treated with sulphuric acid we obtained the muriatic acid. Mayow showed at the same time, that bodies follow certain fixed and general laws in their action on each other. Volatile alkali is separated from all acids by the fixed alkalies. Nitric acid is disengaged from potash by sulphuric acid, which unites with the alkali, and forms with it vitriolated tartar. Acids dissolve metals, but when potash is poured into the solution the metal is disengaged and falls to the bottom, while the alkali unites with the acid in its place. Sulphur and potash unite together; but acids precipitate the sulphur by uniting with the potash and taking its place. In like manner when sulphur is united with a metal, if we digest the sulphuret in an acid the metal combines with the acid and the sulphur is set free.*

Geoffroy's table. 12. These important observations of Mayow were carried still farther by Geoffroy, senior, in 1718. He considered the order in which bodies separated each other from a given body as constant. Thus metals are separated from acids by the absorbent earths; the absorbent earths are separated from acids by volatile alkalies, while volatile al-

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* Mayow de Sal-nitro, p. 232.

kalies are separated by the fixed alkalies. He drew up in consequence the following table exhibiting the order in which bodies separate each other from a given substance. At the head of each column is written the name of the substance with which the bodies enumerated in the column combine. Below it are arranged all the bodies capable of uniting with it. That which separates all the others is placed uppermost, and that which is separated by all the others is placed undermost, and the others in the order of their separations. Thus in the first column the fixed alkalies separate all the bodies below them from the acids. The volatile alkalies separate all except the fixed alkalies. The absorbent earths separate the metals, and the metals are separated by all the other bodies in the column.*

Acids.	Muriatic acid.	Nitric acid.	Sulphuric acid.	Absorbent earth.
Fixed alkalies	Tin	Iron	Phlogiston	Sulphuric acid
Volatile alkalies	Antimony	Copper	Fixed alkalies	Nitric acid
Absorbent earth	Copper	Lead	Volatile alkalies	Muriatic acid
Metals	Silver	Mercury	Absorbent earth	
	Mercury	Silver	Iron	
	Gold		Copper	
			Silver	

Fixed alkalies.	Volatile alkalies.	Metals.	Sulphur.	Mercury.
Sulphuric acid	Sulphuric acid	Muriatic acid	Fixed alkalies	Gold
Nitric acid	Nitric acid	Sulphuric acid	Iron	Silver
Muriatic acid	Muriatic acid	Nitric acid	Copper	Lead
Acetic acid		Acetic acid	Lead	Copper
Sulphur			Silver	Zinc
			Antimony	Antimony
			Mercury	
			Gold	

Lead.	Copper.	Silver.	Iron.	Antimony.	Water.
Silver	Mercury	Lead	Antimony	Iron	Alcohol
Copper	Calamine	Copper	Silver, copper, lead	Silver, copper, lead	Salt

13. The first improvement made in this table was by Gellert. The *Metallurgic Chemistry* of this writer, published at Leipsick in 1751, and of which an English translation by Seiferth made its appearance in 1766, is a work of great merit. It contains a very clear account of the different metallurgic and chemical processes as far as known at the time, given with a degree of conciseness very uncom-

Gellert's table.

* Mem. Paris 1718, p. 202.

mon in a German writer. It contains many original experiments on metallic alloys, at the end of the first part there is a table of *solutions*, as Gellert terms it, drawn up according to the idea of Geoffroy; but much more copious. It was divided into 28 columns. The substances placed at the head of these columns are the following:

1. Refractory vitrescent stones
2. Fusible vitrescent stones
3. Clay and argillaceous stones
4. Plaster and gypseous stones
5. Lime and calcareous stones
6. Fixed alkalies
7. Volatile alkalies
8. Vinegar
9. Muriatic acid
10. Nitric acid
11. Sulphuric acid
12. Aqua regia
13. Salt-petre
14. Sulphur
15. Liver of sulphur
16. Cobalt
17. Arsenic
18. Antimony.
19. Glass of antimony
20. Bismuth
21. Zinc
22. Lead
23. Tin
24. Iron
25. Copper
26. Silver
27. Mercury
28. Glass.

In each column the substances which the body at the head of the column was capable of dissolving, were placed in the inverse order of Geoffroy's table. Those bodies most easily dissolved were placed at the greatest distance, and those most difficultly dissolved stood nearest the head of the column. At the foot of each column, and separated from the rest by a black line, were placed those substances which the body at the head of the column was incapable of dissolving.

Limbourg's table. 14. In the year 1758, the Academy of Sciences of Rouen offered a prize for the best dissertation on *affinity*. The prize was shared between M. Limbourg, a physician, at Theux in the country of Liege, and M. Le Sage of Geneva. The dissertation of Limbourg was published at Liege in 1761. In it he gave a table precisely similar to that of Geoffroy, but much enlarged and corrected. It consists of 33 columns, under some of which were arranged 15 or 16 bodies, each in the supposed order of its affinity. In this dissertation the author endeavoured to explain the nature of affinity, and he pointed out at considerable length the utility of the table which he had con-

structed; mentioning at the same time its faults and imperfections.

In consequence of the appearance of these tables and of some others, which I think it unnecessary to enumerate, the opinions of chemists respecting affinity came to be divided. Some adopted the principles of Geoffroy, that every body a had a particular degree or intensity of affinity by which it was united to another body x, and that whenever a third body b, having a greater affinity for x than a had, is presented to the compound a is displaced, and b unites in its stead with the body x. Others were of opinion that no such difference in the intensity of affinity existed; that b might be capable of displacing a and separating it from x, while at the same time a in its turn might disengage b from x. Or that b might be able to disengage a and incapable of disengaging c, though a was capable of disengaging c.

15. Bergman's dissertation on *Elective Attractions*, first published in 1775, in the third volume of the Memoirs of the Royal Society of Upsala, and afterwards re-published by the author in 1783,* appears to have decided the opinions of chemists in general in favour of the first of these two hypotheses. According to him the affinity of each of the bodies a, b, c, d, &c. for x differs in intensity in such a manner that the intensity of the affinity of each may be expressed by numbers. He was of opinion also that affinity is elective, in consequence of which if a have a greater affinity for x than b has, if we present a to the compound bx, x separates altogether from b and unites to a. Thus barytes has a stronger affinity for sulphuric acid than potash has, therefore if barytes be mixed with a solution of sulphate of potash, the sulphuric acid will leave the potash and combine with the barytes. He examined the alleged exceptions to this general law, and accounted for them with such plausibility as to remove the doubts that had hitherto hung over the subject. Bergman's table of affinities, constructed according to the plan of Geoffroy, was much more copious than any that had preceded it, containing all the chemical substances at that time known. It consists of 59 columns. At the head of each of which is

* Opusc. iii. 291.

Book III. placed a chemical body, and the column is filled with the names of all the substances which unite with it, each in the order of its affinity. Each column is divided into two compartments by a black line. In the first is exhibited the affinities in the order of the decompositions when the substances are in solution. In the second compartment are exhibited the order of the decompositions when the substances are exposed to a strong heat, as for example by heating them to redness in a crucible. The first of these he called the affinities by the *wet way*, the second the affinities by the *dry way*.

Opposed by Berthollet.   16. Bergman's opinion that affinity is elective, and that the order of affinities is determined by decomposition, continued to be universally admitted by Chemists till Berthollet published his Dissertation on Affinity, in the third volume of the Memoirs of the Institute, and his Essay on Chemical Statics in the year 1803. He considered affinity as an *attraction* existing between the bodies which combine, and an attraction probably similar to that which exists between the planetary bodies. But as the distances between those bodies which obey the impulse of affinity are at a very small distance from each other, the strength of their affinity depends not merely upon the quantity of matter which they contain, but likewise upon their shape. Affinity being an attraction, must always produce combination; and as the attraction is analogous to that of the planetary bodies, it follows as a consequence in Berthollet's opinion, that the affinity must increase with the mass of the acting body. Thus though barytes has a stronger affinity for sulphuric acid than potash; yet if we present a great quantity of potash to a small quantity of sulphate of barytes, the potash will separate a portion of the acid.

According to this new doctrine, affinity is not elective. A substance which has a stronger affinity is not capable of separating completely those which have a weaker affinity; or if this happens, some other cause intervenes. Instead of separating the weaker body, it divides with it the base to which that body was united; each combining with a part proportional to the strength of its affinity and the quantity present. This new opinion is exactly the opposite of the old one. According to the former hypothesis, when sulphuric acid is dropped into nitre, it separates the whole of

the nitric acid, and takes its place: According to Berthollet, each of the acids combines with a portion of the base of the nitre, and the portion which unites to each is proportional to the strength of affinity and the quantity of each acid employed.

But it is a matter of fact that the addition of a third body frequently separates two substances previously united, the third body taking the place of one of the constituents, which is thereby separated altogether. Thus if sulphuric acid be dropped into nitrate of barytes, the barytes combines with it, leaving the nitric acid in a disengaged state while the sulphate of barytes precipitates to the bottom. Or if potash be dropped into a solution of nitrate of lime, the lime precipitates to the bottom, and the alkali instead of it unites to the acid. These facts, and many others which will immediately occur to every chemist, appearing at first sight contrary to Berthollet's theory, it was necessary for him to reconcile them to it. According to him, whenever decomposition takes place it is owing either to the insolubility or the elasticity of the ingredient which separates. Sulphate of barytes being insoluble in water, while nitrate of barytes and nitric acid are soluble in that liquid, it must happen when the substances are mixed that the insoluble salt precipitates on account of its insolubility. It is the insolubility of lime that causes its precipitation when potash is dropped into nitrate of lime. Accordingly when potash is dropped into nitrate of soda, no precipitation whatever takes place, because both the potash and the soda are very soluble in water. But if we concentrate the solution sufficiently by evaporation, crystals of nitrate of potash will be deposited, because that salt is much less soluble in water than nitrate of soda. In like manner when nitric acid is poured upon carbonate of potash the carbonic acid is disengaged and flies off; because its elasticity causes it to separate from the liquid and assume the gaseous state, as soon as the nitric acid weakens the attraction by means of which it was attached to the potash.

17. Thus we have two doctrines respecting affinity opposite to each other. According to Bergman, affinity is *elective*. The body which has the stronger affinity displaces that which has a weaker; and the strength of affinity may be measured by decomposition. According to Ber-

thollet, affinity is *not elective*. It never produces decom-positions, but only combinations, and the decompositions which take place are owing to the agency of other causes. The strength of affinity is not an absolute quantity; but increases with the mass of the attracting body. Berthol-let's doctrine leads to the opinion that bodies are capable of uniting together indefinitely in any proportion whatever; Bergman's, that they unite only in determinate propor-tions, and that these proportions are independent of the relative quantities of the combining substances which are present.

Whether affinity be a definite force.

18. With respect to the question whether the affinity of every substance for every other be a definite quantity which may be represented by a number, the present state of the science of chemistry does not enable us to answer it in a satisfactory manner. Barytes appears always capable of separating potash from acids. But the reason may be, that the salts of barytes are less soluble than the salts of potash. There are some cases in which the decompositions take place mutually, so that we have no means of deter-mining which of two substances has the strongest affinity for a third. Thus iron has the property of decomposing water at all temperatures, from that of boiling water to the greatest heat that we can raise in our furnaces, as has been sufficiently shown by the experiments of Gay-Lussac.[*] Priestley ascertained that the oxide of iron is reduced to the metallic state when heated while surrounded by an at-mosphere of hydrogen gas.[†]   These experiments were re-peated by Hassenfratz,[‡] and Berthollet, junior; and Gay-Lussac has shown that the reduction takes place at the very same temperature at which iron is capable of decomposing water. Hence we have no data for determining whether hydrogen or iron have the greatest affinity for oxygen. Each seems capable of depriving the other of oxygen in the very same circumstances.

Most of the decompositions which take place when sub-stances are mixed together are cases of what Bergman called *double elective attractions*; when two neutral salts are mixed together, and the acids and bases of each recipro-

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[*] Ann. de Chim. et Phys. i. 35.   [†] Priestley, on air, i. 259.
[‡] Ann. de Chim. lxxiii. 147.

cally change places. Now some examples occur in which it is difficult to determine on which side the greatest affinities lie. Thus it is well known that if carbonate of barytes be digested in a solution of sulphate of potash, the sulphuric acid combines with the barytes, while the carbonic acid unites with the potash. In this case it will be said that the affinity between sulphuric acid and barytes, together with the affinity between carbonic acid and potash, is greater than the affinity between sulphuric acid and potash, together with the affinity between carbonic acid and barytes. But Mr. Philips has shown that carbonate of potash is likewise capable of decomposing sulphate of barytes.*

Berthollet would probably account for these mutual decompositions by the effect of *mass*. But some other cases may be exhibited, in which that supposed principle cannot act. Pfaff has shown that tartrate of lime is completely decomposed by a quantity of sulphuric acid just capable of saturating the whole of the lime contained in the tartrate. Sulphate of lime is formed, and tartaric acid disengaged in a state of purity. He has shown also that oxalate of lead is completely decomposed by the quantity of sulphuric acid just capable of saturating the whole of the oxide of lead in the oxalate.† Berthollet accounts for these two decompositions by the solubility of tartrate of lime and oxalate of lead, and the insolubility of sulphate of lime, and sulphate of lead in acids.

The doctrine of *mass*, first advanced by Berthollet, is supported by the analogy or supposed identity of *affinity* and *gravitation*, and by a set of experiments which Berthollet made on purpose to prove the truth of his opinion. He found that when equal quantities of the following bodies were boiled together,

1. { Sulphate of barytes
     { Potash

2. { Sulphate of potash
     { Soda

3. { Sulphate of potash
     { Lime

4. { Oxalate of lime
     { Potash

5. { Phosphate of lime
     { Potash

6. { Carbonate of lime
     { Potash

the uncombined base abstracted part of the acid from the

* Journal of Science and Art, i. 80.   † Ann. de Chim. lxxvii. 266.

base with which it was previously combined; though in every one of these instances it was retained by that base by an affinity considered as stronger. The same division of the base took place when equal quantities of oxalate of lime and nitric acid were boiled together. But the accuracy of these experiments has been called in question by Sir H. Davy, who has discussed them with much ingenuity and address, and shown that they are not sufficient to establish the doctrine in support of which they were brought forward.*

Affinity elective.

19. The facts with which we are at present acquainted seem to me fully sufficient to prove that affinity in different bodies differs in *intensity*. The well known fact that the proportions of the constituents of all compounds are constant, appears to me inconsistent with the belief of the supposed efficacy of mass. The facts established by Pfaff and many others that might be mentioned appear to prove that affinity is *elective*; though no satisfactory explanation of this extraordinary property has been offered. Were we to admit that the atoms of bodies possess polarity, and that they always unite by the same poles, we might form an idea of the way in which the union of b with m has the effect of separating a from it. a and b are both attracted to the same pole of m, and b being attracted most powerfully may be conceived capable of insinuating itself into the place which a formerly occupied; a of course being removed to a greater distance may be protruded beyond the sphere of $m's$ attraction, and of course disengaged altogether. The recent discoveries respecting the combinations of bodies with each other, which I shall immediately state, tend still further to overturn Berthollet's doctrine of the efficacy of *mass* in chemical combinations and decompositions.

Richter's law of double decomposition.

20. The first important fact respecting combinations was ascertained by Dr. J. B. Richter, who was for some time mining secretary at Breslau, and afterwards *Arcanist* in the porcelain manufactory of Berlin. In the year 1792, he published the first part of a work entitled *Foundation of Stochiometry, or Geometry of the Chemical Elements.*† This work he continued successively in 1793, 1794, 1795,

* Elements of Chemical Philosophy, p. 117.
† Anfangsgründe der Stochiometrie, oder Messkunst chymischer elemente.

and 1802. It contains the result of his researches on the decompositions and combinations of chemical bodies. He observed that when two neutral salts which mutually decompose each other are mixed together, the two newly formed salts still retain the same neutral state as the two original ones from which they were formed. This circumstance enabled him to examine the accuracy of the results obtained by preceding experiments, and he showed that the numbers assigned by Bergman, Kirwan, and Wenzel, for the constituents of the salts are inaccurate, as they are unable to stand the test of this double decomposition. He was induced in consequence to make a set of experiments in order to obtain more accurate results, and these experiments occupied him about ten years. He drew up the results in tables exhibiting the weight of each base capable of saturating 100 parts by weight of each acid, and the weight of each acid capable of saturating 100 parts by weight of each base. He observed that the different bases follow exactly the same order in each of the tables, and that order according to his tables is as follows:

1. Alumina	4. Lime	7. Potash
2. Magnesia	5. Soda	8. Barytes
3. Ammonia	6. Strontian	

The order in which the different acids saturated each base was likewise the same, and was according to him as follows:

1. Fluoric acid	6. Phosphoric acid	11. Acetic acid
2. Carbonic acid	7. Formic acid	12. Citric acid
3. Sebacic acid	8. Sulphuric acid	13. Tartaric acid
4. Muriatic acid	9. Succinic acid	
5. Oxalic acid	10. Nitric acid	

He observed farther that the numbers in each table constitute a series which have the same ratio to each other in all the tables. Suppose for example, that in the table representing the muriates the quantity of potash requisite to saturate 100 parts of muriatic acid were three times as great as the quantity of alumina requisite to produce the same effect. The same thing would hold in the sulphates, nitrates, and all the other genera of salts. Three times as much potash would be required to saturate 100 sul-

phuric, nitric, or any other acid as would be requisite of alumina.

These facts explain why when two neutral salts decompose each other, the new formed salts are also neutral, and why there is no excess of acid or base upon the one side or the other. The same proportions of bases that saturate a given weight of one acid, saturate all the other acids; and the same proportion of acids that saturate one base saturate all the other bases. Hence numbers may be attached to each acid and base indicating the weight of it, which will saturate the numbers attached to all the other acids and bases. This was accordingly done by Fischer, from Richter's experiments; and Dr. Wollaston constructed his *sliding rule* of chemical equivalents so precious in every point of view to the practical chemist.

Atomic theory of Dalton.

21. Mr. Dalton in 1804, without being aware of the general law already discovered by Richter, turned his attention to the subject, and was struck with the small number of proportions in which simple substances are capable of uniting, and the constancy of these proportions. Thus if we represent the weight of carbon by 75, we find that carbonic oxide and carbonic acid, the only two compounds of carbon and oxygen, are composed as follows:

> Carbonic oxide of 75 carbon + 100 oxygen
> Carbonic acid of 75 carbon + 200 oxygen.

So that the quantity of oxygen in carbonic acid, is to that in carbonic oxide as 2 to 1.

If we represent the weight of azote by 175, we find that all the compounds of azote and oxygen are composed as follows:

> Protoxide of azote of 175 azote + 100 oxygen
> Deutoxide of azote of 175 azote + 200 oxygen
> Hyponitrous acid of 175 azote + 300 oxygen
> Nitrous acid .... of 175 azote + 400 oxygen
> Nitric acid ...... of 175 azote + 500 oxygen

So that the quantity of oxygen in these compounds, supposing the azote to remain always the same, is as the numbers 1, 2, 3, 4, 5.

Similar observations may be made respecting the composition of the metallic oxides, the chlorides, the neutral

salts, and indeed all chemical combinations with which we are acquainted. The fortunate thought occurred to Mr. Dalton, that these proportional numbers represented the respective weights of the atoms of the combining bodies; that bodies combine either 1 atom of one with 1 atom of another, or with 2 atoms, or with 3, 4, 5, or 6 atoms. According to this notion, if we represent the weight of an atom of carbon by 0·75, an atom of oxygen will be 1, and carbonic oxide will be a compound of 1 atom carbon and 1 atom oxygen, and carbonic acid of 1 atom carbon and 2 atoms oxygen. If the weight of an atom of azote be 1·75, and that of oxygen 1, then the compounds of azote and oxygen are composed as follows:

Protoxide of azote of 1 atom azote + 1 atom oxygen
Deutoxide of azote .. 1 .... + 2
Hyponitrous acid .. 1 .... + 3
Nitrous acid .. 1 .... + 4
Nitric acid .. 1 .... + 5

The simplicity and beauty of this opinion made a speedy and strong impression upon chemists in general. Its truth is now almost universally admitted. I have illustrated it at considerable length in the preceding part of this work, and have endeavoured to determine the weight of the atom of all the different simple bodies, and likewise the different compounds which they are capable of forming. But this theory, which has been denominated the atomic theory, seems to me to present an insuperable objection to the opinion advanced by Berthollet that *mass* produces an effect upon chemical combinations and decompositions.

22. I have already in a preceding part of this work endeavoured to give an idea of the ingenious attempt of Berzelius and Davy to generalize our notions of chemical affinity still farther, by showing it to be synonimous with the opposite states of electricity. Every body in their opinion possesses a permanent electric state, either resinous or vitreous. Two bodies in the same electrical state have no affinity for each other. Those in opposite states have an affinity, and the strength of the affinity is proportional to the degree of intensity of the different electricities in the two bodies. In order to make bodies separate from each other, we have only to bring them to the same electrical

Hypothesis of Davy and Berzelius.

Book III. state by making them both vitreous, or both resinous. Both Davy and Berzelius have supported this hypothesis with much ingenuity. To it indeed we are in some measure indebted for the brilliant discoveries with which Davy has enriched the science. But the facts which they have brought forward in support of this theory, ingenious and plausible as they are, do not seem to me of a nature capable of convincing us that it is an accurate representation of what takes place in nature. That bodies possess permanent electrical states has not I think been proved in a satisfactory manner, nor can it be admitted without entirely subverting the very foundations of the science of electricity as it at present exists. The very foundation of that science depends upon the supposition of the existence of two subtile fluids, to which the name of *vitreous* and *resinous* electricity has been given. When bodies containing each of these bodies come into contact, it is believed that the two electricities combine together, and are by this union deprived of all their characteristic properties, so that they cease to give any indications of their presence. It is true that electricity is capable of decomposing a variety of bodies; but so is *heat*, and no evidence can be adduced to prove that heat and electricity do not act exactly in the same way on bodies.

CHAP. II.

OF GASES.

THE gases are a numerous class of bodies, differing greatly from each other in their chemical properties; some are acid, as carbonic acid; some alkalies, as ammonia; some are combustible, as hydrogen; some supporters of combustion, as oxygen, &c.: but however different in other respects, they all agree in that aerial form, in that peculiar kind of elasticity, which constitutes them gases. We shall, in this chapter, consider how far this aerial form affects and modifies the combinations into which they enter with each other, and with the remaining classes of bodies. But this inquiry pre-supposes a knowledge of the constitution of gaseous bodies, a subject which we must therefore discuss

in the first place. We shall afterwards consider the mixture of gases with each other, and their combinations with gases, with liquids, and with solids. The subject, of course, naturally divides itself into five heads; namely,

1. The constitution of gases.
2. The mixture of gases with each other.
3. The combination of gases with each other.
4. The combination of gases with liquids.
5. The combination of gases with solids.

These shall be the subject of the five following Sections.

SECT. I.

OF THE CONSTITUTION OF GASES.

IT has been proved by mechanical philosophers, that gaseous bodies are *fluids*; that they yield to the smallest impression, and have their parts easily moved; that besides the properties which they have in common with liquids, they possess one peculiar to themselves, namely, *elasticity*; in consequence of which, they may be forced to assume a smaller bulk by pressure, but as soon as the force which confined them is removed, they again resume their former volume. If from a vessel filled with water one-half of the liquid be taken, the remaining portion will fill only one-half of the vessel; but this is not the case with air. If, by any contrivance, we take away one-half of the air contained in a vessel, the other half immediately expands, and still continues to fill the vessel. The same thing happens if we take away $\frac{3}{4}$ths, $\frac{11}{12}$ths, $\frac{99}{100}$th parts, &c. of the air; the small portion which remains always expands so as to fill the vessel. Nor has any limit to this expansion been hitherto discovered. A good air-pump will easily rarefy air to 300 times its former bulk; while, on the other hand, we may readily, by means of a condenser, reduce air to $\frac{1}{10}$th of its usual bulk. Thus the bulk of air may be easily increased or diminished 3000 times. Indeed the experiment is said to have been carried as far as 3,000,000 of times. I am not acquainted with any accurate set of trials hitherto made which warrant that conclusion, though there does

Gases elastic.

Book III. not appear to be any reason for doubting the possibility of it.*

This unlimited change of bulk which gaseous bodies are capable of undergoing, has led mechanical philosophers to conceive them as composed of particles or *atoms* which do not touch each other, which mutually repel each other, and which, therefore, unless prevented by the pressure of the surrounding bodies, would recede from each other to an indefinite distance.

Elasticity as the pressure. Boyle ascertained by experiment, that the diminution of bulk in air is always proportional to the pressure, and the increase of bulk to the diminution of pressure; or, in general, that the bulk of air is inversely as the pressure which it sustains. Thus air at the earth's surface sustains a pressure equal to the weight of the incumbent atmosphere, which is nearly equivalent to a column of mercury 30 inches in height. If we double this pressure, we reduce the bulk of the air to one-half; if we triple it, to one-third; and so on. If we remove one-half of the pressure, we double the bulk of the air; if we remove nine-tenths of the pressure, we increase the bulk ten times.† The same result was obtained by Mariotte and by other philosophers.

Repulsion between the particles of gases as $\frac{1}{d}$. Sir Isaac Newton demonstrated, that if this law be correct, then the force by which the particles of air recede from each other, increases or diminishes at the same rate that the distance between the centres of the particles or atoms of which it is composed diminishes or increases; or, which is the same thing, that the repulsion between the particles of gaseous bodies is always inversely as the distance of their centres from each other.‡

Distance inversely as the cube root of the density. Now the distance between the centres of the atoms of elastic fluids always varies as the cube root of their *density,* taking the word in its common acceptation. Thus, if the density of air under the mean pressure of the atmosphere be supposed 1; if it be forced into $\frac{1}{8}$th of its bulk, its density becomes 8. In these two cases we have the distance between the atoms of air inversely as the cube root of 1 to

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* The older philosophers were misled in their calculations on this subject by not attending to the effect of moisture.

† Shaw's Boyle, ii. 671.   ‡ Principia, Lib. ii. Prop. 23.

the cube root of 8, or as 1 to 2. So that if air be compressed into $\frac{1}{8}$th of its bulk, the distance between its particles is reduced to one-half, and of course the repulsion between them is doubled. If air be rarefied 300 times, we have its density reduced to $\frac{1}{100}$th of that of common air. Here we have the distance between the atoms of common and the rarefied air as $\sqrt[3]{1} : \sqrt[3]{300}$, or nearly as $1 : 7$. So that when air is rarefied 300 times, the distance between its particles becomes almost seven times greater, and of course their repulsion is diminished almost sevenfold.

2. Such is the opinion at present entertained respecting the constitution of gaseous bodies. The experiments on which it is founded were made almost exclusively on atmospherical air, and they have been extended from analogy to other gaseous bodies. This analogy holds in many instances exactly, as has been ascertained by recent experiments; but in some few gases it fails to a certain extent.

No degree of compression has been found capable of producing any change in the constitution of air; as soon as it is removed, the air resumes its original bulk, and has lost nothing of its elasticity. But upon some gases the effect of violent compression is to reduce them to the state of liquids, or even of solids. These gases are of course intermediate between *vapours* and *airs*, strictly so called.

Heat, as has been explained in a preceding part of this Work, has the property of increasing the elasticity of gases, while, on the contrary, cold diminishes their elasticity. No degree of cold hitherto applied has any effect in altering the constitution of air; but upon some of the other gases it acts so powerfully as to reduce them to the state of liquids, or even of solids. These gases are the same that are affected by compression, and doubtless for the same reason.

3. The gases are probably very numerous; but those hitherto examined with accuracy amount only to 34. Of these, five are still undecompounded; the rest are known to be compounds. The following table exhibits a list of all the gases known, arranged according to their composition. I include among them the vapour of water, of alcohol, and of ether; vapours which deserve attention, and which will assist us in examining the nature of various bodies considered as gaseous.

I. SIMPLE GASES.

1. Oxygen   3. Iodine vapour   5. Azote
2. Chlorine   4. Hydrogen   6. Sulphur

II. COMPOUND GASES.

a. Simple gases combined.

7. Hydriodic acid   11. Deutoxide of azote
8. Protoxide of chlorine   12. Steam
9. Protoxide of azote   13. Ammonia
10. Muriatic acid

b. Oxygen and a solid base.

14. Sulphuric acid   16. Carbonic oxide
15. Sulphurous acid   17. Carbonic acid

c. Hydrogen and a solid base.

18. Cyanogen   21. Carbureted hydrogen
19. Sulphureted hydrogen   22. Hydroguret of phosphorus
20. Olefiant gas   23. Bihydroguret of phosphorus

d. Fluorine, chlorine, cyanogen, with a base.

24. Fluoboric acid   26. Hydrocyanic acid
25. Chlorocyanic acid   27. Chlorocarbonic acid

e. Two solid bases.

28. Sulphuret of carbon.

f. Triple or quadruple compounds.

29. Hydriodic ether   32. Muriatic ether
30. Chloric ether   33. Alcohol
31. Sulphuric ether   34. Oil of turpentine

4. The difference between the specific gravity of the gases under the same pressure, and at the same temperature, is much greater than that which exists between most liquid bodies. The following table exhibits the density and the weight of 100 cubic inches of all the gases at the temperature of 60°, and when the barometer stands at 30 inches; supposing the specific gravity of common air 1·000, and the weight of 100 inches of it 30·5 grains troy.*

* The experiments on which this table is founded have been detailed in the preceding part of this work.

Gases.	Sp. gravity.	Weight of 100 cubic inches.
Air	1·000	30·5
Vapour of iodine	8·678	264·679
Hydriodic ether	5·475	166·987
Oil of turpentine vapour	5·013	152·896
Hydriodic acid	4·375	133·434
Chlorocarbonic acid	3·472	105·896
Chloric ether	3·474	105·957
Sulphuric acid vapour	2·777	84·698
Sulphuret of carbon vapour	2·6447	80·663
Sulphuric ether vapour	2·586	78·873
Chlorine	2·500	76·250
Protoxide of chlorine	2·440	74·420
Fluoboric acid	2·3709	72·312
Sulphurous acid	2·222	67·771
Muriatic ether	2·219	67·679
Chlorocyanic acid vapour	2·152	65·636
Cyanogen	1·804	55·028
Alcohol vapour	1·6133	49·206
Protoxide of azote	1·5278	46·598
Carbonic acid	1·527	46·373
Muriatic acid	1·284	39·162
Sulphureted hydrogen	1·180	35·890
Sulphur vapour	1·111	33·888
Oxygen	1·111	33·888
Deutoxide of azote	1·0416	31·769
Olefiant gas	0·974	29·720
Azote	0·9722	29·652
Carbonic oxide	0·9722	29·652
Bihydroguret of phosphorus	0·9716	29·634
Hydrocyanic acid vapour	0·9368	28·572
Hydroguret of phosphorus	0·9022	27·517
Steam	0·625	19·062
Ammonia	0·590	18·000
Carbureted hydrogen	0·555	16·99
Hydrogen	0·0694	2·117

5. Of these gaseous bodies there are two whose specific gravities are equal to the weight of their atoms. These are, Weight of their atoms.

	Sp. gr. oxygen being 1.	Weight of an atom.
Oxygen	1·000	1·000
Olefiant gas	0·876	0·876

Fifteen of them have their specific gravity equal to half the weight of their atoms. These are,

	Sp. gr. oxygen being 1.	Weight of an atom.
Chlorocarbonic acid	3·095	6·190
Chlorine	2·250	4·500
Sulphurous acid	2·000	4·000
Cyanogen	1·625	3·242
Protoxide of azote	1·375	2·750
Carbonic acid	1.374	2·750
Sulphureted hydrogen	1·062	2·124
Sulphur	1·000	2·000
Azote	0·875	1·750
Carbonic oxide	0·875	1·750
Hydroguret of phosphorus	0·8125	1·625
Steam	0·5625	1·125
Carbureted hydrogen	0·4995	0·999
Carbon	0·375	0·750
Hydrogen	0·0625	0·125

Five of them have their specific gravity equal to one fourth of the weight of their atoms. These are,

	Sp. gr. oxygen being 1.	Weight of an atom.
Hydriodic acid	3·986	15·944
Muriatic acid	1·1557	4·625
Deutoxide of azote	0·9375	3·750
Hydrocyanic acid	0·8433	3·3732
Ammonia	0·53125	2·125

It follows as a consequence from the preceding facts, that the number of atoms in a given volume of these three sets of gases are to each other as the following numbers:

First set 4
Second set 2
Third set 1

Hence a cubic inch of oxygen gas contains twice as many atoms as a cubic inch of azotic gas, and 4 times as many atoms as a cubic inch of ammonia. It is obvious from this, that if common air be a mixture of 4 volumes azote and 1 volume of oxygen, a given bulk of it is a mixture composed of 2 atoms azote and 1 atom oxygen.

Elasticity of the gases   6. Philosophers have speculated a good deal concerning

the cause of the elasticity of gaseous bodies. The opinion which seems at present most prevalent is, that repulsion resides in the substance called heat; that the gases are combinations of this substance with a base; and that they owe the permanency of their elastic form to the intimacy of the union between the atoms of the base and this heat, the particles of which, though they repel each other, are conceived to have a strong affinity for the atoms of other bodies. This opinion can be considered in no other view than that of a plausible hypothesis, as it is by no means susceptible of direct proof. Were it well founded, we might conclude from it, that the elasticity of gases ought not to increase precisely at the same rate as their diminution of bulk; for when air is compressed forcibly, a considerable quantity of heat is evolved. From the experiments of Dalton, we learn that the heat evolved, when air is suddenly condensed to half its bulk, is at least equal to 50°; but the more recent experiments of Biot demonstrate that the heat evolved in cases of sudden compression of gaseous bodies is often much greater than this. When a mixture of oxygen and hydrogen gases is suddenly condensed, the heat generated is sufficient to set them on fire, and convert them into water. The experiment was made by forcibly compressing them by means of a piston in the barrel of an air gun. The barrel, though iron and very stout, was torn by the violence of the explosion.* So great an extrication of heat ought to diminish the elasticity sensibly, provided the compression be continued till the condensed gas has time to cool. On the other hand, when gaseous bodies are rarefied, the diminution of elasticity ought not to follow so great a rate as the increase of bulk; for when air is dilated, it absorbs heat probably in the same ratio as it parts with it when condensed.

7. There has been a good deal of discussion likewise respecting the constitution of gaseous bodies with respect to water. According to some philosophers, the presence of a portion of this liquid is essential to the elastic state of the gases; nay, some have even gone so far as to affirm that the whole of the ponderous matter contained in gases was water, and that gases consist only of water combined with some body not possessed of sensible weight, as the magnetic fluid, the

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* Phil. Mag. xxi. 362.

electric fluid, &c. It would be needless to enter particularly into these opinions, as they are not susceptible of proof, and have been proposed merely as ingenious speculations, or as the means of avoiding some difficulty.

From the experiments of Saussure, we learn, that when common air is left in contact with water for a sufficient time, at the temperature of 57°, dry alkalies are capable of extracting from every 100 cubic inches of it 0·35 of a grain troy of water. The experiments of Mr. Dalton give almost exactly the same result; but Desormes and Clement, at the temperature of 54°, only obtained 0·236 of a grain of water from 100 inches of air, by passing it through muriate of lime.*

Saussure ascertained that equal bulks of common air, hydrogen gas, and carbonic acid, left a sufficient time in contact with water, at the same temperature and height of the barometer, afterwards deposited the very same weight of moisture if treated with dry alkali. Clement and Desormes tried a similar experiment with air, oxygen, hydrogen, azotic, and carbonic acid gases, and obtained exactly the same result. † From these experiments we may conclude that the quantity of moisture contained in gases depends upon their bulk, and not upon their density; that 100 inches of all gases at the same temperature, and under the same pressure, if left in contact with water, mix or combine with the very same weight of it, or at least are disposed to part with the same weight. This accords completely with Mr. Dalton's experiments on the subject.

All gases in common cases contain moisture; for they all give out a little when kept in contact with dry alkalies, muriate of lime, sulphuric acid, lime, and similar substances, which have a strong affinity for water; but when these substances cease to act upon them, are we to consider the gases as completely freed from water, or do they still retain a portion upon which these bodies have no longer any effect? We have no means of determining this point in a perfectly satisfactory manner. But when gases are exposed to the action of substances which, like sulphuric acid, have a strong affinity for water, and at the same time are cooled down as far as possible, the quantity of moisture remaining must be very small.

* Ann. de Chim. xlii. 125.   † Ibid.

The presence of moisture produces a considerable effect upon the specific gravity of gases, especially those that are light. When hydrogen gas, for instance, is kept in contact with water, at least half its weight may be safely ascribed to moisture. Hence, when gases are weighed in order to obtain their specific gravity, they ought to be as nearly as possible in the same relative state with respect to moisture and dryness. The presence or the absence of moisture will also have a considerable effect in our calculations respecting the proportions in which gaseous bodies combine; though the observations of Dalton prove that the effect of it is not nearly so great as has been alleged by some.

When gases stand over water, it is obvious that they will be as moist as possible. In that case the proportion of water which they contain will depend upon the temperature. The lower the temperature, the smaller a proportion of moisture will be present; and if the temperature be very low, the gas will be almost perfectly free from moisture.

8. Such is the present state of our knowledge respecting the constitution of gaseous bodies. *Vapours* bear a considerable resemblance to them, and have thrown considerable light on their properties, though they differ in some essential particulars. *Vapours* are elastic fluids, which may be made at pleasure to assume the form of *liquids*. In this they differ from the gases.

When a vapour is compressed, a portion of it loses the elastic form, and is condensed into a liquid. The consequence of this condensation is, that the remaining portion continues of the same elasticity as before the compression. Hence the elasticity of vapours does not increase as the pressure, like that of gases.

When vapours are heated, their elasticity is not only increased, but a new portion of liquid, if any be present, is converted into vapour. Hence the elasticity *apparently* increases at a much greater rate than that of gases.

On these two circumstances depend all the differences between vapours and gases. If allowance be made for them, then it is true that the elasticity of vapours increases by compression and by heat, precisely as that of the gases does. The higher the temperature of vapours, the greater is the

pressure which they can support without assuming a liquid form.

There are some vapours, as those of mercury and sulphuric acid, that do not become sensibly elastic, except at a temperature considerably higher than that of the medium heat of the atmosphere, or when the ordinary pressure of the atmosphere is removed. Others, as those of water, alcohol, and ether, have a very sensible elasticity even in low temperatures, and can bear a certain degree of pressure without assuming the liquid form. Among those bodies commonly considered as gases there are some which, in very low temperatures, and when subjected to strong pressure, assume the liquid form. This is the case with ammonia; and it is probable that it is the case also with muriatic acid, fluoric acid, and all those gases that are absorbed in great quantities by water. The other gases cannot be made to assume a liquid form by any degree of compression or cold hitherto applied. These facts strongly corroborate the opinion at present most generally received, that the elastic fluids owe their elasticity to heat, that they are combinations of heat and a base, and that they owe their permanency to the strength of the affinity by which the heat and the base are united together. When the affinity is not sufficient to resist the forces usually applied, the elastic fluids are called vapours; when it is, they are called *gases*. But in each of these classes the affinity has various degrees of strength. In some vapours the elasticity does not become sensible, except at temperatures higher than those usually applied; in others, it becomes sensible at the common temperature: in some gases degrees of compression or of cold, which, though not common, are still within our reach, destroy the elasticity, while in others it continues however cold we make them, or however forcibly we compress them.

SECT. II.

OF THE MIXTURE OF GASES.

GASEOUS bodies may be mixed together like other fluids. Now when such mixtures are made, there are some gases

which unite together and form a new compound, very different in its properties from the gases which enter into its composition. Thus *muriatic acid* and *ammoniacal gas* Gases *mix,* form *sal ammoniac,* and *nitrous gas* and *oxygen* form *nitric* and com- acid. There are others which mix together without any *bine.* apparent change, as *oxygen* and *hydrogen* gases, hydrogen and azote, &c. In the first case a *combination* manifestly takes place; in the second, there is more the appearance of a *mechanical mixture.* We shall consider the second case in the present Section, and the first in the succeeding Section.

1. The following table exhibits a list of the gases which Table of may be mixed together without any apparent change in the gases their state. that mix.

I. *Gases that mix, but never combine intimately.*

Oxygen with fluoboric, fluosilicic, and carbonic acids.

Hydrogen with muriatic acid, fluoboric acid, fluosilicic acid, carbonic oxide, olefiant gas, carbureted hydrogen, bihydroguret of phosphorus, sulphureted hydrogen, ammonia.

Azote with most other gases.

Fluoboric and fluosilicic acids with most gases.

II. *Gases which mix without change; but by peculiar treatment may be made to combine.*

Oxygen with chlorine, iodine, hydrogen, azote, carbonic oxide, sulphurous acid, protoxide of azote.

Hydrogen with chlorine, iodine, azote.

III. *Gases which mix without change; but by peculiar treatment may be made to decompose each other.*

Oxygen with carbureted hydrogen, bihydroguret of phosphorus, olefiant gas, sulphureted hydrogen, cyanogen, ammonia.

Hydrogen with carbonic acid, deutoxide of azote, protoxide of azote, sulphurous acid, &c.

2. When any two or more of the gases contained in the preceding list are put into the same vessel, each of them diffuses itself equally through the whole space so as to be equally dense in every part of it. Every portion of the mixture contains exactly the same proportion of each of All gases the gases. When the gases have once diffused themselves mix equal-

ly

equally through the vessel, the mixture always continues sensibly uniform, notwithstanding any difference that may exist between the specific gravity of the mixed gases. The heaviest gas does not fall to the bottom of the vessel, nor the lightest gas rise to the top.

The first set of experiments on this subject was made by Dr. Priestley. He put into the same cylindrical vessel common air and carbonic acid, hydrogen and nitrous gas, nitrous gas and carbonic acid, oxygen and hydrogen, sulphurous acid and fluosilicic acid; and, allowing them to remain at rest for a whole day, he carefully separated a portion of the mixture at the top and at the bottom of the vessel, but they were always very nearly the same in every respect.*

When brought into contact.
It remained to examine, whether two gases, when merely brought into contact, the lightest being placed uppermost, and the heaviest lowest, will mix together of their own accord without any agitation. This has been done by Mr. Dalton. The gases tried were introduced each into a phial fitted with a perforated cork, which were afterwards connected together by a glass tube, 10 inches long and $\frac{1}{20}$th of an inch in bore. He first filled the lowest phial with carbonic acid gas, and put into the upper successively common air, hydrogen, azotic, and nitrous gases. The effect in all these trials was the same. After standing an hour, the upper phial, when examined, was found to contain no sensible portion of carbonic acid, but in three hours it contained it abundantly. It was examined afterwards every half hour, and never failed to exhibit signs of the presence of carbonic acid. He then filled the upper phial with hydrogen gas, and the lowest part with common air, and afterwards with oxygen gas. The result was the same; after a day or two the gases were found diffused through both phials. Nitrous gas and hydrogen, azote and hydrogen, azote and oxygen, were tried with the same success.†

These experiments were carefully repeated by M. Berthollet. His apparatus consisted of two small globular glass vessels, furnished each with a stop-cock; the capacity of the first was 1·591 cubic inch, that of the second 1·693 cubic inch. They were joined by a tube 0·197 inch in diameter, and 10·43 inches long. The experiments

* Priestley on Air, ii. 441.   † Phil. Mag. xxiv. 8.

were made in a cellar, where the temperature was equable. The stop-cocks were kept shut, and all communication prevented, till the vessels had acquired exactly the same temperature. The stop-cocks were then opened, with the proper precautions not to alter the temperature. At the end of the experiment, the stop-cocks were shut, and the gases in each vessel examined. The following table exhibits the result of these experiments.

Glass vessel.	Gases used.	Time.	Gases found in each vessel.
1 2	Hydrogen Carbonic acid	48 hours	41·73 Car. acid gas 43·26 Ditto
1 2	Hydrogen Air	48 hours	47·24 Hydrogen gas 47·62 Ditto
1 2	Hydrogen Carbonic acid	24 hours	43 Carbonic acid 46 Ditto
1 2	Air Carbonic acid	24 hours	28 Carbonic acid 56 Ditto
1 2	Air Carbonic acid	24 hours	27·2 Carbonic acid 59·8 Ditto
1 2	Azotic Oxygen	24 hours	60 Oxygen 39·33 Ditto
1 2	Hydrogen Oxygen	24 hours	50 Oxygen 50 Ditto
1 2	Hydrogen Azotic	24 hours	46 Hydrogen 45 Ditto
1 2	Azotic Carbonic acid	24 hours	22 Carbonic acid 60 Ditto
1 2	Azotic Carbonic acid	48 hours	35 Carbonic acid 61 Ditto
1 2	Oxygen Carbonic acid	24 hours	24 Carbonic acid 60 Ditto
1 2	Air Carbonic acid	17 days	42 Carbonic acid 50 Carbonic acid

Book III.   From these experiments we may safely conclude, that
all gases mix intimately when brought into contact, inde-
pendent of agitation, and when once mixed they never
afterwards separate again.

The bulk is   3. When two or more gases are mixed together, the bulk
not altered, is not sensibly altered.   If two gases, each two cubic inches
in volume, be mixed, the bulk after mixture will still con-
tinue to be four cubic inches; each gas *appearing* to occupy
just the same space as when separate.   The truth of this
observation is too well known to practical chemists to re-
quire any particular illustration.

Nor the   4. The specific gravity of such mixtures is precisely the
specific   mean of that of the gases mixed, allowance being made
gravity.   for the proportions of each that enter into the mixture.
This obviously follows from the last proposition, and is well
known to all experimental chemists.

5. Such are the phenomena of the mixture of gaseous
substances with each other.   Two different explanations
have been given of them.

Supposed   According to the first, which is the common explanation,
to dissolve   all the gases have an affinity for each other, and they mix,
each other.   and continue mixed or united, in consequence of this affi-
nity.   The supposed mixture is in reality a *combination*, and
may be compared to the combination of alcohol and water,
alcohol and ether, which unite slowly when brought into
contact, but when once united never afterwards separate.
The force of this affinity is very weak; it therefore pro-
duces no sensible change in the bulk or specific gravity of
the compound.   For that reason, Berthollet, who has con-
sidered this subject at great length, and treated it with his
usual address, has given the combination the name of *dis-
solution.**

Supposed to   The second explanation was first proposed by Mr. Dalton,
mix me-   who published a most ingenious dissertation on the subject
chanically.   in the fifth volume of the Manchester Memoirs.   Accord-
ing to him, the particles of one elastic fluid possess no re-
pulsive nor attractive power, or are perfectly inelastic with
regard to each other; and consequently the mutual action
of the fluids is subject to the laws of inelastic bodies.†

The first of these opinions, though commonly received,

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* Statique Chimique, i. 274 and 487.   † Manchester Mem. v. 543.

presents several difficulties when closely examined. In all other cases of chemical combination, some change takes place in the density of the compound; but in the gases under consideration no such change ever happens, the specific gravity is always the mean of that of the gases be fore mixture. Besides, several of the gases that thus mix or combine, without any change in their density or other properties, are capable of entering into a still more intimate combination, in which they constitute a new substance possessed of very different properties. Thus oxygen and hydrogen form water, oxygen and azote form nitric acid. These, and several other phenomena, have induced Dalton to consider the notion of combination, in those cases in which the density and elasticity are not altered, as absurd.

It must be allowed, that Mr. Dalton's hypothesis accords very well with the phenomena, and explains, in a satisfactory manner, many circumstances which do not so well tally with the notion of combinations. According to this hypothesis, if m measures of A be mixed with n measures of B, the two will occupy $m + n$ measures of space. The particles of A meeting with no repulsion from those of B further than that repulsion which as obstacles in the way they may exert, would instantly recede from each other as far as possible in their circumstances, and consequently arrange themselves just the same as in a void space; their density, considered abstractly, becoming $\frac{m}{m + n}$, (that of the compound being supposed unity). In like manner the particles of B must recede from each other, till they become of the density $\frac{n}{m + n}$. Thus the two gases become rarefied to such a degree that their united forces only amount to the pressure of the atmosphere. Here the particles of one fluid not pressing at all upon those of the other, the consideration of specific gravity does not enter. That part of the atmospheric pressure which the fluid A sustains will be $\frac{m}{m + n}$; and the remainder, $\frac{n}{m + n}$, is the part that the fluid B sustains. The weight or pressure upon any one particle of any fluid mixture of this sort will arise solely from the particles of its own kind.*

And not to be mutually elastic.

* Manchester Memoirs, v. 453.

According to this statement, it follows, that when two gases are mixed, each occupies the whole space which constitutes the bulk of the whole; that the elasticity of the mixture is the sum of the elasticities of the two gases, supposing each to retain its new bulk; and that the bulk after mixture is the sum of the bulk of each before mixture.

Mr. Dalton has not brought any evidence in support of this very ingenious hypothesis, except its conveniency in accounting for the phenomena. It has been opposed by Mr. Gough and Mr. Berthollet with much keenness, but upon different grounds; the former conceiving it as inconsistent with the mechanical properties of elastic fluids; * the latter, as not according with their chemical properties.†

6. After considering the matter with attention, there still appear to me to be several circumstances inconsistent with the ingenious hypothesis of Dalton.

Objections to the last hypothesis.

It is certainly conceivable that the particles of one elastic fluid may not repel another, just as a magnet does not repel an electric body, though both magnetic and electric bodies are elastic towards each other; but if this non-elasticity exists, there can be nothing to hinder the particles of a gas from rushing into the space occupied by another when the two are brought into contact, except the mechanical resistance opposed by the particles against which those of either gas may impinge: but if we consider the great degree of compression which gases may be made to undergo, we cannot but allow that, under the common pressure of the atmosphere, the distance between their particles must be many times greater than their bulk. Of course, the resistance to the expansion from this impinging of one against another must be comparatively small. They ought therefore to rush into the space occupied by other gases almost with the velocity with which they rush into a vacuum. Neither ought the difference of specific gravity to produce so great a difference in the time of mixture as we find it does. These, and some other circumstances of a similar nature, do not seem to agree with the notion of non-elasticity; at least they have not been shown to agree with it.

If gases were mutually non-elastic, and if the slowness of their mixture were to be ascribed to their impinging

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* Phil. Mag. xxiv. 103.   † Statique Chimique, i. 485, &c.

against each other, it is impossible to conceive any reason why, in such a case, they should not combine together. Suppose oxygen and hydrogen gases in contact and mixing, why should the atoms of oxygen not unite with the atoms of hydrogen, against which they impinge and form water? We know that they have an affinity for each other; they are supposed by the hypothesis to come into contact, what then, if they have no repulsion, prevents them from uniting? In like manner, azote and hydrogen should form ammonia; azote and oxygen, nitrous gas, &c. Now, as this never happens except when one of the constitutents is destitute of elasticity, there is every reason to believe that it is this elasticity which prevents the union; and if so, the different gases must be mutually elastic.

But if we consider this mechanical obstacle which the particles of one gas oppose to the dilatation of another, it will be difficult to distinguish it from elasticity. Suppose a given bulk of one gas to be brought in contact with a given bulk of another, they remain for some considerable time before they begin to mix, the surface of the one presenting an obstacle to the expansion of the other. But this surface is kept in its place by the elasticity of the whole gas of which it constitutes a part. The gases cannot mix till this obstacle be removed. Now this appears to be allowing, in unequivocal terms, that the gases are mutually elastic.

I am disposed therefore to reject both the opinion of Berthollet, that the intimate mixture of the gases with each other is owing to *affinity*, and the hypothesis of Dalton, that different gases are not mutually elastic to each other. I conceive that when two gases are mixed the particles of each are beyond the sphere of the affinity of the particles of the other. If the elasticity be owing to the action of heat, it seems to follow as a consequence that different gases must be mutually elastic towards each other. But I think the elasticity itself is sufficient to account for this mutual mixture gradually taking place, without being under the necessity of having recourse to the hypothesis of Mr. Dalton.

7. The vapour of water and (for any thing we know to the contrary) all vapours mix with gases precisely in the same way as gases mix with each other. We are indebted to Mr. Dalton for the most complete set of experiments on *Vapours mix with gases in the same manner as gases.*

this subject. The following is the general conclusion which he was enabled to draw from his numerous trials. Let 1 represent the space occupied by any kind of gas of a given temperature, and free from moisture; p, the given pressure upon it in inches of mercury; f, the force of vapour from any liquid at that temperature in a vacuum : then the liquid being admitted to the air, an expansion ensues, and the space occupied by the air becomes $= 1 + \dfrac{f}{p-f}$, or, which is the same thing) $= \dfrac{p}{p-f}$. Thus let the temperature be 180°, $p = 30$ inches, and let the liquid be water; then $f = 15$ inches.* Then $\dfrac{p}{p-f} = \dfrac{30}{30-15} = 2.$ So that the bulk of the air in this case is doubled.†

Thus it appears that when a vapour and a gas are mixed, the elasticity of the mixture is the sum of the elasticities which the two constituents would have, supposing each to occupy the bulks of the whole; and that the volume of the mixture is equal to the sum of the volumes of the two constituents, supposing both separately subjected to the same pressure which the compound sustains after mixture. Now this is precisely what happens when two gases are mixed.

Opinions respecting the nature of the mixture. No less than three opinions have been advanced respecting the nature of the mixture of gases and vapour. According to the two first, the ingredients are chemically combined; according to the last, they are mechanically mixed.

According to the first opinion, the gas combines with the liquid and dissolves it, not in the state of a vapour, but of a liquid. The phenomena do not well accord with this hypothesis. Indeed the experiments of Dalton, just recited, are incompatible with its truth. It cannot therefore be admitted.

According to the second opinion, the gas dissolves the vapour precisely as one gas does another : or the vapour exists in a gaseous state, forming the same imperfect combination with the gas as mixed gases do with each other. This is the opinion which has been most commonly received ever since the hygrometrical experiments of Saussure and De Luc.

* Mr. Dalton's table of the force of vapour at different temperatures has been given in Vol. I. p. 537, of this Work.

† Manchester Memoirs, v. 572.

The third opinion is that of Mr. Dalton. According to him, the particles of gases and vapours are not mutually elastic to each other. When they are mixed, the elasticity of the vapour frees the gas from part of the pressure which it sustained. The gas of course dilates, in consequence of the excess of its elasticity, till its elasticity, when joined with that of the vapour, just balances the pressure. The two fluids are mixed, but do not act upon each other. Each of them supports a part of the pressure. If either of them be destroyed, and the other be made to sustain only its own part of the pressure, the bulk will not be altered. The reader will perceive that this is precisely the hypothesis respecting the mixture of gases which was stated above. Indeed it seems to have been the phenomena of the vapours, when mixed with gases, which first led Dalton to form that hypothesis.

This hypothesis explains the phenomena remarkably well. We see from it, why, other things being the same, the quantity of vapour is always proportional to the bulk of the gas, why all gases contain the same proportion of it, and why the bulk of the mixture is equal to the previous bulk of the two ingredients. But it is liable to the same difficulties as stated above when considering the mixture of gases.

I conceive that the phenomena are explicable without the supposition that gases and vapours are not mutually elastic towards each other. I consider the vapours as existing in gases in the elastic state. The small proportion of them, when compared to the gases, necessarily places their particles at such a distance, that small changes in the density of the gases do not bring the particles of vapour near enough to convert them into liquids.

8. Mr. Dalton has applied his hypothesis to the explana- tion of a very curious set of experiments made by Dr. Priestley. He found that when moist earthenware retorts are heated, the vapour of water passes outwards through the pores of the vessel, while at the same time the external air makes its way inwards through the same pores, and may be collected in considerable quantities.* He afterwards extended his experiments to different kinds of gases, and

* Priestley on Air, ii. 407.

found, that if the earthenware vessel be filled with one species of gas, and surrounded with another, if heat be applied, a portion of the gas makes its escape through the pores of the vessel, while an equal quantity of the external gas enters through the same pores.* The same thing takes place in bladders without the application of heat. If a bladder be filled with hydrogen gas and suspended in the air, it soon acquires the property of detonating, in consequence of the external air with which it is mixed. Mr. Dalton has shown that these curious experiments are easily explained by means of his hypothesis. The heat increases the size of the pores, which furnish a communication between the air without the vessel and the vapour or gas within. The two mix by means of these pores, for the same reason that they would mix if brought into contact in two vessels communicating with each other. † But it is not necessary to suppose the truth of Dalton's hypothesis to explain these phenomena: the same mixture ought to take place even though the two gases be mutually elastic, provided pores exist in the vessel.

Distillation in close vessels full of air, impracticable.

9. Fontana made a set of experiments on distillation, and published them in 1779. These experiments show that air is not passive in cases of evaporation, as it must be according to Dalton's hypothesis. He united two matrasses together by means of a glass tube, and sealed the joinings hermetically. One of the matrasses contained water, the other was empty. He made the water boiling hot, and kept it in that state, while the other matrass was kept cool ; but the water did not distil over into the empty matrass. In like manner, ether exposed to a heat of above 140° in the one matrass, while the other was surrounded with ice, refused equally to distil over. ‡ These experiments, if we allow them to be correct, show very decisively that air is not passive; for had the matrass been previously deprived of air, we know that the liquids would have distilled over very readily. Nothing can prove more decisively that gases and vapours are mutually elastic; for it can be the elasticity of the enclosed air alone, greatly increased by the heat, which not only retards, but prevents the distillation.

* American Phil. Trans. v. 14.   † Phil. Mag. xxiv. 14.
‡ Berthollet, Statique Chimique, i. 498.

SECT. III.

OF THE COMBINATION OF GASES.

THERE are various elastic fluids which have the property of uniting together, and of forming a new compound, either gaseous or not, and which possesses very different properties from the constituents of it when merely mixed. Now these gaseous bodies may be divided into two classes; some combine in all circumstances by mere mixture; others only unite in particular states.

I. The following table exhibits a list of the gases that unite by mere mixture, and of the products which they form.

1. Gases which combine by mixture.

	Products.
Oxygen with nitrous gas	{ Nitrous acid { Nitric acid
Ammonia with vapour	Liquid ammonia
muriatic acid....	Muriate of ammonia
fluoboric acid....	Fluoborate of ammonia
fluosilicic acid ...	Fluosilicate of ammonia
carbonic acid....	Carbonate of ammonia
sulphurous acid..	Sulphite of ammonia
sulphuret. hyd. ...	Hydrosulph. of amm.

1. It was first observed by Gay-Lussac and made out by him, by a set of observations and experiments that appear satisfactory, that gaseous bodies unite always either in equal volumes, or 1 volume of the one with 2, 3, &c. volumes of the other.* The following table exhibits the volumes of the preceding gases that are capable of uniting together, and the names of the products which they form.

Volumes.	Products.
Oxygen 100 + 133 nitrous gas.	Nitric acid
Oxygen 100 + 200 nitrous gas.	Nitrous acid
Ammonia 100 + 100 muriatic acid.	Sal ammoniac
Ammonia 100 + 100 fluoboric acid	Fluoborate of ammonia
Ammonia 100 + 50 fluoboric acid	Subfluoborate of ammonia
Ammonia 300 + 100 fluoboric acid	
Ammonia 100 + 50 fluosilicic acid........	Fluosilicate of ammonia
Ammonia 100 + 100 carbonic acid	Carbonate of ammonia
Ammonia 100 + 50 carbonic acid	Subcarbonate of ammonia
Ammonia 100 + 100 sulphurous acid	Sulphite of ammonia
Ammonia 100 + 100 sulphureted hydrogen..	Hydrosulphuret of amm.

* Mem. d'Arcueil, ii. 207

II. The gases which may be mixed without any striking combination, though they are capable of uniting in certain circumstances, are by no means numerous. The following table exhibits a list of them, and of the products which they form when united.

		Products.
Oxygen with	hydrogen	Water
	carbonic oxide	Carbonic acid
	azote	Nitric acid
	chlorine	Chloric acid
	sulphurous acid	Sulphuric acid
	nitrous oxide	Nitric acid
Hydrogen with chlorine		Muriatic acid
	iodine	Hydriodic acid
Hydrogen with cyanogen		Hydrocyanic acid
Chlorine with carbonic oxide		Chlorocarbonic acid

1. These, like the preceding gases, combine either in equal volumes, or in volumes that are multiples of each other, as was first observed by Gay-Lussac, and as will appear by the following table :

Volumes.				Products.
Oxygen	100	+ 200	hydrogen	Water
Oxygen	50	+ 100	carbonic oxide	Carbonic acid
Oxygen	250	+ 100	azote	Nitric acid
Oxygen	250	+ 100	chlorine	Chloric acid
Oxygen	50	+ 100	sulphurous acid	Sulphuric acid
Oxygen	200	+ 100	protoxide of azote	Nitric acid
Chlorine	100	+ 100	hydrogen	Muriatic acid
Iodine	100	+ 100	hydrogen	Hydriodic acid
Cyanogen	100	+ 100	hydrogen	Hydrocyanic acid

2. The greater number of these products are permanently elastic fluids, belonging to that class which possess the gaseous properties less completely, or which approach to the state of vapours; the rest are liquids. Thus it appears that these gaseous bodies, by combination, lose a portion of their elasticity.

3. Oxygen combines with hydrogen and with carbonic oxide by combustion, while it unites with azote by means of electricity, or at the temperature at which hydrogen burns. Thus these bodies, though they do not unite spon-

taneously, may combine, while the two ingredients which enter into union are both in a gaseous state. It is highly probable that heat and electricity in these cases act precisely in the same way.

Now, if the common opinion be true, that gases are compounds of bases and heat, and that when they combine they lose a great quantity of caloric, it may seem at first sight difficult to conceive how heat causes them to unite together. That a body which increases the repulsion of the gases should, by its accumulation, occasion their union or the destruction of that repulsion, seems, at first sight, a contradiction. Monge, long ago, offered a very ingenious solution of this difficulty, which has been generally received as the true one. Repulsion is a force which occasions motion. If, by any means, the repulsive force of one atom of a gas be increased, this atom will act with increased energy upon all the neighbouring atoms; it will set them in motion, and they in their turn will act upon those in their neighbourhood, and thus the motion will be propagated through the whole fluid. Suppose, in a mixture of oxygen and hydrogen gas, that an atom of oxygen were suddenly heated; it would act with increased energy on the atom next to it, and drive it against the atom next farthest off. The rapidity of the motion of the repelled atom will increase with the temperature of the repelling atom. Now we may conceive the heat of this repelling atom to be increased to such a pitch as to drive off the neighbouring atoms with such velocity that they shall approach indefinitely near other atoms before they have time to remove. But when an atom of oxygen approaches indefinitely near an atom of hydrogen, they will combine and form water. The combination is attended with the disengagement of heat, which repels the atoms in the neighbourhood, and thus propagates the combination. According to this explanation, caloric occasions the union of two gases, not by dilating, but by compressing their atoms, and forcing them indefinitely near each other; and electricity confessedly acts in the same way.

According to this notion, heat acts only indirectly when it occasions the combination of gaseous bodies: by forcibly expanding one portion of the gas, a sudden compression is produced in the portion in the neighbourhood. This com-

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pression causes the atoms to combine; and if the combination is attended with the evolution of heat in sufficient quantity, the same thing is constantly renewed till the whole gaseous mixture has combined. Hence those gases only combine when set on fire which give out a great deal of heat in the act of union, as oxygen and hydrogen, oxygen and carbonic oxide. Others, which combine without the evolution of much heat, as oxygen and azote, require constant renewals of the external agent, and after all, it is difficult to unite a whole mixture of these gases; a great part usually escapes untouched. Hence the reason why azote and oxygen combine only when exposed to the repeated shocks of electrical explosions, or when assisted by the constant heat of burning hydrogen. That compression has the property of causing oxygen and hydrogen to combine has been proved by the experiments of Biot. It has the same effect upon all those bodies that give out much heat when they unite. Hence the reason why so many substances detonate when suddenly struck upon an anvil, or when smartly rubbed between two hard bodies. Sir H. Davy has lately made a curious set of experiments on this subject, and has shown that the combustion and explosion of gaseous mixtures depends upon the temperature entirely; that each has a particular temperature at which it explodes.* He concludes from this fact that the hypothetical explanation of Monge is inaccurate. I do not however see any incompatibility between the two. Indeed if we consider that gaseous mixtures do not explode unless when mixed in certain determinate proportions, it cannot but give a tendency to adopt the opinion that the combination is the effect of the pressure produced by the great evolution of heat.

Sulphurous acid and oxygen.   4. It is probable, that when sulphurous acid gas and oxygen are mixed together, they combine and form sulphuric acid: but, as the experiment has not been made in a decisive manner, as no remarkable appearance takes place when the two gases are mixed together, I have not ventured to arrange them among those which combine spontaneously. Dr. Priestley left a mixture of sulphurous acid gas and common air standing over mercury for two

* Annals of Philosophy, ix. 151.

days in a jar. On absorbing the gas, and examining the common air, he found that it had been deprived of a portion of its oxygen.* The two are known to combine in a red heat; but whether a portion of sulphur be first separated, and then enters into combustion, has not been ascertained.

5. All the gaseous bodies contained in the preceding table can be made, by any of the methods with which we are acquainted, to unite in one proportion only; and if we apply Dalton's hypothesis to the compounds formed, we shall find that the gases unite, either atom to atom, or two atoms of one to one atom of the other. Whenever oxygen and hydrogen gas combine, the product is water; oxygen and carbonic oxide gas produce carbonic acid, and oxygen and azotic gas always nitrous acid. This is the more remarkable, because the bases in the last case are capable of uniting in various proportions. What fixes them down to this particular compound, nitrous acid, when both are gaseous?

These gases unite only in one proportion.

6. Several of these gases experience a marked condensation when they combine. The degree of this can be ascertained with more accuracy than in the first set of gases, because few of them change their form. It may be seen in the following table. The first column exhibits the volumes of the gases which combine; the second, the volume of the compound formed, supposing it to remain in the gaseous state; and the last shows the condensation or the volumes which have disappeared by the condensation.

Condensation occasioned by the combination.

Constituents.	Volumes of ditto.	Products.	Volume of ditto.	Volumes condensed.
Oxygen Hydrogen	1 2	Water	2	1
Oxygen Carbonic oxide	1 2	Carbonic acid	2	1
Oxygen Azote	2·5 1	Nitric acid	1 ?	2·5 ?

* Priestley on Air, ii. 316.

Constituents.	Volumes of ditto.	Products.	Volume of ditto.	Volumes condensed.
Oxygen Chlorine	2·5 1	Chloric acid	Unknown	Unknown
Oxygen Sulphurous acid	1 2	Sulphuric acid	1·2	1·8
Oxygen Protoxide of azote	2 1	Nitric acid	1 ?	2 ?
Hydrogen Chlorine	1 1	Muriatic acid	2	0
Hydrogen Iodine	1 1	Hydriodic acid	2	0
Hydrogen Cyanogen	1 1	Hydrocyanic acid	2	0
Chorine Carbonic oxide		Chlorocarbonic acid		

3. Gases which decompose each other on mixture.

III. Besides the two set of gases described in the preceding part of this Section, there are two others which deserve attention, because, though they do not combine together, yet they have a marked action upon each other. The first set mutually decompose each other whenever they are mixed, and produce new compounds of a different nature; the second set do not act on each other spontaneously, but they may be made to decompose each other in peculiar circumstances.

1. The following table exhibits a list of the principal gases, which mutually decompose each other when mixed together.

Oxygen with .... phosphureted hydrogen
Chlorine with .... ammonia
        phosphureted hydrogen
        carbureted hydrogen
        olefiant gas
        sulphureted hydrogen
        nitrous gas
Sulphureted hydrogen with nitrous gas
        sulphurous acid

2. The decompositions in the first three cases in the table are attended with combustion; for phosphureted hydrogen gas immediately takes fire when mixed with oxygen gas or chlorine, as does ammonia when mixed with the latter gas. The other decompositions take place without any sensible combustion; and yet, what is singular, some of the new substances formed seem in every case to be products of combustion.

3. Phosphureted hydrogen is a compound of a gas and a solid or non-elastic body. We may consider it as phosphorus dissolved in hydrogen, and of course deprived of its cohesion. This increases the facility with which oxygen acts upon it, and enables it gradually to combine with that principle at the temperature of the atmosphere, precisely as happens when it is dissolved in azotic gas: But when the proportion of the two gases coming in contact is considerable, the temperature produced is sufficient to set fire to the hydrogen, or to cause it to combine with oxygen. This accounts for the brilliancy with which phosphureted hydrogen burns: it accounts also for the deposit of phosphorus sometimes observable when the quantity of oxygen gas is not sufficiently great. Hydrogen has a stronger affinity for oxygen than phosphorus; but its elasticity prevents the combination. The phosphorus being neither restrained by elasticity nor cohesion, begins the combination, and supplies the requisite temperature. The hydrogen then burns rapidly, or combines with oxygen in preference to the phosphorus; which of course must remain only partially combined with oxygen, unless there be a sufficient supply of that principle. The products when the combustion is complete, are water and phosphoric acid; when the combustion is incomplete, water, phosphorous and hypophosphorous acids.

4. The spontaneous combustion of ammonia in chlorine is owing to the combination of the hydrogen of the ammonia with the chlorine, and the subsequent union of the muriatic acid formed with the undecomposed ammonia. Exactly one fourth of the ammonia is decomposed; and the gases to obtain a complete effect must be mixed in the proportion of 8 volumes of ammonia to 3 volumes of chlorine. For the 8 volumes of ammonia are equal to 6 + 2 volumes, and 2 volumes of ammonia contain 3 vo-

lumes hydrogen + 1 volume azote. The three volumes of hydrogen uniting with the three volumes of chlorine will form 6 volumes of muriatic acid, which uniting with the 6 volumes of undecomposed ammonia form solid sal ammoniac, while 1 volume of azotic gas remains behind. So that a mixture of 8 cubic inches of ammonia, and 3 cubic inches of chlorine will form 3·3675 grains of sal ammoniac, and 1 cubic inch of azote will remain in the gaseous form. The gaseous product of such a decomposition amounts to $\frac{1}{11}$th of the original bulk of the gaseous mixture.

5. As phosphorus, even in the solid state, rapidly melts, and burns with a pale white flame in chlorine gas, we need not be surprised that phosphureted hydrogen gas, in which the phosphorus is in a much more favourable state for combustion, should exhibit the same phenomenon. The flame is more lively than when the gas burns in common air. Three volumes of chlorine are required for the decomposition of 1 volume of phosphureted hydrogen. Two of the volumes combine with the phosphorus and convert it into bichloride of phosphorus. The other volume uniting with the hydrogen becomes muriatic acid.

6. When carbureted hydrogen and olefiant gas are mixed with chlorine, each previously as dry as possible, little immediate effect is produced. But the chlorine gradually unites to the hydrogen of the combustible gas and is converted into muriatic acid, while the carbon is precipitated. This effect is facilitated by heat or electricity.

7. Chlorine unites with both of the constituents of sulphureted hydrogen, and the products are chloride of sulphur and muriatic acid. Two volumes of chlorine are necessary for every volume of sulphureted hydrogen.

8. Chlorine has no action on deutoxide of azote, as has been ascertained by the experiments of Sir H. Davy, and by my own. But if a little water be admitted, or if the experiment be made in vessels moistened with water, nitric or nitrous acid, and muriatic acid are formed. This had been observed by Humboldt,[*] but he was not aware of the necessity of the presence of water.

Nitrous gas and sulphureted hydrogen.

9. The spontaneous decomposition produced when nitrous gas and sulphureted hydrogen gas are mixed to-

* Ann. de Chim. xxviii. 142.

gether, was first observed by Mr. Kirwan. The gases ought to be dry, otherwise their mutual action is greatly impeded. This mutual action of these two gases was also ascertained by Austin,* and was afterwards more minutely examined by Davy,† who confirmed the fact previously asserted, that no sulphurous or sulphuric acid is formed; and showed that the new compounds are protoxide of azote, ammonia, and water; and that the nitrous gas suffers a diminution in bulk, varying from 0.55 to 0.7. During the decomposition a quantity of sulphur is deposited. This decomposition does not accord very well with the atomic theory. Let us suppose a mixture of four volumes nitrous gas, and five volumes of sulphureted hydrogen. The constituents of these will be as follows :

$$\begin{aligned}
\text{Oxygen gas} & \dots\dots\dots\dots & 2 \text{ volumes} \\
\text{Azotic gas} & \dots\dots\dots\dots & 2 \\
\text{Hydrogen gas} & \dots\dots\dots & 5 \\
\text{Sulphur} & \dots\dots\dots\dots & 5
\end{aligned}$$

Now these volumes ought to be converted into an integrant particle of ammonia, an integrant particle of water, and an integrant particle of protoxide of azote.

	Oxygen volumes.		Azote volumes.		Hydrogen volumes.
Ammonia is composed of ...	0	+	1	+	3
Water....................	1	+	0	+	2
Protoxide of azote.........	1	+	2	+	0
	2		3		5

It is evident that a volume of azote is wanting. If we supply this by increasing the quantity of nitrous gas to six volumes, there will in that case be 1 volume of oxygen gas redundant. On this last supposition, which is the most probable, the residual gas will be a mixture of 1 volume protoxide of azote, and 1 volume of oxygen gas.

Such are the phenomena of the action of those gases on each other, which mutually decompose each other spontaneously. Almost the whole of them consist in the action of a supporter on a compound combustible; the new compounds are usually products of combustion; of course the

* Phil. Trans. 1788, p. 384. † Researches, p. 203.

process is similar to combustion, and heat we may presume is evolved. The action is facilitated by the diminished elasticity and loose state of combination of one of the ingredients. The products in some of these mixtures are constant; but in others they vary with the proportion of the ingredients of the decomposing gases.

IV. The gases which mix without spontaneous decomposition, but which may be made to decompose each other in particular circumstances, as on the approach of an ignited body, when electric explosions are passed through them, &c. are more numerous than the preceding.

4. Gases which decompose only in certain circumstances.

1. The following table exhibits a list of the most remarkable of these mixtures:

Oxygen with sulphureted hydrogen
    carbureted hydrogen
    olefiant gas
    vapour of ether
    ————— alcohol
Nitrous oxide with hydrogen
     phosphureted hydrogen
     sulphureted hydrogen
     carbonic oxide
     carbureted hydrogen
     olefiant gas
     vapour of ether
     vapour of alcohol
     sulphurous acid
Nitric acid with hydrogen, and probably all the preceding
     combustible gases and vapours
   sulphurous acid
Nitrous gas with hydrogen
     sulphurous acid
Hydrogen with sulphurous acid
Hydrogen with carbonic acid
Vapour of water with carbureted hydrogen
     olefiant gas

These decompositions are of two kinds: some are accompanied or produced by combustion, and are of course instantaneous; others take place without combustion, and are of course very slow. The first kind supposes the mixture of a gaseous supporter of combustion with a combus-

tible gas : the second supposes either the absence of a supporter, or the presence of one which cannot be decomposed by the combustible base, or, finally, the absence of a combustible base. The list of the compound gases capable of decomposing each other without combustion is probably very incomplete.

2. Sulphureted hydrogen gas may be kept mixed with common air or oxygen without undergoing any change; but if the mixture be made to approach an ignited body, combustion immediately takes place, and the products vary according to the proportion of the gases mixed. If the oxygen be small, or (which is the same thing) if it be admitted slowly, as by setting fire to a phial full of sulphureted hydrogen gas standing in the open air, in that case a great proportion of the sulphur is deposited unaltered, and some sulphurous acid is formed. In this case we see that it is the hydrogen which burns. The combustion is analogous to that of pure hydrogen. The heat produced is sufficient to set fire to a portion of the sulphur, but the greatest part escapes unaffected. If sulphur were combustible at as low a temperature as phosphorus, sulphureted hydrogen would burn spontaneously as well as phosphureted hydrogen. It is this circumstance which distinguishes them: The phenomena of the combustion are absolutely the same. It is the hydrogen which unites with oxygen, and not the solid which it holds in solution. But the heat evolved is sufficient to maintain the combustion of this solid; accordingly it also combines with oxygen, if the proportion of that principle be sufficient.

3. The phenomena attending the combustion of carbureted hydrogen and olefiant gas with oxygen have been examined by Cruikshanks, Berthollet, Henry, and myself. When the volume of oxygen is sufficient to saturate both the constituents of these gases nothing is formed but water and carbonic acid. Carbureted hydrogen requires twice its volume, and olefiant gas thrice its volume of oxygen gas to produce complete decomposition. When olefiant gas is mixed with a smaller quantity of oxygen gas than is requisite to consume it completely, and when an electric spark is passed through the mixture, a detonation takes place, charcoal is precipitated, and the gaseous residue is more bulky than the original gas before explosion. Thus

Book III. in my experiments a mixture of 4 volumes olefiant gas and 3 volumes oxygen gas, left a residue amounting to 11 volumes. This residue there is reason to believe is a mixture of carbonic oxide and hydrogen gas. So that a portion of the hydrogen is set at liberty by the deposition of the carbon; while a portion of the carbon is converted into carbonic acid, and another portion into carbonic oxide.* Sir H. Davy has shown that carbureted hydrogen is the least combustible of all the combustible gases.

Ether an oxygen.

4. Dr. Ingenhousz first discovered that the vapour of ether has the property of detonating with common air and oxygen gas. Cruikshanks discovered that the detonation takes place only when a certain proportion of the elastic fluids are mixed, and that in that case the decomposition is complete. The same remarks apply to the vapours of alcohol. These two vapours, then, agree exactly with carbureted hydrogen and olefiant gas in the nature of the decompositions which they undergo when fired with oxygen gas, as they correspond with them in the elements of which they are composed.

Cruikshanks found, that when one measure of the vapour of ether is mixed with seven measures (or more precisely 6·8) of oxygen, the mixture explodes by electricity with prodigious violence; that the decomposition is complete, the residual gas, amounting to 5 (or rather 4·6) measures, being carbonic acid. Mr. Dalton hit upon a very simple and ingenious method of producing this detonation and decomposition at pleasure. He puts into a detonating tube any quantity of oxygen gas, and lets up into it (standing over water) a little ether. Its bulk immediately increases, in consequence of the conversion of a portion of the ether into vapour; so much so as to be sometimes doubled. By agitating the tube a little, a portion of this vapour is dissolved in the water, and of course the bulk of the gas diminishes. By repeating these agitations, the proportion of ether left may be diminished at pleasure. We have only to continue them till the bulk is $\frac{1}{7}$th more than before the admission of the ether; for then we know that the vapour of the ether amounts just to $\frac{1}{8}$th of the whole.

From the experiments of M. de Saussure, junior, it fol-

* Memoirs of the Wernerian Society, i. 521.

lows that both ether and alcohol vapour may be considered as mixtures of olefiant gas and vapour of water, in the proportions pointed out in a preceding chapter of this work.* Hence the observations just made on the combustion of olefiant gas will apply equally to these vapours.

5. The phenomena which take place when the combustible gases are fired with nitrous oxide, are similar to those that happen when they are fired with oxygen. The products vary with the proportion of the ingredients; but they are always constant when the quantity of nitrous oxide is sufficiently great to produce complete decomposition. As this supporter of combustion is itself a compound, it is always decomposed by its action on the other gas, and this adds greatly to the complexness of the result. It is to Davy that we are indebted for the most exact set of experiments on these decompositions.

Nitrous oxide.

It may be inferred from the experiments of Davy and the observations of Gay-Lussac, that when equal volumes of protoxide of azote and hydrogen are fired by electricity, water is formed, and a quantity of azote evolved, amounting exactly to the original volume of the protoxide of azote. Hence the phenomenon is precisely the same as when oxygen and hydrogen are exploded by electricity. The whole of the azote is set at liberty, and the whole oxygen of the protoxide of azote combines with the hydrogen.

6. When 1 volume of phosphureted hydrogen is mixed with 3 volumes of protoxide of azote, and the mixture burnt by means of electricity, there remains after the explosion exactly 3 volumes of azotic gas. Hence the combustion is the same as if the phosphureted hydrogen had been mixed with $1\frac{1}{2}$ volume of oxygen gas. The azote is entirely passive.

Indeed it is not necessary to enter into details respecting the action of protoxide of azote on the combustible gases. It is exactly analogous to the action of oxygen gas on the same elastic fluids. We have only to use double the volume of protoxide of azote to obtain the very same products as with oxygen, and there will always remain behind a residue of azote equal in volume to the protoxide employed.

7. There can be little doubt that nitrous gas or deut-

* See Vol. ii. p. 328 and 333.

Book III. oxide of azote will act upon combustibles exactly as prot-oxide of azote. Davy indeed could not succeed in firing mixtures of nitrous gas and hydrogen, or phosphureted hydrogen.* But this was probably from not having hit upon the requisite proportions. For I found no difficulty in my experiments to fire such mixtures. Indeed nitrous gas and phosphureted hydrogen explode spontaneously if a bubble of oxygen gas be let up to the mixture of them.

Nitrous gas and nascent hydrogen. There is a decomposition of nitrous gas by nascent hydrogen extremely difficult to explain. It was first ob-served by Priestley and Austin, and afterwards examined by Davy.† It takes place when moist iron is placed in con-tact with nitrous gas. The iron is oxidized at the expense of the water, hydrogen is evolved, the nitrous gas is con-verted into nitrous oxide, and some ammonia is formed. 100 measures of nitrous gas, by this process, are reduced to about 41⅔ measures of nitrous oxide, indicating a loss of 58⅓ per cent. The simplest explanation is to suppose that 2 volumes of hydrogen are evolved for every 4 volumes of nitrous gas. These two volumes when nascent would com-bine with 1 volume of oxygen from the nitrous gas, and would leave 1 volume of oxygen and 2 volumes of azote, which by condensing into half the bulk of the nitrous gas would form protoxide of azote. On that supposition the diminution of the gas ought to be half its former bulk, and no ammonia ought to be formed. I am disposed to believe that this is really what takes place, and that the formation of ammonia is owing to some unknown action of the iron itself.

8. In the remaining examples of decomposition exhibited in the table no combustion takes place ; the change is slowly produced by the continued action of electricity, and is in several instances not a little complicated.

Hydrogen and carbo-nic acid. One of the most remarkable of these decompositions is what happens when a mixture of hydrogen and carbonic acid are subjected to electric explosions, or passed through a red-hot tube. In both cases water is formed, and carbonic oxide evolved. Indeed, from the observations of Saussure, it is probable that this decomposition takes place spontane-ously. This change can be ascribed only to the superior

* Researches, p. 136.

† Priestley, ii. 41, and 54 ; Austin, Phil. Trans. 1788, p. 383 ; Davy, Researches, p. 206.

affinity of hydrogen for oxygen. It is curious that the Chap. II. elasticity of the hydrogen does not prevent its combination with oxygen, especially as that oxygen is intimately combined with another principle.* It is extremely probable that many similar decompositions are going on in the atmosphere.

When electric sparks are taken in carbureted hydrogen Vapour and containing the vapour of water, the bulk is increased, and carbureted hydrogen. carbonic acid formed.   Henry has shown that in this case water is decomposed, its hydrogen set at liberty in the elastic state, while its oxygen combines with a portion of the carbon of the gas, and forms carbonic acid.   This decomposition seems at first sight incompatible with the well-known greater affinity of oxygen for hydrogen than for carbon.   It appears directly the reverse of the last example, in which hydrogen decomposed carbonic acid by the same means.   Nor does it seem possible to explain it without having recourse to the doctrine of Berthollet, of the great effect of mass in chemical action.   In the first case, the hydrogen bears a considerable proportion to the carbon; but in the second, the proportion of carbon is much greater than that of hydrogen.

SECT. IV.

OF THE COMBINATION OF GASES WITH LIQUIDS.

As liquids and gases are in a different state, and as the particles of the latter must be brought into a more condensed state by their union with liquids in any notable proportion, the elasticity of the gases must oppose a resistance to this kind of combination, and regulate the proportion of elastic fluid which any liquid is capable of absorbing.   Below this proportion, it is obvious that a liquid will unite with any quantity, indefinitely, of a gas for which it has an affinity. Thus the only fixed point in these combinations is when the elasticity of the gas is just balanced by the affinity.   The

* See the experiments of Saussure, Jour. de Phy. liv.; and of Clemen and Desormes, Ann. de Chim. xxxix.

liquid is then said to be *saturated* with the elastic fluid, be-
cause it will not absorb any more of it.

Though the number of liquid bodies is pretty consider-
able, the action of one only, namely *water*, upon the gases,
has hitherto occupied almost exclusively the attention of
chemists. To it, therefore, we must confine ourselves in
the present Section. A few observations only can be offered
on the other liquids.

That water has the property of absorbing a certain por-
tion of air, which may be again separated by boiling, has
been known ever since the discovery of the air pump. That
if previously freed from air, it will take up some part of
every gaseous fluid whatever, was early perceived by Dr.
Priestley, who directed a good deal of his attention to the
effect which water produced upon different kinds of air.
Mr. Cavendish ascertained the proportion of carbonic acid
gas absorbed by air in different circumstances. Priestley
made similar experiments upon a variety of other gases.
The subject was prosecuted by Delametherie, Senebier, and
other foreign chemists; but it is to the recent experiments of
Dr. Henry, Mr. Dalton, and M. de Saussure, that we are
indebted for almost all the precise notions which we possess
respecting this curious subject.

The gases, if considered with reference to their absorp-
tion by water, may be divided into two classes; those that are
absorbed in a small proportion, and those that are absorbed
in a great. Almost all the gases belong to the first class;
ammonia, muriatic acid gas, and a few other acid gases, are
the only ones known at present which belong to the second.
We shall consider, in the first place, the union of the first
class of gases, and afterwards those of the second class.

I. The following table exhibits a list of the gases which
are but little absorbable by water, placing them in the
order of their absorption, and beginning with the least ab-
sorbable:

Azotic gas	Oxygen gas
Hydrogen gas	Nitrous gas
Arsenical hydrogen	Olefiant gas
Carbureted hydrogen	Nitrous oxide
Carbonic oxide	Carbonic acid
Phosphureted hydrogen	Sulphureted hydrogen

1. When water, impregnated with any of these gases, is placed under the exhausted receiver of an air pump, the gas separates from the water and assumes its elastic form. Hence it follows, that the force by which these gases are retained by water is inferior to that of their elasticity. They continue in the water only as long as they are subjected to an external pressure, equal to that which they sustained when the water was impregnated with them. If this pressure be increased, the proportion of them which water is capable of taking up increases; if the pressure be diminished, the proportion taken up by water dimishes in like manner. Hence, in making experiments, similar results can be obtained only when the pressure is the same, or when the barometer stands at the same height.

The quantity of gas taken up by water is likewise affected by the temperature, because the temperature increases the elasticity. The quantity of gas absorbed diminishes as the temperature increases, and increases as the temperature diminishes. Similar results, therefore, can be obtained only when the thermometer stands at the same point.

Common water always contains a certain quantity of air, which varies in its nature and proportion according to circumstances. This air affects the power of water to absorb gases. Similar results can only be obtained when it is removed. This is done by subjecting the water to long boiling, or by placing it under the exhausted receiver of an air pump.

2. When the pressure, temperature, and purity of the water are the same, then water absorbs a determinate quantity of every individual gas. This has been decisively demonstrated by the experiments of different chemists, especially by those of Dr. Henry, Mr. Dalton, and M. de Saussure. It is by no means an easy matter to determine with accuracy the absolute quantity or bulk of gas which water will take up, because that is affected by a variety of circumstances that cannot always be appreciated. The experiments of the three chemists just mentioned are most to be depended on. Those of Dr. Henry were made with much precision, and with an apparatus well calculated to ensure accuracy; while that of Dalton is distinguished by that simplicity which characterizes all his experiments. Dr. Henry employed a glass syphon, one of the legs of which

was long and narrow, the other was a cylindrical glass much wider, and terminating both above and below in a stop-cock. This vessel was accurately graduated, as well as the narrow leg of the syphon. The horizontal portion of this syphon consisted partly of a tube of caoutchouc, which made it flexible, and enabled the operator to agitate the glass cylinder, or wide leg of the syphon, without risking the fracture of the whole. The cylindrical vessel was first filled with mercury. The requisite portion of water was introduced by the upper stop-cock, while the same bulk of mercury escaped by the lowermost stop-cock. The requisite portion of gas was introduced over the water in the same way. Thus the surface of the mercury was made horizontal in both legs of the syphon. The wide leg was agitated. The subsidence of the mercury in the narrow leg marked the absorption, and the quantity of mercury, added to restore the horizontal level, gave correctly the bulk of the gas which was taken up by the water.* Mr. Dalton employed a phial provided with a very accurate ground-stopper for the less absorbable gases, and for the more absorbable, a glass tube accurately graduated. It was filled with the gas, a small portion was expelled under water, and a little water admitted; it was then agitated, the mouth being shut with the finger. The finger being removed occasionally under water, the quantity of that liquid which entered marked the proportion of gas absorbed.†

The following table exhibits the bulk of each gas absorbed by 100 cubic inches of water at the temperature of 60°, according to the experiments of these philosophers:

	Absorption according to.		
Gases.	Henry.	Dalton.	Saussure.
Sulphureted hydrogen	106	100	253
Carbonic acid	108	100	106

* See Phil. Trans. 1803, and Nicholson's Jour. vi. 229. The only exceptionable part of this apparatus was the caoutchouc joint. It would yield somewhat according to the weight of mercury, and thus prevent the absorption from being accurately measured by the height of the mercury in the narrow leg of the syphon.

† See Manchester Mem. Vol. i. second series; and Phil. Mag. xxiv. 15. For a description of the apparatus of de Saussure, I refer to the Annals of Philosophy, Vol. vi. p. 346, and Vol. vii. p. 218.

	Absorption according to			Chap. II.
	Henry.	Dalton.	Saussure.	
Nitrous oxide	86	100	76	
Olefiant gas	—	12·5	15·3	
Nitrous gas	5·	3·7	—	
Oxygen gas	3·7	3·7	6·5	
Phosphureted hydrogen ..	2·14	—	—	
Carbureted hydrogen	1·4	3·7	5·1	
Azotic gas.............	1·53	1·56	4·1	
Hydrogen	1·61	1·56	4·6	
Carbonic oxide..........	2·01	1·56	6·2	

The difference between these columns is not greater than might be expected in experiments of such delicacy. Indeed, in several instances, this difference may be explained in a satisfactory manner. But it is necessary to mention, in the first place, that Mr. Dalton's numbers are not the direct results of his experiments, but these results corrected by the application of a theory which he invented; whereas Dr. Henry's and de Saussure's are without any such correction.

Mr. Cavendish found, that at 55° Fahrenheit 100 inches of water absorbed in some cases 116 inches of carbonic acid, or nearly 1⅕ time its bulk. Dr. Henry likewise found the quantity exceed the bulk of the water. Now it is difficult to see, from his experiments on the absorption of this gas, how the error, at least of Cavendish, should be on the side of excess. We may presume, therefore, that Mr. Dalton's number is rather small. The same reasoning applies to sulphureted hydrogen.

Mr. Dalton informs us, that he has succeeded in making water absorb very nearly its own bulk of nitrous oxide.* In Dr. Henry's first experiments, he found the absorption of this gas only 50;† while Davy stated it at 54.‡ It has been since ascertained, that this deficiency was owing to the impurity of the gases examined. I consider Saussure's number as pretty nearly correct.

The quantity of nitrous gas absorbed by water is usually greater than it ought to be, because water contains a little oxygen gas; this gas combines with and converts a portion

* Phil. Mag. xxiv. 15.   † Nicholson's Journal, vi. 231.
‡ Researches, p. 140.

of the nitrous gas into nitrous acid. For this reason we may consider Mr. Dalton's statement respecting this gas as nearly correct.

The carbureted hydrogen gas examined by Dalton was from marshes, and of course pure. Dr. Henry does not mention the source from which he procured his. If it was from moist charcoal, as is not unlikely, the greatest part of it must have been carbonic oxide, which would account for the difference between his statement of the absorbability of carbureted hydrogen and that of Dalton. Upon the whole, Dalton's numbers do not deviate far from the truth.

Mr. Dalton is of opinion that Saussure is wrong in the absorbability of oxygen, azote, and indeed all the gases which are but very little absorbable by water. He conceives the error to proceed from the capacity of the vessel, in which the gases were measured, having been ascertained while it was dry, but the gases were put into it, and their quantity measured when the inside surface of the vessel was moist.*

3. Were we to consider Dalton's table as correct, it would follow from it that all these gases may be arranged under four sets. Water absorbs its own bulk of the first set, $\frac{1}{8}$th of its bulk of the second set, $\frac{1}{27}$th of its bulk of the third set, and $\frac{1}{64}$th of its bulk of the fourth set. But these fractions are the cubes of the reciprocals of the natural numbers; thus $\frac{1}{1^3}$, $\frac{1}{2^3}$, $\frac{1}{3^3}$, $\frac{1}{4^3}$. Now this very unexpected consequence follows from this, that the distance between the particles of each gas, when contained in the water, is always either the same as before its absorption, or some multiple of it. In the first series of gases it is the same. The density of carbonic acid, sulphureted hydrogen, and nitrous oxide, and the distance between their particles, is the same in water as when they constitute an elastic atmosphere. The density of olefiant gas is $\frac{1}{8}$th, and the distance between its particles twice as great as when constituting an elastic atmosphere. The density of oxygen, and the other gases which constitute the third series, is $\frac{1}{27}$th, and the distance between their particles three times as great when in water as when constituting an elastic atmosphere. The

* Annals of Philosophy, vii. 218.

density of azote and the fourth series of gases is $\frac{1}{64}$th, and the distance between their particles four times as great as when elastic. But the subsequent experiments of Saussure given in the third column of the table show us that this law does not exist, and that there are no such simple relations, as Dalton has supposed, between the density of gases in and out of water.

4. From the experiments of Dr. Henry upon gases sub- jected to different degrees of pressure, from that of one to that of two or three atmospheres, and thus reduced to double or triple their usual density, that philosopher has deduced the following very important general law : Water, of the same temperature, always takes up the *same bulk* of each gas, whatever be its density. Thus, if we suppose that water at 60° absorbs just its bulk of carbonic acid gas in its ordinary state of density, it will still continue to absorb its own bulk, though that gas be condensed into half its usual space, or $\frac{1}{3}$d its usual space, and so on. Hence it follows, that by increasing the pressure sufficiently, we may cause water to absorb any quantity of gas we please. To cause water to absorb what is equivalent to twice its bulk of carbonic acid, we must make it absorb the gas under an additional pressure of 30 inches of mercury; to make it absorb what is equal to thrice its bulk, we must subject it to a pressure of 30 inches, and so on. To cause water to absorb what is equal to $\frac{1}{3}$d of its bulk of oxygen gas, there would be required a pressure of about 10 atmospheres, or a column of mercury 270 inches, or $22\frac{1}{2}$ feet long.

On the other hand, if we diminish the usual atmospheric pressure, and thus expand gases to twice, thrice, &c. their usual bulk, water at the same temperature will still absorb exactly the same number of cubic inches, and of course only one-half or one-third the weight of gas which is taken up under the usual pressure of the atmosphere. Hence we see the effect of placing water impregnated with gases under the exhausted receiver of an air-pump. The same bulk of gas will still continue in the water, but its density will be diminished according to the exhaustion. If the exhaustion be carried to 300 times, the quantity remaining in the water will be only $\frac{1}{300}$th of the original quantity.

5. If the quantity of gas absorbed by water depends

entirely upon the pressure, if it increases and. diminishes precisely as the pressure does, we cannot hesitate to allow
that the gases still retain their elasticity after they have been absorbed by the water. The combination (if the absorption of gases by water be entitled to that name) seems at first sight scarcely comparable with chemical affinity; for the water takes up any quantity of gas whatever, provided the bulk be the same. The proportion of the ingredients in this case is entirely regulated by the bulk, whereas in chemical combinations it is regulated by the weight.

Here, then, we have a species of combination seemingly different from every other; the law of which is, that there must always exist a constant ratio between the density of the portions of gas within and without the water. Mr.
Dalton conceives that the absorption of the gases is merely mechanical; that they do not really combine with the water, but are forced into its pores; that the gas contained in the water does not press upon that liquid, but merely on the containing vessel; and that it is precisely in the same state with regard to the water as if it were diffused in a vacuum. But there are two circumstances which appear to me to be incompatible with this notion. The first is, that heat is evolved when carbonic acid gas and sulphureted hydrogen are absorbed by water. Dr. Henry observed that a thermometer plunged in the liquid rose form $\frac{1}{2}$ to $\frac{3}{4}$ths of a degree.* The second is, that the bulk of the water is increased by the impregnation; for the specific gravity of water impregnated with carbonic acid gas is less than it ought to be. Thus Bergman found the specific gravity of water, saturated with carbonic acid at the temperature of 36°, to be 1·0015,† compared with that of water of the same temperature; whereas it ought to have been 1·0019, even on the supposition that it had taken up only its own bulk of acid gas, while Bergman expressly assures us, thar the water took up more than its bulk. Thus it appears that water suffers an expansion by absorbing carbonic acid gas, which would be impossible unless the gas acted upon it. For surely it will not be contended, that any supposed elasticity in the water itself is equivalent to so great a change of bulk as that above mentioned.

* Nicholson's Jour. v. 225.   † Opusc. i. 9.

There must then be an action between the atoms of the gas absorbed and the water. Farther, the evolution of heat, notwithstanding this expansion, is altogether inconsistent with what happens in every case, unless we suppose that a species of combination takes place between the particles of gas and the water, and that the evolution is the consequence of this combination.

If the mixture of gas and water were merely mechanical, no good reason could be assigned why the very same bulk of each should not be forced by the same pressure into the pores of water. It is this circumstance, apparently so puzzling, that serves as a key to the whole, and enables us to reduce the absorption of the gases by water to the simple principles of chemical affinity. It is, in reality, only a peculiar case of chemical dissolutions, as Berthollet has termed it. Gaseous bodies dissolve each other in all proportions, because they are both in the same state, and not restrained by the cohesion of their particles; but when a liquid dissolves a gas, the proportion is limited by the difference of the state. The elasticity of the gas, as Berthollet has shown, opposes its union with bodies that are non-elastic, and limits the quantity of gas which can combine; for when the attraction between the liquid and gas is just balanced by the elasticity, no more gas can be absorbed. Were it not for this elasticity, the proportion of gas that might be dissolved by a liquid would be indefinite.

Let us suppose the pressure of the atmosphere to be completely annihilated. In that case the gaseous bodies would expand indefinitely till their atoms exercised no sensible repulsion. Let us now suppose a quantity of such a gas to be exposed to the action of water. The liquid would absorb it, and the particles of gas thus taken up would arrange themselves in regular order at determinate distances from each other. These distances would regulate the quantity of each gas taken up, while the distances themselves would be regulated by the affinity between the gas and the water. The greater the affinity, the nearer might the atoms of gas approach each other before their elasticity balanced the affinity between them and the water. In such a supposed case we have no means of determining what the bulk of each gas absorbed would be; though we are certain that it would bear some proportion to the affinity between it

and water. The quantity absorbed, estimated by weight, would be altogether inappreciable.

Now let us suppose that the gases are subjected to a certain pressure, as that of 30 inches of mercury, equivalent to an atmosphere. In that case they undergo a great augmentation of density, and a proportional augmentation of elasticity; but this increase of elasticity being just balanced by the pressure, it is the same thing with respect to their absorption by water as if there was no augmentation; or, in other words, the gas, notwithstanding its increase of density, presents no greater obstacle to its absorption by water than before; for whatever the density of gases may be, in as far as that density is produced by pressure, it is balanced by the pressure. Hence whatever the density of a gas may be from pressure, water ought to absorb always the same bulk of it; and the knowledge that this is in reality the case, we owe to the experiments of Dr. Henry. This law, so far from being a demonstration that the absorption of gases by water is merely a mechanical effect of the pressure, ought to hold even on the supposition that the combination is chemical; while the determinate proportions of each gas absorbed is a demonstration that the combination is chemical, and that it is regulated by the proportion which exists between the repulsion of the particles of gas and the attraction of water for these particles. The water will absorb such a portion of each, that the repulsion between the particles absorbed just balances the affinity of water for them. If the affinity be double, the repulsion may be double; if the affinity be one-half, the repulsion must be one half; and so on.

From the experiments of Henry and Dalton we learn, that the affinity between water and carbonic acid is such as nearly to balance the elasticity. Hence that gas combines with water with but little or no change in its destiny; but the affinity between water and olefiant gas being only half as great as the elasticity, the distance between its particles when it combines with water must be double, and of course water will only combine with $\frac{1}{8}$th of the bulk of this gas that it does of carbonic acid, supposing both gases before absorption to be under the same pressure. For that portion of olefiant gas, when it combines with water, must expand when in the water so as to occupy eight times its for-

mer bulk. In like manner, the affinity of oxygen gas being only $\frac{1}{3}$d that of the elasticity, water will take up 27 times as much in bulk of carbonic acid as it will of oxygen; because, when the atoms of oxygen combine with the water, they must separate to triple their former distance, that the affinity and elasticity may balance each other. The affinity of azote for water being only $\frac{1}{4}$th of its elasticity, water will absorb 64 times as much of carbonic acid as of it; because, when the atoms of azote combine with the liquid, they must separate to four times their former distance before the affinity is capable of balancing the elasticity.

6. From the experiments of Dr. Henry, amply confirmed by those of Mr. Dalton, we learn, that the proportion of any gas absorbed by water depends greatly upon the nature of the gaseous residue. Thus, if we take 100 cubic inches of water, and agitate them in 200 cubic inches of carbonic acid at the common temperature, at least 100 inches of the gas will be absorbed. In this case the residue is pure carbonic acid; but if we mix together 200 inches of carbonic acid and 100 inches of common air, and agitate 100 inches of water in them, in that case the residue will not be pure carbonic acid, but a mixture of carbonic acid and air. The quantity of acid gas taken up from such a mixture will not be 100 inches as before, but only 60 inches.* Here, when the residue was pure carbonic acid, a much greater proportion of gas was absorbed than when it was a mixture of carbonic acid and air. This holds generally when the residue contains a foreign gas; the quantity absorbed is less than usual, and it diminishes in proportion to the quantity of foreign gas present.

Proportion of gas absorbed depends upon the residue.

If a quantity of water fully impregnated with any gas be put into a vessel containing any other gas, a portion of the gas makes its escape out of the water, and mixes with the superincumbent elastic fluid. The quantity which thus escapes is proportional to the bulk of the superincumbent gas compared with the bulk of the water. Hence if water, impregnated with carbonic acid, be exposed to the open air, almost the whole of the acid makes its escape, and the water becomes insipid. If a little water impregnated with sulphureted hydrogen, or nitrous oxide, be let into a large

Gases separated from water when brought in contact with other gases.

* Henry, Nicholson's Jour. v. 233.

jar full of oxygen or any other gas, the sulphureted hydro-
gen, or nitrous oxide, makes its escape in a great measure,
and mingles with the oxygen. To preserve the impregna-
tion entire, the water must either be kept in close vessels, or
pressed upon by an atmosphere of the very same gas which
it contains.

This curious law was first discovered by Dr. Henry, who
announced it as a demonstration of the truth of Mr. Dal-
ton's peculiar theory of the non-elasticity of gases to each
other.* For if a gas can be retained in water by the pres-
sure of an atmosphere of its own gas, and not by that of
any other, it was inferred that gases do not mutually press
upon each other.

Proportion
of gas ab-
sorbed de-
pends upon
tempera-
ture.

7. The proportion of gases absorbed by water is consider-
ably influenced by the temperature. Dr. Henry found,
that 100 inches of water at 55° absorbed 108 inches of
carbonic acid; but the same quantity of water at 85° ab-
sorbed only 84 inches. One hundred cubic inches of water
at 55° absorbed 106 inches of sulphureted hydrogen, while
at 85° it absorbed only 95 inches.† We are not to consider
these numbers as correct, because Dr. Henry did not at-
tend to the purity of the residue; but they are sufficient to
show us that the proportion of gas absorbed is affected by
the temperature.

The reason of this is quite obvious. The elasticity of
gases increases with their temperature; but the proportion
of them absorbed by water must of course diminish at the
same rate as their elasticity increases. That this is the
true explanation has been shown by an experiment of
Dalton. If water impregnated with gas, and having an
atmosphere of the same gas over it, be confined in a well-
stopped phial, it may be exposed to any change of tem-
perature between 32° and 212° without any change in the
proportion of the gas contained in the water.‡ In this
case the superincumbent gas suffers the same change of its
elasticity as the portion contained in the water, and con-
sequently balances that change. The gas and the water
continue exactly in the same situation with respect to each
other as if no change whatever had taken place.

8. If a sufficient quantity of pure water be agitated with

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* Nicholson's Jour. viii. 298.   † Ibid. p. 235.
‡ Phil. Mag. xxiv. 18.

any pure gas whatever, the whole of that gas will be ab-
sorbed without leaving any residue; but if the water is not
absolutely pure, then there will always remain a residue,
and that residue will consist partly of the gas absorbed,
and partly of the gas previously contained in the water.

A great number of experiments have been made on this Water sup-
subject by different chemists, especially Dr. Priestley* and posed by
some to
Mr. Berger; † but as they neglected to notice the nature convert
and quantity of gas with which the water used was impreg- gases into
azote.
nated, and likewise (in many cases) the purity of the gas
used, no satisfactory conclusions can be drawn from their
experiments.

Berger found that when common air was allowed to stand
over water till it had lost ⅕th of its bulk, the residuum con-
sisted wholly of azotic gas, for phosphorus produced no
sensible change in its bulk. Dr. Priestley found the
same change produced when the bulk of the air was re-
duced to 0·7 or to ·75. This change is obviously con-
nected with some particular change which takes place in
stagnant water; probably a species of putrefaction. Some
substances contained in the water, and taken up from the
vessel, seem to acquire the property of uniting with oxy-
gen, and thus withdrawing it from the water as rapidly
as it dissolves. Thus Mr. Dalton found, that water kept
in a wooden trough very soon lost the whole of its oxygen.‡
It is not so easy to explain the result obtained by these
philosophers when nitrous gas and hydrogen gas were
left standing over water. Bergman found that both gases,
by long standing, lost ¾ths of their bulk; the residue was
azote.

Such are the phenomena of the absorption of gases by
water. They all admit an easy explanation, on the sup-
position that there exists an affinity between the gases
and water, and that the proportion of each gas which is
absorbed is regulated by its affinity for the water and by
its elasticity. Let us now consider the more absorbable
gases.

II. All the very absorbable gases belong to the class of
supporters, acids or alkalies. The following is a list of

* Amer. Trans. v. 21. † Jour. de Phys. lvii. 5.
‡ Phil. Mag. xxiv. 17.

such of them as have been hitherto examined, placed in the inverse order of their absorbability:

List of the more absorbable gases.

1. Chlorine	5. Muriatic acid
2. Cyanogen	6. Fluoboric acid
3. Sulphurous acid	7. Ammoniacal gas.
4. Fluosilic acid	

Bulk of them absorbed by water.

1. The following table exhibits the number of measures of each of these gases absorbed by one measure of pure water:

Chlorine	2
Cyanogen	$4\frac{1}{2}$
Sulphurous acid	43·78*
Fluosilic acid	363 + *
Muriatic acid	516
Fluoboric acid	700 †
Ammoniacal	780

Expansion of the water.

2. When a cubic inch of water is saturated with the preceding gases, it undergoes an increase of bulk. The following table exhibits the bulk of the water when thus saturated, supposing the original bulk to have been 1.

Saturated with	Cubic Inches.
Chlorine	1·002 +
Sulphurous acid	1·040
Fluosilic acid	——
Muriatic acid	1·500
Ammoniacal	1·666

Thus the particles of the water, by this impregnation, are separated farther from each other than they were at first. Hence the density of the gas absorbed is not so great as it would appear to be at first sight from the bulk of it absorbed. Thus, though one cubic inch of water absorbs 516 cubic inches of muriatic acid gas, yet as the cubic inch expands during the absorption so as to become $1\frac{1}{2}$ cubic inch, it is obvious that only ⅔ds of the 516 inches of gas are contained in a cubic inch; the remaining third is necessary for the additional half inch produced by the expansion of the water. Hence the density of the

* By Saussure's experiments. My own trials gave 33.
† John Davy, Phil. Trans. 1812, p. 357, 367.

muriatic acid gas in the mixture is just ⅔ds of 516 or 344.
That is to say, that every cubic inch of such saturated water
contains 344 cubic inches of muriatic acid. By a similar
method may the density of each of the gases in water satu-
rated with them be ascertained. The following table exhi-
bits these densities:

<div style="float:right">Quantity
contained
in a given
bulk of the
water.</div>

Chlorine.................... 1·5
Sulphurous .... 31·7
Muriatic ....344·0
Ammonia ..;............ ..468·0

From this table it appears that the atoms of sulphurous acid
gas in water saturated with it are nearly three times nearer
each other than in their usual state; those of muriatic acid
seven times nearer, and those of ammonia are almost eight
times nearer.

3. It will not surely be denied that the absorption of
these gases by water is the consequence of an affinity
between them and that liquid; for it is impossible on any
other supposition to explain the enormous condensation
which they experience, notwithstanding their elasticity.
Yet the phenomena are in every respect the same, except
in degree, with those of the gases considered in the preced-
ing part of this section. Not only the rapidity of absorp-
tion, but even the quantity absorbed, is materially affected
by the mixture of them with other gases. They only expel
each other partially from water, as happens to the other
gases. When liquid ammonia is thrown up into a baro-
meter tube, the mercury immediately sinks ten inches.
The other gaseous solutions produce a similar effect. They
are expelled likewise when the impregnated liquid is placed
under the receiver of an air-pump, and when it is exposed to
a boiling heat. In short, it is impossible to point out a
single circumstance in which the absorption of these
gaseous bodies by water differs from that of the first class
of gases, excepting merely the bulk of them absorbed.
In most of the gases belonging to the first class, the gases
experience an expansion when absorbed: while in all those
of the second they undergo a condensation. The conden-
sation demonstrates that the affinity of the gases for water is
greater than their elasticity; while the expansion indicates
just the contrary.

If the affinity be measured by the cube root of the relative condensation, then it will follow that the affinity of muriatic acid for water is 28 times greater than that of azote, and the affinity of ammonia 32 times greater; that the affinity of muriatic acid is seven times greater than that of carbonic acid; and so on.

Absorption of gases by other liquids. III. With respect to the absorption of gases by other liquids, we are not in possession of many experiments of a decisive nature. Dr. Priestley tried the absorption of various gases by alcohol, ether, and different kinds of oils. Mr. Dalton has likewise made some experiments on the subject, but he has only announced the result of them in general terms. M. Theodore de Saussure however has made some experiments on this subject which are possessed of considerable value, and which show us that the absorption of gases by other liquids follows different proportions from their absorption by water. This is a further reason for considering chemical affinity as the cause of that absorption. The following table exhibits the volumes of different gases absorbed by 100 volumes of alcohol of the specific gravity 0·84, according to the experiments of De Saussure.*

Sulphurous acid gas 11577
Sulphureted hydrogen 606
Carbonic acid 186
Protoxide of azote 153
Olefiant gas 127
Oxygen gas . . . . 16·25
Carbonic oxide . . . . 14·5
Oxy-carbureted hydrogen . . . . . . 7·0
Hydrogen . . . . 5·1
Azote . . . . 4·2

From this table it appears that alcohol absorbs above eight times as much olefiant gas as water does. It would be curious to know the effect of this absorption on the specific gravity of the alcohol.

The following table exhibits the volumes of four different gases absorbed by 100 volumes of the following liquids, according to the experiments of Saussure : †

* Annals of Philosophy, vi. 340.
† Ibid. p. 341.

1. Native naphtha, of the specific gravity 0·784.
2. Oil of lavender, of the specific gravity 0·88.
3. Olive oil.
4. A saturated solution of muriate of potash in water.

	Naphtha.	Oil of lavender.	Olive oil.	Solution of muriate of potash.
Olefiant gas ...	261	209	122	10
Nitrous oxide .	254	275	150	21
Carbonic acid .	169	191	151	61
Carbonic oxide	20	15·6	14·2	5·2

The following table, from the experiments of the same chemist, exhibits the volumes of carbonic acid gas absorbed by 1 volume of a great number of liquids, differing very much from each other in the proportion of their viscidity and fluidity.*

Liquids.	Sp. Gr. of Ditto.	Volumes of gas absorbed.	100 Parts of the solution contain
Alcohol	0·803	2·6	
Sulphuric ether	0·727	2·17	
Oil of Lavender....	0·880	1·91	
Oil of thyme	0·890	1·88	
Spirit of wine	0 84	1·87	
Rectified Naphtha..	0·784	1·69	
Oil of turpentine ...	0·86	1·66	
Linseed oil	0·94	1·56	
Olive oil	0·915	1·51	
Water	1·000	1·06	
Sal ammoniac	1·078	0·75	27·53 crystals. Saturated solution
Gum arabic.........	1·092	0·75	25 gum
Sugar	1·104	0·72	25 sugar
Alum.............	1 047	0·7	9·14 crystals. Saturated solution
Sulphate of potash..	1·077	0·62	9·42 crystals. Saturated solution
Muriate of potash ..	1·168	0·61	26 crystals. Saturated solution
Sulphate of soda....	1·105	0·58	11·14 salt dried at a red heat. Saturated solution
Nitre	1·139	0·57	20·6 crystals. Saturated solution
Nitrate of soda	1·206	0·45	26·4 crystals. Saturated solution
Sulphuric acid	1·84	0 45	
Tartaric acid	1·285	0·41	53·37 crystals. Saturated solution
Common salt	1·212	0·329	29 salt. Saturated solution
Muriate of lime	1·402	0·261	40·2 salt dried at a red heat. Saturated solution

From the preceding table, it would appear that alcohol and oils absorb a much greater proportion of gases than water. Saussure is of opinion that the power which liquids possess of absorbing gases diminishes as their specific gravity

* Annals of Philosophy, vi. 342.

increases. But the preceding table does not accord very well with that opinion. For sulphuric ether, although specifically lighter than alcohol, absorbs a smaller proportion of carbonic acid gas. Nitric acid absorbs an enormous quantity of nitrous gas, for which it has a strong affinity, and is gradually converted into nitrous vapour, while the other acids act upon it nearly as water does. The same gas is absorbed in considerable quantities by sulphate, nitrate, and muriate of iron ; in small quantities by sulphate of tin, sulphate of zinc, muriate of zinc,* and several of the salts of copper.

SECT. V.

OF THE COMBINATION OF GASES WITH SOLIDS.

As gases and solids are in a state still more different from each other than gases and liquids, their combinations must be attended with still greater difficulties. It will be opposed on the one hand by the *elasticity* of the gases, and on the other by the force of *cohesion*, which unites together the particles of the solid; and no combination can take place unless the affinity be sufficiently strong to overcome the one or the other of these forces. The new compound will be either gaseous, solid, or liquid, according to the proportion of the constituents combined, and the intimacy of their union. Let us examine, in the first place, the combination of the simple gases with solids, and afterwards turn our attention to the compound gases.

Simple gases.

I. The simple gases are in number four; namely, *oxygen*, *chlorine*, *hydrogen*, and *azote*.

1. The only simple bodies known are *carbon*, boron, silicon, phosphorus, sulphur, and the metals. Now oxygen is capable of combining with them all.

Oxygen with carbon.

With carbon it unites only in two proportions, as far at least as we know at present, and forms the two compounds called *carbonic acid* and *carbonic oxide*. We have seen in a former part of this work that carbonic acid is a compound of 1 atom carbon and 2 atoms oxygen ; and carbonic oxide of

* Priestley on air, i. 372; ii. 229. Davy's Researches, p. 160.

2

1 atom carbon and 1 atom oxygen; and that if the weight of an atom of oxygen be 1, an atom of carbon will weigh 0·75. Hence we have

Carbonic oxide composed of 0·75 carbon + 1 oxygen
Carbonic acid . . . . 0·75   + 2

Or, which is the same thing,

Carbonic oxide, composed of 3 carbon + 4 oxygen
Carbonic acid, ... 3   + 8

Or

Carbonic oxide, composed of 100 carbon + 133·3 oxygen
Carbonic acid, ... 100 . . . . . . + 266·6

The specific gravity of a volume of carbon, supposing it in the gaseous state, is 0·416. Carbonic oxide is composed of a volume of carbon and half a volume of oxygen condensed into 1 volume. Carbonic acid of a volume of carbon and a volume of oxygen, condensed into 1 volume. Hence the specific gravity of carbonic oxide is $0·416 + 0·555 = 0·972$ and the specific gravity of carbonic acid $0·416 + 1·111 = 1·527$ numbers which agree sufficiently with experiment.

It is remarkable that carbonic oxide cannot be formed directly by the union of oxygen and carbon or charcoal. It is only obtained by the decomposition of a product of combustion by means of a combustible. The products thus decomposed are carbonic acid by metallic oxides, and hydrogen and water by charcoal.

2. Oxygen combines, as far as we know at present, with only 1 proportion of boron, constituting boracic acid. We have concluded, from the phenomena stated in a preceding part of this work, that boracic acid is a compound of 1 atom boron and 2 atoms oxygen; and that an atom of boron weighs 0·875. Hence boracic acid is composed of

Oxygen with boron.

0·875 boron + 2 oxygen, or of
100   + 228·57

3. Oxygen is capable of uniting likewise with at least three proportions of phosphorus, forming the compounds called hypophosphorous acid, phosphorous acid, and phosphoric acid. They are all solid substances. In this respect they differ extremely from the combinations of oxygen and carbon, which are chiefly gaseous. This is directly the

Oxygen with phosphorus.

reverse of what one would have expected *a priori*; carbon is
the least disposed to assume the elastic form of all the solid
bodies known : for no degree of heat is capable of melting it,
far less of volatilizing it; whereas phosphorus may be con-
verted into vapour with comparative ease, since the heat of
our fires is capable of boiling it very readily. The difference
seems to depend upon the density of the atoms of phospho-
rus, and upon the comparatively small quantity of oxygen
with which they unite. We have found reason to conclude,
from the phenomena stated in a preceding part of this work,
that an atom of phosphorus weighs 1·5, and that these
three acids are composed respectively of 1 atom of phospho-
rus united to 1, 2, and 3 atoms of oxygen. Hence they are
composed as follows :

Hypophosphorous acid of .... 1·5 phosphorus + 1 oxygen
Phosphorous acid of. .... 1·5   + 2
Phosphoric acid of .... 1·5   + 3

Or, which is the same thing,

Hypophosphorous acid of 100 phosphorus + 66·6 oxygen
Phosphorous acid of 100   + 133·3
Phosphoric acid of 100   + 200

The weight of a volume of phosphorus is 0·8328, suppos-
ing it in the gaseous state. But as the compounds of phos-
phorus and oxygen are none of them gaseous, we cannot
determine the condensation which takes place. But it is
obvious that in the three acids, 1 volume of phosphorus is
united with $\frac{1}{2}$ volume, 1 volume, and $1\frac{1}{2}$ volume respectively
of oxygen. Probably the resulting compound in each case
would be 1 volume, if it could be exhibited in the gaseous
state.

Oxygen
with sul-
phur.
4. Oxygen unites likewise with three proportions of sul-
phur, forming three acids exactly analogous to the acids of
phosphorus; namely, hyposulphurous acid, sulphurous acid,
and sulphuric acid. The first of these has never been
obtained in a separate state; but the other two are well
known, and there is reason for believing that both, when
pure, are gaseous bodies. We have already concluded,
from the phenomena that an atom of sulphur weighs 2,
and that the three acids of sulphur are composed of 1 atom

3

of sulphur combined respectively with 1, 2, and 3, atoms of oxygen. Hence they are composed as follows :

Hyposulphurous acid of .... 2 sulphur + 1 oxygen
Sulphurous acid of 2   + 2
Sulphuric acid 2   + 3

Or, which is the same thing,

Hyposulphurous acid of ..... 100 sulphur + 50 oxygen
Sulphurous acid of 100   + 100
Sulphuric acid of 100   + 150

The weight of a volume of sulphur, when in the state of vapour, is 1·111. Sulphurous acid is composed of a volume of sulphur and a volume of oxygen condensed into 1 volume ; sulphuric acid of 1 volume sulphur + $1\frac{1}{2}$ volume oxygen condensed into 1 volume. Hence the specific gravity of sulphurous acid is .... $1\cdot111 + 1\cdot111 = 2\cdot222$ and the specific gravity of sulphuric acid $1\cdot111 + 1\cdot666 = 2\cdot777$ Numbers which correspond with experiment. Hyposulphurous acid, from analogy, ought to be composed of 1 volume of sulphur and half a volume of oxygen condensed into 1 volume. Hence its specific gravity, if it could be exhibited in the gaseous form, would be 1·666.

5. Oxygen has the property of uniting in various doses with all the metals; but the compounds formed are always solids. In these combinations, then, it is the solid body which retains its state, while the oxygen loses it. We must ascribe this to the very great cohesive force by which all the metallic particles are united; a force weakened no doubt by the combination of oxygen, but not overcome. Some of the metallic oxides possess the properties of acids; others of alkalies, while some are intermediate between the two. But I can add nothing to the account of these bodies already given in a preceding part of this work. I refer to the tables in Vol. I. p. 521, of this work.

6. We are still but imperfectly acquainted with the combinations which chlorine forms with the different solid bodies. With phosphorus it forms two compounds, one liquid, the other solid ; with sulphur it forms a liquid compound. It unites with all the metals, and forms solid compounds, the greater number of which have been but imper-

fectly examined. With carbon it does not appear to be capable of uniting. Its action on boron has not been tried.

7. Though there exists a considerable affinity between hydrogen and carbon, phosphorus and sulphur, they do not unite when brought into contact, unless either the cohesion of the solid bodies be removed, or the elastic fluid be exhibited in a nascent state. This shows us that it is the force of cohesion of the solids, and the elasticity of the gas, which prevents the combination. Heat does not destroy the cohesion of carbon; therefore it cannot be united to hydrogen by heat: but Gengembre found that when sulphur and phosphorus were kept melted in hydrogen gas, a combination took place. It is chiefly, however, by the decomposition of water that these combinations are accomplished.

All the known combinations of hydrogen with a simple combustible are gases except one, namely, supersulphureted hydrogen, which is liquid, but readily converted into vapour. This is the consequence of the great elasticity of hydrogen gas. None of the other elastic fluids are to be compared with it in this respect. The atoms of which it is composed must be smaller, and their distances from each other greater than in any other gas. Hence it will oppose a greater resistance to those affinities which would condense it into a solid or liquid state, and will always be disposed to resume again its elasticity.

Hydrogen combines with two proportions of carbon, sulphur, and phosphorus. All these compounds are perfectly analogous. They consist of 1 or 2 atoms of hydrogen combined with 1 atom of carbon, phosphorus, and sulphur. The weight of an atom of hydrogen is $0 \cdot 125$, and an atom of carbon weighs $0 \cdot 75$; an atom of phosphorus $1 \cdot 5$, and an atom of sulphur 2. Hence the compounds of these substances are as follows:

Olefiant gas, hydrogen	1 atom	$= 0 \cdot 125$ +	carbon 1 atom	$= 0 \cdot 75$
Carbureted hydrogen	2	$= 0 \cdot 250$ +	1	$= 0 \cdot 75$
Hydroguret of phosphorus	1	$= 0 \cdot 125$ +	phosph. 1	$= 1 \cdot 5$
Bihydroguret of phosphorus	2	$= 0 \cdot 25$ +	1	$= 1 \cdot 5$
Sulphureted hydrogen	1	$= 0 \cdot 125$ +	sulphur 1	$= 2$

Olefiant gas is composed of 2 volumes carbon and 2 volumes hydrogen condensed into 1 volume. Carbureted hydrogen is composed of 1 volume carbon and 2 volumes

hydrogen condensed into 1 volume. The hydroguret of
phosphorus is composed of 1 volume phosphorus and 1
volume hydrogen condensed into 1 volume; bihydroguret
of phosphorus of 1 volume phosphorus and 2 volumes hy-
drogen condensed into 1 volume. And, finally, sulphureted
hydrogen is a compound of 1 volume sulphur and 1 volume
hydrogen condensed into 1 volume. With these determina-
tions, the specific gravities, as ascertained by experiment,
agree with precision.

We found reason to conclude, from the phenomena for-
merly stated, that alcohol is a compound of olefiant gas and
water, in the proportion of 1 volume olefiant gas and 1
volume of vapour of water. While ethers are composed of
2 volumes of olefiant gas combined with 1 volume of vapour,
or chlorine, or an acid, according to the particular ether
formed.

It is during the decomposition of water by the compound
agency of an acid and a metal united to sulphur, that sul-
phureted hydrogen is usually formed. In this case every
thing concurs to facilitate the combination. The hydrogen
is nascent, and the sulphur, just separated from the metal, is
not restrained from uniting with the hydrogen by the cohe-
sion of its particles; but in some rare instances the sulphur
appears to have the property of decomposing water, and
forming at the same time sulphureted hydrogen and sul-
phuric acid.

Carbureted hydrogen is disengaged spontaneously from
stagnated water, and is obviously produced by the putrefac-
tion of vegetable matter. Mr. Dalton has very ingeniously
explained its formation. When the carbon is disengaged,
two particles of it decompose at once two atoms of water
precisely as in the former examples; one unites with all the
hydrogen, and the other with all the oxygen; so that both
carbonic acid and carbureted hydrogen are formed toge-
ther. Let the symbols for oxygen, hydrogen, and carbon,
be as follows:

Oxygen . . . . O
Hydrogen . . . . . . ⊙
Carbon. . . . . ⬤

In that case water and carbureted hydrogen will be re-
presented thus:

Water ○⊙

Carbureted hydrogen ⊙●⊙

And 2 atoms of carbon decomposing 2 atoms of water and converting them into carbureted hydrogen and carbonic acid may be represented thus:

⊙●⊙ . . . . . . ⊙●⊙ Carbureted hydrogen

. . . . . . ○●○ Carbonic acid

The composition of the greater number of animal and vegetable bodies is too complicated for us to form a correct idea of the way in which their atoms are united.

8. We are acquainted with only one gaseous compound of azote with a solid. It combines with carbon and forms *cyanogen*, which, from the experiments of Gay-Lussac, appears to be a compound of 2 atoms of carbon and 1 atom of azote. It consists of 1 volume azote and 2 volumes of carbon condensed into 1 volume.

Action of compound gases on solids.

II. Though the compound gases be more numerous than the simple, we are acquainted with fewer combinations into which they enter with solids; at least if we except the salts which the acid gases form with the alkalies, earths, and metallic oxides, and which ammonia forms with the solid acids.

In most cases, when solids act upon compound gases, the result is a decomposition, and the elements of the gas combine in a different manner. Thus, nitrous oxide, nitric acid, and chloric acid, are decomposed by carbon, phosphorus, and sulphur, and by many of the metals. Nitrous gas is decomposed by carbon and phosphorus when assisted by a sufficient heat. Sulphurous acid is decomposed by some of the metals, and probably by carbon. Carbonic acid is decomposed in certain circumstances by phosphorus.

But very frequently solids have no action whatever upon compound gases; as is the case with most of the gaseous compounds of carbon, and several others. I recollect at present only four instances of the direct combination of a compound gas with a solid base; these are the following:

Carbonic acid and charcoal.

It has been shown by the experiments of Cruikshanks, and by those of Clement and Desormes, that when carbonic acid is passed through red-hot charcoal, it is converted into carbonic oxide. But carbonic acid being a compound of

2 atoms of oxygen with 1 atom of carbon, and carbonic ox-
ide of 1 of oxygen with 1 of carbon, it is obvious, that in
this case an atom of carbon must have combined with every
atom of carbonic acid. The experiment is of difficult ex-
planation. The acid is a product of combustion, while the
oxide is a combustible. This would lead us to suppose
that the superinduced carbon alone is susceptible of com-
bustion, were not the diminished specific gravity inexplica-
ble upon any other supposition than the union of a new dose
of heat.

The second example is nearly similar. It was ascertained
by Scheele, and afterwards by the experiments of Clouet and
other French chemists, that when ammoniacal gas is passed
through red hot charcoal, prussic acid is formed. But
prussic or hydrocyanic acid is a compound of 2 atoms car-
bon, 1 atom azote, and 1 atom hydrogen; while ammonia
is a compound of 1 atom azote and 3 atoms hydrogen. We
must suppose therefore that 3 atoms of carbon act upon
each atom of ammonia. One of these atoms unite with 2 of
the atoms of hydrogen in the ammonia and constitute car-
bureted hydrogen, and the other 2 atoms of carbon uniting
to the remaining atom of azote and atom of hydrogen in the
ammonia constitute an atom of hydrocyanic acid.

The third example consists in the combination of sulphu-
reted hydrogen and sulphur, and the formation of super-
sulphureted hydrogen, when both are disengaged together
from an alkali.

Sulphureted hydrogen gas has the property of dissolving
phosphorus. This constitutes the fourth example.

CHAP. III.

OF LIQUIDS.

It has been sufficiently ascertained that the state of most
bodies depends upon temperature; that solids may be con-
verted into liquids by heating them, and liquids into solids
by cooling them. This state of solidity or liquidity has a
considerable effect upon the combination of bodies with
each other. At the medium temperature of the atmosphere

Book III. some bodies are always solid; others always liquid.   As it
is usually in that temperature that they are employed, they
have received from it their characteristic name; those bo-
dies only being called liquids which are liquid under the
medium temperature of the air.   We shall, in this chapter,
after a few introductory remarks on the constitution of li-
quids, consider how far the state of liquidity affects the union
of these bodies with each other, and with solids.   The sub-
ject thus divides itself into three heads.

1. The constitution of liquids.
2. The combination of liquids with each other.
3. The combination of liquids with solids.

These are treated of in the three following sections.

SECT. I.

OF THE CONSTITUTION OF LIQUIDS.

Definition.   NEWTON has defined a *fluid* to be a body whose parts
yield to any force impressed upon them, however small, and
which thus move easily among each other.*   Objections
have been made to this definition, but no better has been
substituted in its place.   Fluids have been divided into two
classes; namely, 1. Those which are *elastic*, or diminish in
bulk according to the pressure, but recover it again when
the pressure is removed; and, 2. The *non-elastic*, or those
which do not sensibly diminish in bulk when pressed upon.
The first class are called *airs* or *gases*; the second, *liquids*.

1. A *liquid*, then, is a fluid not sensibly elastic, the parts
of which yield to the smallest impression, and move upon
each other; but we are not acquainted with any perfect
liquid.   The particles of all of them oppose a sensible re-
sistance to an impressing force, or have a certain degree of
viscidity.

Cause of   Very little progress has been made in ascertaining the
fluidity.   formal cause of fluidity.   Some have supposed that the
atoms of liquids consist of very minute spheres finely po-
lished.   But this hypothesis alone would not explain the

* Fluidum est corpus omnes cujus partes cedunt vi cuicunque illatæ,
et cedendo facile moventur inter se.   Principia, Lib. ii. Sect. 5.

mechanical properties of liquids. Others have concluded that the difference between solids and liquids depends upon the particles of the latter being constantly in motion, while those of the former are at rest. But this hypothesis is equally inconsistent with the phenomena.

It is very evident, from the facility with which the particles of liquids move among each other, that they must meet with little or no resistance from their own particles; while the property which they all have of collecting into drops, shows that they all act upon and attract each other. Hence it follows, that the particles of liquids must have such a figure that they may move freely among each other without altering their mutual action, or, which is the same thing, their relative distances from each other. Mathematicians have demonstrated that this property belongs to spheres. Hence it has been concluded, that the particles of liquids are spherical; and that viscidity is owing to the want of perfect sphericity.

2. The most important mechanical properties of liquids depend upon this mobility of their particles, in consequence of which they propagate pressure in all directions. But the consideration of these properties belongs to the sciences of hydrostatics and hydraulics.

3. The particles of liquids cohere together, as well as Liquids those of solids, and there is a considerable difference be- cohere. tween this force in different liquids. Thus the cohesion of mercury is much greater than that of water. The reason why this cohesion does not prevent the particles of liquids from separating like those of solids, is the mobility of those particles without changing their relative distances. Hence they obey the action of gravitation, sliding upon each other, so that the number of particles which support the cohesion is continually diminishing till it becomes too weak to resist the opposing force. As the cohesion of liquids does not prevent the motion of the particles of which they are composed, it offers no resistance to their combination with other bodies; excepting in as far as that combination may tend to alter the relative distances of the particles of the liquid, or the form of these particles.

4. Though liquids are not sensibly compressed by the Compres application of an external force, or by their own weight, sible. like gases, it has been ascertained that they experience a cer-

Book III. tain dimunition of bulk, which may be made sensible by a proper apparatus. Mr. Canton found, in a set of experiments which he made on the subject, that when liquids were freed from the pressure of the atmosphere, they underwent a certain expansion, and were proportionally compressed when the pressure of the atmosphere was doubled. The following table exhibits the increase of bulk experienced by the several liquids tried by that philosopher when the pressure of the atmosphere is removed by placing them in the vacuum of an air-pump, or the diminution of bulk when subjected to the pressure of a double atmosphere :*

Mercury	0·000003
Sea water	0·000040
Rain water	0·000046
Oil of olives	0·000048
Spirit of wine	0·000066

It must be owned, that these experiments are liable to some objections; but, all things considered, it would be difficult to explain them without supposing the compressibility of liquids, especially as Zimmerman repeated some of the experiments in a different way, and obtained a similar result.

5. The liquids taken individually are numerous; but as many of them constitute classes of bodies possessed of similar properties, they may be taken collectively, and in that point of view the number is not great. The following table exhibits a list of almost the whole of them, arranged according to their composition.

I. SIMPLE.

List of li-   1. Mercury.
quids.
II. COMPOUND.

a. Simple gases combined.

2. Water.   3. Nitric acid.

b. Gases with a solid base.

4. Sulphuric acid.   8. Fixed oils.
5. Alcohol.   9. Petroleum.
6. Ethers.   10. Supersulphuret of hydrogen.
7. Volatile oils.   11. Bichloride of tin.

* Phil. Trans. vols. lii. and liv. Not having these volumes at hand, I have quoted the table from Cavallo's Natural Philosophy, ii. 23.

c. Solids combined.

12. Phosphuret of sulphur.   13. Sulphuret of carbon.

6. If we were to exclude mercury from the preceding list, then all the known liquids would be compounds. The differences among their specific gravities, also, would be very small when compared with that which exists among gases and solids. The following table exhibits a view of their specific gravities respectively, at the temperature of 60°, that of water being supposed 1·000:

Liquids.	Specific gravity.
Water	1·000
Ethers	0·632 to 0·900
Petroleum	0·730 .. 0·878
Volatile oils.................	0·792 .. 1·094
Alcohol	0·794 .. ——
Fixed oils	0·913 .. 0·968
Supersulphureted hydrogen	—— ——
Sulphuret of carbon	1·272
Nitric acid	1·583
Sulphuric acid	1·898
Phosphuret of sulphur	——
Bichloride of tin	——
Mercury ....13·568

7. This difference in the specific gravity of liquids must be either owing to a difference in the density of the atoms of which they are composed, or to a difference in the distance of the atoms which constitute each liquid from one another. Probably both causes contribute; but the last in the most powerful manner.

8. It has been demonstrated, that the particles of liquids owe their liquid form to their combination with heat; that they are all compounds of heat with a solid base. They differ essentially from those of gases in wanting that elasticity which is produced by the mutual repulsion existing between the particles of gases. The particles of liquids, instead of repelling, cohere together, and oppose a certain force to their farther separation. This cohesive force bears a relation to the density of liquids, and to the difficulty of converting them into steam or vapour; and indeed seems to depend upon these two things. We may conceive with

Book III. Boscovich, that the atoms of liquids are placed in the limit between attraction and repulsion. Their atoms cannot be forced nearer each other without experiencing a repulsion from the increased action of the combined heat; they cannot be separated farther without experiencing an attraction from the diminished action of the combined heat, compared with that of the attracting particles. The distances of the atoms are so regulated, that the attraction and repulsion by which they are at once actuated just balance one another; while their form is such, that they can move freely among each other without altering these distances. It is this which seems to constitute the real cause of fluidity.

The greater number of liquids contain *water* as an ingredient: it gives liquidity to a vast number of solid bodies. but it has not been contended that the presence of water is essential to liquidity, as it has been respecting the gaseous state of bodies.

SECT. II.

ON THE ACTION OF LIQUIDS ON EACH OTHER.

WHEN liquid bodies are mixed together, they act in various ways according to the nature of the substances employed. 1. Some *dissolve* each other in any proportion, as happens when most of the gases are mixed; 2. Some unite in certain determinate proportions; 3. Some do not act sensibly upon each other at all, separating again, though mixed ever so carefully; 4. While some decompose each other. We shall, in this section, take a view of these different modes of action.

Liquids which may be mixed in any proportion.
I. The following table exhibits a list of the liquids which may be mixed together in any proportion, and which, when once mixed, do not afterwards separate spontaneously.

Water with alcohol
nitric acid
sulphuric acid
Alcohol with ether
Sulphuric acid with nitric acid
Fixed oils with petroleum
volatile oils
fixed oils

Volatile oils with petroleum
volatile oils

2. When the liquids contained in the preceding list are brought into contact, they gradually and slowly penetrate each other, and each at length distributes itself equally through the mixture; so that if any portion whatever of the compound be taken, it will contain equal proportions of both ingredients. The difference of specific gravity does not prevent this uniform mixture, though it has considerable influence upon the time which elapses before it is completed. If the densest liquid be uppermost, the mixture is very rapid; but if it be undermost, the combination is exceedingly slow: weeks or even months elapsing in many cases before it is completed. Agitation produces a sensibly equal mixture in a few minutes; though there is reason to believe that it is not so intimate at first as it becomes afterwards. The partial opacity or muddiness which takes place when water and alcohol, water and sulphuric acid, are first mixed, is a proof of this. It is even said by some that the density of a mixture of sulphuric acid and water increased somewhat by keeping it for some days. But when the two liquids are well agitated, I have not been able to perceive any such increase, though my balance was sufficiently delicate to have detected an increase not exceeding $\frac{1}{200000}$th part.

3. When the two liquids have been once thoroughly mixed either by agitation or long contact, they present all the appearances of a homogeneous compound, and do not afterwards separate from each other. To this general law, however, there are some exceptions; though I presume only apparent ones. When common *spirits* are kept in tall vessels, it is well known that the portion at the top of the vessel is often specifically lighter than that at the bottom. If a glass bubble, nearly of the specific gravity of such spirits be thrown into the vessel, it always rests at a particular part. Hence the portion of liquid above is lighter, while that below is heavier than the bubble. It has not been correctly ascertained that this difference in specific gravity takes place in spirits that have been thoroughly agitated. I have not observed such a separation when the alcohol is strong. If it always takes place in weak alcohol, it indicates a disposition in that liquid to unite with water only in certain proportions. Sulphuric acid is said to have exhibited the same separation. I presume it must have been the sulphuric

Form a homogeneous compound.

acid of commerce, in which some saline bodies are always dissolved, or rather suspended, and these collect often in sensible quantities in the bottom of a tall vessel filled with that acid.

The union accompanied by heat and condensation.

4. The union of liquids with each other is accompanied by the evolution of heat, and by a certain degree of condensation; for the specific gravity is always greater than the mean. The heat evolved is very considerable when water is mixed with sulphuric or nitric acid, and likewise when sulphuric and nitric acids are mixed together. It is very sensible when alcohol and water are mixed; but in the other cases it has not been observed. The condensation seems to keep pace with the evolution of the heat, though from the experiments hitherto made, the two do not seem to be proportional to each other. Both vary with the proportions of the liquids mixed; but the condensation seems always greatest when the liquids are mixed in equal quantities, whereas this is not always the case with the heat evolved. Thus the mixture of sulphuric acid and water becomes hottest when one part of the water is poured into four parts of acid.

The following table exhibits the increase of density which takes place when sulphuric acid of the specific gravity 2·00 is mixed with various proportions of water by weight, calculated by Mr. Kirwan from his own experiments:

Condensation of sulphuric acid and water.

Sulph. Acid.	Water.	Increase. of Density.
5	95	0·0252
10	90	0·0679
15	85	0·0679
20	80	0·0856
25	75	0·0999
30	70	0·1119
35	65	0·1213
40	60	0·1279
45	55	0·1319
50	50	0·1333

From this table we see, that when equal parts of sulphuric acid and water are mixed, the density is increased by 13 per cent. Mr. Kirwan likewise ascertained, that when equal parts of water and nitric acid of the specific gravity 1·5543 are mixed together, the increase of density is equal to $\frac{1}{12}$th of the whole weight. From the experiments of Lowitz,

we learn that the specific gravity of a mixture of equal weights of water and pure alcohol is ·917. It ought to be only ·886, being an increase of density of more than $\frac{1}{28}$th of the whole. The increase of density is probably still greater when alcohol and ether are united together; but no exact set of experiments has been made, either to ascertain the condensation in this case, or when the oils are mixed with each other and with the petroleum, or when nitric and sulphuric acids are mixed together.

5. Thus it appears that the union of these liquids with each other presents every thing which characterizes a chemical combination. The density increases, heat is evolved, the mixture becomes perfectly uniform in every part, the liquids do not separate spontaneously, and the separation can only be accomplished by means purely chemical. We must therefore consider it as a case of chemical affinity. As the change of the properties is much less remarkable when liquids unite with each other than in many other compounds, as the combination takes place but slowly, and as the constituents may in general be separated again by a distilling heat, it is obvious that the affinity which unites them is much feebler than in many other combinations. Hence Berthollet has given it the name of *dissolution;* a term under which he has classed a variety of feeble combinations.

Liquids dissolve each other

II. The following table exhibits a list of the liquids that unite with each other only in certain proportions:

Liquids which dissolve fixed quantities of others.

    Water with ether
                  volatile oils
                  sulphuret of carbon
  Alcohol with volatile oils
                  petroleum
                  supersulphureted hydrogen?
                  phosphuret of sulphur?
    Ether with volatile oils
                  petroleum
  Volatile oils with petroleum

1. The experiments hitherto made upon the solutions of liquids by water, alcohol, ether, and volatile oils, are not sufficiently numerous nor precise to enable us to state the exact proportions taken up. We know, however, that they are limited, and that every substance has a degree of solubility peculiar to itself.

Water, from the experiments of Lauraguais, dissolves

$\frac{1}{10}$th of its bulk of *sulphuric ether.* There is reason to believe that the proportion is not so great. The ether tried must have contained alcohol; as chemists, at the time Lauraguais' experiments were made, were not in possession of a method of separating the two liquids. Now, whenever ether containing alcohol is mixed with water, a very considerable proportion of the alcohol is taken up without injuring the solubility of the ether.

Volatile oils are soluble in very minute quantities only by water. They communicate their odour to that liquid, but scarcely any other of their properties.

2. Alcohol dissolves a considerable proportion of the volatile oils; but the quantity of each is limited and peculiar. The quantity of petroleum which it dissolves is small. I do not know the effect of this liquid upon the two other substances contained in the table; they have been placed here merely from analogy.

The action of ether on volatile oils and petroleum is considerable.

3. The affinity of this second set of liquids for each other seems to be weaker than that which exists between the liquids which unite in all proportions, for the latter generally decompose the former. Thus, if alcohol, holding a volatile oil in solution, be poured into water, the greatest part of the oil separates, while the alcohol unites with the water.

It seems to be the weakness of the affinity, together with the difference between the cohesion of the particles of the two liquids, which limits the combination to certain proportions.

Liquids not acting sensibly on each other. III. The liquids which do not sensibly combine in any proportion are not numerous. The following list comprehends the most remarkable of them:

Water with petroleum
                        fixed oils
                        supersulphureted hydrogen
Fixed oils with alcohol
                        ether
Mercury with water
                        alcohol
                        ether
                        volatile oils
                        petroleum

The action of liquids upon each other has been explained

by Berthollet in a very satisfactory manner. When the affinity of two liquids is not sufficient to counterbalance the cohesion between the particles, or the difference in the specific gravity of each, then they cannot combine. In these cases, however, they sometimes exhibit a degree of affinity, though not sufficiently strong to produce combination. Thus oil spreads itself upon the surface of water, and adheres to it as water does to a solid.*

IV. When a liquid has a marked affinity for one or more of the constituents of a liquid in a separate state, but not for the liquid itself, it often happens, if the density of the liquid be not very great, that it decomposes it, and forms new compounds with its constituents. The following table contains a list of the principal liquids which decompose each other. *[Liquids decomposing each other.]*

Water by phosphuret of sulphur

Nitric acid by all the liquids, except water and sulphuric acid.

Sulphuric acid by all the liquids, except water and nitric acid.

Phosphuret of sulphur gradually decomposes water; sulphureted and phosphureted hydrogen exhale, and no doubt sulphuric and phosphoric acids are formed. The decomposition is greatly facilitated by a high temperature. This curious decomposition seems to be the effect of the action of a particle of the phosphuret upon two atoms of water at once.

The decompositions produced by nitric and sulphuric acids are very curious; but they are all too complicated to admit of a satisfactory explanation in the present state of the science.

V. When solid bodies are brought into a liquid state, either by heat or any other means, their action upon each other is similar to that of common liquids. It is modified by the degree of affinity: some such liquids uniting in all proportions, as most of the metals, the solid oils, resins, &c.; some only in certain proportions, as tin and iron, lead and iron, and different salts; some refusing to combine, as zinc and cobalt, bismuth and cobalt; and some decomposing each other, as nitre and sulphur, nitre and phosphorus. *[Action of solids liquefied.]*

* Statique Chimique, i. 41.

The proportion of the ingredients which enter into com-bination is in these cases affected not only by the affinity, but by the tendency of the new compound, or any of its parts, to assume the solid state.

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SECT. III.

OF THE COMBINATION OF LIQUIDS WITH SOLIDS.

IN treating of the combination of liquids with solids, we may exclude three, on account of their circumscribed ac-tion, and the want of correct experiments respecting them. These are *supersulphureted hydrogen*, *phosphuret of sulphur*, and *bichloride of tin*. Upon these liquids I have no re-marks to offer. There are two others which act with great energy upon many solids; but as their mode of action is precisely similar to a class of bodies which will come under our consideration in the next Chapter, we shall defer the examination of them till we come to treat particularly of the action of the acids. These two are *sulphuric* and *nitric* *acids*. Seven liquids only remain, namely,

Water	Petroleum	Mercury
Alcohol	Volatile oils	
Ether	Fixed oils	

Of these seven, the action of the first is by far the most general, and has been most closely examined. We shall consider the action of this liquid in the first place: A few observations will suffice for the rest.

Water.   I. Water has an affinity for a very great number of bo-dies, and its presence in general greatly facilitates the ac-tion of substances on one another. Hence it is almost al-ways indispensable when artificial combinations or decom-positions are to be produced.

Unites with solids in two states.   1. Water, as has been already observed in a former part of this Work, has the property of entering into two dif-ferent kinds of combinations with solid bodies. In the one species the compound continues solid, in the other it be-comes liquid. In the first species the proportion of the solid ingredient is greater than that of the liquid: Hence

the cohesion of its particles is not destroyed. In the second, the proportion of the liquid exceeds the proportion of the solid: Hence it gives its peculiar state to the compound.

To the first species of combination Proust has given the name of *hydrate*. A hydrate is a compound of a solid body and water, still retaining the solid state. The following solid bodies are capable of entering into this combination with water.

1. Sulphur. The hydrate is a very pale sulphur yellow powder, usually called *lac sulphuris*. Native sulphur is often in this state.

2. Metallic oxides. The hydrates of these bodies are powders remarkable for the intensity of their colours. They have usually a strong taste, and are easily acted upon by acid or alkaline solutions.

3. The earths. These hydrates are powders, and in some cases crystals.

4. The fixed alkalies. The hydrates of these bodies are what are usually termed the crystals of alkalies.

5. All the acids which may be exhibited in a solid state; which is the case with the whole of that class of bodies except 13. The hydrates of these bodies are what are usually called the *crystallized acids*.

6. All the class of salts. Those excepted which contain no water of crystallization. The hydrates of the salts are the *saline crystals*, in those salts capable of assuming that form; and powders or solid masses, in those which are not.

7. All the hydrosulphurets capable of assuming a solid form. The hydrates of these bodies are the crystallized hydrosulphurets.

8. Many earthy combinations. Water exists as a constituent in many combinations of earths found native. But the examination of these bodies has not hitherto been conducted in such a manner as to warrant us to venture upon a list of such native hydrates.

9. Soaps. All soaps contain water as a constituent. It is not, then, quite correct to say that soap combines with water and forms a hydrate. The soap is itself a hydrate; but we have no name for soap free from water, if such a compound be possible.

10. Tannin and many animal and vegetable solids.

In the first eight classes of hydrates contained in the preceding list, the quantity of water seems to be determinate, or nearly so; but this does not appear to be the case in the two last classes.

2. Solution. The second species of combination into which water enters with solid bodies has been usually termed the *solution* of these bodies in that liquid. · The bodies which it dissolves are not so numerous as those with which it forms *hydrates*. They are those which are contained in the preceding list, excepting sulphur, most of the metallic oxides, most of the earths, many salts, and almost all the earthy combinations. In these combinations there is a minimum of water necessary to dissolve the solid; but beyond this proportion the quantity of liquid may be increased at pleasure.

Explanation of the action of water on solids. 2. The action of water upon solid bodies has been explained in a very luminous manner by Berthollet.* This liquid has obviously an affinity for all those bodies with which it is capable of combining. But affinity is mutual. We may say with as much propriety, that the solid acts upon the liquid, as that the liquid acts upon the solid. Both act upon each other reciprocally, and at the same time; but the force exerted by each will be proportional to its mass. Now there is this peculiarity in the action of liquids upon solids, that they can only act at the point of contact, or at least near it. Hence, as far as the mass is concerned, it is quite the same thing whether a solid be acted upon by a large quantity of liquid or a small quantity; since the points of contact, and of course the sphere of the liquid's activity, must in both cases be the same.

When a solid body, then, is plunged into a liquid for which it has an affinity, whatever the quantity of liquid may be, the action is always limited to a very small portion. Hence the liquid is not capable at first of destroying the cohesion of the solid; which imbibes it, and combines with it, while new portions of liquid come into contact, and begin to exert their action. If the affinity between the solid and liquid be weak, the combination proceeds only till the force of affinity is so far weakened by the quantity of water united, that it is no longer able to overcome the

* Statique Chimique, i. 35.

cohesion of the particles of the solid, and then it necessarily stops. The compound continues solid. With such solids water is capable only of forming a *hydrate*; it does not dissolve them.

If the affinity be strong, new doses of water continue to combine with the atoms of the solid, and thus these atoms are separated farther and farther from each other; but as this distance increases, the force of cohesion continually diminishes, while the liquid, by its increased mass, is enabled to act with greater and greater energy. Hence the cohesion of the solid is gradually destroyed; the particles of it are separated to too great a distance, and are dispersed equally through the liquid. This is what is termed solution.

If we continue to add more of the solid after a portion has been dissolved in this manner by the liquid, it will be dissolved in the same way. But by this new portion the particles of the dissolved solid are brought nearer each other in the liquid; their mass is increased in proportion to that of the liquid. Hence they exert a greater force upon it, and of course the liquid is enabled to exert only a smaller force upon new portions of the solid. If we continue to add new portions of the solid, a time will come when the action of the liquid will be so much weakened, that it will no longer be able to overcome the cohesion of the solid; it will then refuse to dissolve any more of it. When a liquid has come to this state, it is said to be *saturated* with the solid. Were we to suppose the solution to go on, the particles of the solid in solution would be brought so near one another, that their force of cohesion would overbalance the affinity of the liquid for them; they would, in part, cohere and form again a new portion of the solid. The saturation of a fluid, then, does not mean that its affinity for the solid is satisfied, but that it is not greater than the tendency of the combined particles to cohere. Now, when a liquid is saturated with a solid, if by any means we can abstract part of that liquid, the cohesive force of the particles of the solid must gain the superiority; and the consequence will be, that they will unite and form solid bodies anew, till their number be so much diminished that their mutual attraction is again counterbalanced by the affinity of the liquid. Hence the reason that evapora-

tion occasions the crystallization of those bodies which are held in solution by liquids.

If the affinity between water and the solid be not sufficiently great to enable it to overcome any part of the cohesion of the particles of the solid, in that case none of it combines with that body; it only moistens its surface. If the affinity is even weaker than the cohesion between the particles of the liquid, in that case the surface of the solid is not even wetted.—Such is a sketch of Mr. Berthollet's explanation of the mutual action of water and solids upon each other.

Combination chemical.

3. The combination of water with solid bodies is accompanied by the usual phenomena of chemical combinations. The density is considerably increased, while heat is usually evolved. The hydrates seem to be the most intimate combination; in them the density is greatest, and the heat evolved during their formation is considerable. The solution of the hydrates in water is often accompanied by an expansion rather than condensation; of course cold is produced, and the new compound is much less intimate than the old.

Many experiments have been made to determine the density of the solutions of solids in water; but as the distinction was not always observed between the pure solids and the hydrates, the results are not so satisfactory as they otherwise would have been. The most valuable experiments by far on this subject, which I have had an opportunity of seeing, are those by Dr. Watson,* and Mr. Hassenfratz.† Dr. Watson first set the subject in a clear point of view, by explaining the real nature of the solution, and the changes of density which accompany it. His experiments show very clearly the difference between the hydrates and the pure solids in the density produced by their solution in water. To Hassenfratz we owe by far the most copious set of facts hitherto offered to the public. His experiments were made upon pure substances in a determinate state, so as to be susceptible of comparison. He generally employed hydrates; but he has pointed out very clearly the difference between hydrates and pure solids when dissolved in water.

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* Phil. Trans. 1770, and Chemical Essays, v. 43.
† Ann de Chim. xxvii. 116; xxviii. 3, and 282; xxxi. 284.

The following are the most important facts ascertained by
these philosophers.

4. When solid bodies unite with water and form a
hydrate, the increase of density is sometimes very great;
in such cases there is a vast quantity of heat evolved. Mr.
Hassenfratz united water in different proportions to lime,
and ascertained the specific gravity after each addition.
The following table exhibits the result of these curious ex-
periments on three different specimens of lime varying in
their specific gravity. The weight of lime used was
always 10000:

	Quantity of water added to the Lime.	Spec. Grav. of the Compound.	Spec. Grav. by Calcula-tion.	Differ-ence.
	0	1·5949	——	——
	183	1·6137	1·5841	+ 296
1st.	1620	1·4877	1·5123	− 246
	3355	0·7852	1·4449	− 6597
	0	1·4558	——	——
	629	1·4819	1·4292	+ 527
2d.	1562	1·4737	1·3941	+ 796
	2500	1·4000	1·3648	+ 354
	5000	0·8983	1·3038	− 4055
	0	1·3715	——	——
	312	1·4506	1·3602	+ 904
3d.	937	1·4781	1·3397	+ 1318
	1875	0·9727	1·3128	− 3401

These experiments were made by weighing the compound,
first separately, and then in a phial which was filled with
mercury. The weight of mercury displaced gave the bulk
of the compound. The first numbers in each series give
the specific gravity of the lime employed. From these
tables it appears that the first additions of water actually
increased the specific gravity of the lime, and of course
the bulk must have diminished by combination. The third
column gives the specific gravity which would have resulted
if the lime and water had combined without any change of
density whatever. The last column gives us the excess of
the real over the calculated specific gravity, or its diminu-
tion. Thus it appears that the hydrate of lime is specifi-
cally heavier than pure lime. The density diminishes as
the proportion of water increases, till at last the compound

now reduced to the state of a fine powder, and moist, becomes lighter than water.*

Hydrate of alum. Alum furnishes another good example of the intensity of that species of combination to which the name of hydrate has been given. The hydrate of alum is nothing else than the salt in the state of crystals. In that state its specific gravity, as taken by Hassenfratz, is 1·7065; but when the salt is deprived of its water by calcination, its specific gravity is reduced to 0·4229. Here the density is quadrupled by the combination of water. The following table exhibits the increase of density which takes place when this salt is combined with water up to the state of hydrate. The quantity of calcined alum used was always 1000.

Proportion of Water.	Spec. Grav. of Compound.	Ditto by Calculation.	Differences.
0	0·4229	——	——
322	0·5531	0·6094	− 563
404	1·1423	0·6558	+ 4865
412	1·7165	0·6606	+ 1·0559

Here the first additions of water produced expansion; but when the proportion is increased, the condensation becomes extremely great.

The crystals, or hydrate of nitre, are of the specific gravity 1·9639; but nitre deprived of its water, and in the state of a dry powder, has the specific gravity 1·7269.†

Solution of bodies in water. 5. When solid bodies are dissolved in water, the bulk of the liquid is increased. The density of the solution appears to be always greater than the mean when the pure solids are employed; but when it is the hydrates which are dissolved, the specific gravity is more frequently less than the mean. This will appear very clearly from the following table, exhibiting the result of the experiments of Hassenfratz on the solution of various salts in water. They were all used in the state of hydrates, or crystallized, except a small number which could not be conveniently used in that state. The first column contains the names of the salts; the second their specific gravity; the third, the specific

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* This diminution of the lime below the density of water, notwithstanding Mr. Hassenfratz's explanation of it, on the principle of pulverization diminishing the specific gravity, appears not a little extraordinary. We know that such a powder of lime, if thrown into water, immediately sinks to the bottom of that liquid.

† Hassenfratz, Ann. de Chim. xxxi. 287.

gravity of water saturated with each of them at the tem- perature of 55°; the fourth, the weight of salt contained in 1000 parts, by weight of the saturated solution; the fifth gives the density of the salts, supposing the specific gravity of the saturated solution exactly the mean. When the density of the salts thus found is less than the real, it indicates a condensation; when greater, it indicates an expansion.

Table of densities.

Salts.	Specific gravity.	Sp. gravity of saturated solution.	Salt in 1000 parts of the solution.	Sp. gravity of the salts by calculation.	Differences.
Sulphate of soda	1·4457	1·060	161	1·373	72
potash	2·4073	1·055	64	1·859	548
alumina	1·7109	1 026	55	1·473	237
magnesia	1·6603	1·294	533	1·551	109
iron	1·8399	1·219	335	1·654	185
zinc	1·912	1·373	555	1·672	240
copper	2·1943	1·189	250	1·720	474
Muriate of soda	2·2001	1·210	301	1·697	503
potash	1·9357	1·145	305	1·475	461
ammonia	1·5442	1·070	244	1·287	257
lime	1·7603	1·351	538	1·652	108
magnesia	1·601	1·272	648	1·419	182
barytes	2·8257	1·265	283	1·937	988
zinc	1·577	1·607	785	1·773	+196
copper	1·719	1·271	389	1·699	20
Nitrate of soda	2·0964	1·231	340	1·679	417
potash	1·9369	1·157	249	1·628	308
lime	1·6207	1·143	338	1·423	197
barytes	2·9149	1·047	66	1·712	202
zinc	2·096	1·489	572	1·855	241
copper	2·174	1·530	566	1·937	237
Acetate of soda	2·109	1·189	517	1·365	744
lime	1·005	1·098	178	1·550	+545
magnesia	1·378	1·252	500	1·504	+126
alumina	1·245	1·107	106	1·009	+764
iron	1·368	1·134	322	1·416	+548
lead	2·345	1·198	244	1·811	134
Tartrate of soda	1·743	1·196	333	1·588	155
potash	1·5567	1·435	617	1·705	+49
Phosphate of soda	1·333	1·030	80	1·381	+48
Borax	1·723	1·013	34	1·382	341
Soda of commerce	1·545	1·158	317	1·498	47
American potash	1·927	1·301	428	1·703	226

In those only marked +, in the last column, does the calculated specific gravity exceed the real; in all the others it falls short of it.

Table of saline solutions.

6. As a knowledge of the quantity of salt contained in saline solutions is of considerable importance, both to chemists and manufacturers, I shall insert here the following table of Hassenfratz, which exhibits the specific gravity of saline solutions, differently impregnated at the temperature of 55°. The first column gives the quantity of salt contained in 100 parts, by weight of the solution: the others, the specific gravity of each solution so impregnated. The column belonging to each salt terminates when water is saturated with it at the temperature of 55°. The salts were in general crystallized. The fundamental experiments from which the table was calculated appear to have been made with precision; the results in general agree very nearly with those obtained by Dr. Watson. For a minute account of the method employed in constructing this table, the reader is referred to Mr. Hassenfratz's Dissertation on the subject.*

* Ann. de Chim. xxvii. 118; and xxviii. 282.

Table of Saline Solutions.

Weight of Salt in 100 Parts of the Solution.	Sulphate of Soda.	Sulphate of Potash.	Alum.	Weight of Salt in 100 Parts of the Solution.	Sulphate of Magnesia.	Sulphate of Iron.	Sulphate of Zinc.	Sulphate of Copper.
1	1·0039	1·0086	1·0047	2	1·0096	1·0096	1·0080	1·0141
2	1·0078	1·0171	1·0094	4	1·0192	1·0203	1·0165	1·0280
3	1·0116	1·0257	1·0142	6	1·0286	1·0314	1·0255	1·0413
4	1·0154	1·0343	1·0189	8	1·0379	1·0436	1·0345	1·0539
5	1·0192	1·0429	1·0236	10	1·0470	1·0560	1·0440	1·0660
6	1·0230	1·0515	—	12	1·0555	1·0696	1·0540	1·0795
7	1·0268	—	—	14	1·0646	1·0829	1·0665	1·0938
8	1·0306	—	—	16	1·0711	1·0961	1·0790	1·1083
9	1·0344	—	—	18	1·0771	1·1095	1·0915	1·1230
10	1·0381	—	—	20	1·0860	1·1220	1·1040	1·1380
11	1·0418	—	—	22	1·0976	1·1358	1·1165	1·1513
12	1·0455	—	—	24	1·1092	1·1498	1:1290	1·1747
13	1·0492	—	—	26	1·1178	1·1638	1·1420	—
14	1·0528	—	—	28	1·1324	1.1781	1·1550	—
15	1·0564	—	—	30	1·1440	1·1920	1·1680	—
16	1·0598	—	—	32	1·1557	1·2031	1·1820	—
				34	1·1675	—	1·1960	—
				36	1·1789	—	1·2100	—
				38	1·1905	—	1·2240	—
				40	1·2122	—	1·2380	—
				42	1·2262	—	1·2525	—
				44	1·2302	—	1·2680	—
				46	1·2432	—	1·2855	—
				48	1·2562	—	1·3045	—
				50	1·2683	—	1·3310	—
				52	1·2833	—	1·3485	—
				54	1·2973	—	1·3565	—

Table of Saline Solutions, continued.

Weight of Salt in 100 Parts of the Solution.	Muriate of Soda.	Muriate of Potash.	Chlorate of Potash.	Muriate of Ammonia.	Muriate of Barytes.
1	1·0064	1·0047	1·0055	1·0029	1·0073
2	1·0128	1·0095	1·0105	1·0059	1·0146
3	1·0192	1·0143	1·0150	1·0089	1·0217
4	1·0256	1·0192	1·0193	1·0118	1·0289
5	1·0320	1·0240	1·0220	1·0149	1·0360
6	1·0384	1·0288	1·0301	1·0179	1·0430
7	1·0448	1·0338	1·0376	1·0209	1·0503
8	1·0502	1·0388	1·0463	1·0239	1·0575
9	1·0576	1·0438	1·0567	1·0269	1·0647
10	1·0640	1·0490	—	1·0300	1·0720
12	1·0775	1·0612	—	1·0358	1·0919
14	1·0910	1·0701	—	1·0416	1·1014
16	1·1045	1·0801	—	1·0474	1·1309
18	1·1182	1·0901	—	1·0532	1·1504
20	1·1320	1·1000	—	1·0590	1·1700
22	1·1462	1·1090	—	1·0642	1·1901
24	1·1608	1·1178	—	1·0693	1·2227
26	1·1760	1·1264	—	—	1·2363
28	1·1920	1·1344	—	—	1·2600
30	1·2100	1·1420	—	—	—

Table of saline solutions, continued.

Weight of salt in 100 parts of the solution.	Muriate of Magnesia.	Muriate of lime.	Muriate of zinc.	Muriate of copper.
2	1·0068	1·0125	1·0114	1·0100
4	1·0136	1·0212	1·0228	1·0206
6	1·0204	1·0319	1·0342	1·0311
8	1·0274	1·0429	1·0458	1·0425
10	1·0340	1·0540	1·0573	1·0540
12	1·0408	1·0650	1·0687	1·0653
14	1·0476	1·0759	1·0802	1·0767
16	1·0544	1·0870	1·0966	1·0881
18	1·0612	1·0979	1·1033	1·0995
20	1·0681	1·1000	1·1150	1·1110
22	1·0751	1·1212	1·1267	1·1239
24	1·0823	1·1323	1·1382	1·1369
26	1·0895	1·1445	1·1498	1·1499
28	1·0967	1·1547	1·1614	1·1629
30	1·1040	1·1670	1·1730	1·1760
32	1·1114	1·1803	1·1864	1·1904
34	1·1190	1·1935	1·1967	1·2080
36	1·1266	1·2067	1·2106	1·2273
38	1·1343	1·2198	1·2228	1·2466
40	1·1420	1·2330	1·2360	—
42	1·1507	1·2478	1·2497	—
44	1·1597	1·2528	1·2639	—
46	1·1686	1·2789	1·2783	—
48	1·1777	1·2949	1·2927	—
50	1·1870	1·3120	1·3070	—
52	1·1963	1·3310	1·3244	—
54	1·2068	—	1·3402	—
56	1·2164	—	1·3567	—
58	1·2261	—	1·3733	—
60	1·2380	—	1·3900	—
62	1·2507	—	1·4071	—
64	1·2646	—	1·4253	—
66	—	—	1·4457	—
68	—	—	1·4675	—
70	—	—	1·4900	—
72	—	—	1·5164	—
74	—	—	1·5427	—
76	—	—	1·5700	—
78	—	—	1·5987	—

Table of saline solutions, continued.

Weight of salt in 100 parts of the solution.	Nitrate of potash.	Nitrate of soda.	Nitrate of barytes.	Nitrate of lime.	Nitrate of zinc.	Nitrate of copper.
1	1·0063	1·0059	1·0062	1·0052	1·0061	1·0059
2	1·0125	1·0119	1·0123	1·0104	1·0125	1·0119
3	1·0186	1·0180	1·0185	1·0156	1·0189	1·0192
4	1·0244	1·0240	1·0250	1·0208	1·0255	1·0252
5	1·0302	1·0300	1·0320	1·0260	1·0320	1·0320
6	1·0353	1·0359	1·0409	1·0310	1·0387	1·0390
7	1·0408	1·0419	—	1·0361	1·0442	1·0457
8	1·0468	1·0480	—	1·0411	1·0509	1·0526
9	1·0531	1·0540	—	1·0481	1·0574	1·0592
10	1·0595	1·0600	—	1·0510	1·0640	1·0655
12	1·0722	1·0719	—	1·0601	1·0786	1·0778
14	1·0850	1·0840	—	1·0690	1·0926	1·0918
16	1·0984	1·0960	—	1·0777	1·1063	1·1060
18	1·1119	1·1081	—	1·0864	1·1183	1·1201
20	1·1235	1·1202	—	1·0950	1·1340	1·1350
22	1·1389	1·1336	—	1·1044	1·1508	1·1521
24	1·1520	1·1482	—	1·1112	1·1676	1·1716
26	—	1·1628	—	1·1185	1·1844	1·1915
28	—	1·1779	—	1·1257	1·2012	1·2117
30	—	1·1920	—	1·1320	1·2180	1·2320
32	—	1·2099	—	1·1383	1·2348	1·2513
34	—	1·2294	—	—	1·2515	1·2712
36	—	—	—	—	1·2683	1·2912
38	—	—	—	—	1·2851	1·3113
40	—	—	—	—	1·3020	1·3320
42	—	—	—	—	1·3203	1·3533
44	—	—	—	—	1·3395	1·3749
46	—	—	—	—	1·3601	1·3978
48	—	—	—	—	1·3810	1·4206
50	—	—	—	—	1·4050	1·4440
52	—	—	—	—	1·4271	1·4686
54	—	—	—	—	1·4494	1·4944
56	—	—	—	—	1·4727	1·5205

Table of saline solutions, continued.

Weight of salt in 100 parts of the solution.	Acetate of Lime.	Acetate of Alumina.	Acetate of Lead.	Acetate of Soda.	Acetate of magnesia	Acetate of iron.
1	1·0049	1·0090	1·0070	1·0028	1·0041	1·0035
2	1·0098	1·0190	1·0140	1·0058	1·0082	1·0075
3	1·0147	1·0280	1·0211	1·0087	1·0124	1·0112
4	1·0197	1·0380	1·0283	1·0117	1·0166	1·0150
5	1·0247	1·0470	1·0366	1·0146	1·0208	1·0188
6	1·0297	1·0570	1·0430	1·0176	1·0250	1·0225
7	1·0348	1·0670	1·0505	1·0206	1·0293	1·0264
8	1·0400	1·0780	1·0580	1·0237	1·0337	1·0302
9	1·0453	1·0880	1·0655	1·0267	1·0380	1·0341
10	1·0507	1·0990	1·0731	1·0299	1·0424	1·0380
12	1·0615	—	1·0891	1·0361	1·0512	1·0458
14	1·0735	—	1·1055	1·0424	1·0603	1·0537
16	1·0860	—	1·1221	1·0488	1·0696	1·0616
18	—	—	1·1330	1·0553	1·0790	1·0697
20	—	—	1·1560	1·0619	1·0885	1·0780
22	—	—	1·1740	1·0685	1·0983	1·0863
24	—	—	1·1928	1·0751	1·1086	1·0948
26	—	—	—	1·0817	1·1180	1·1045
28	—	—	—	1·0883	1·1294	1·1140
30	—	—	—	1·0955	1·1400	1·1224
32	—	—	—	1·1018	1·1507	1·1323
34	—	—	—	1·1090	1·1614	—
36	—	—	—	1·1165	1·1723	—
38	—	—	—	1·1242	1·1834	—
40	—	—	—	1·1320	1·1946	—
42	—	—	—	1·1399	1·2058	—
44	—	—	—	1·1432	1·2172	—
46	—	—	—	1·1567	1·2287	—
48	—	—	—	1·1656	1·2403	—
50	—	—	—	1·1755	1·2520	—

Table of saline solutions, continued.

Weight of salt in 100 parts of the solution.	Tartrate of Soda.	Tartrate of potash.	Phosphate of soda.	Borax.	Soda of Commerce.	American potash.
1	1·0034	1·0050	1·0040	1·0040	1·0042	1·0050
2	1·0072	1·0102	1·0081	1·0084	1·0086	1·0102
3	1·0108	1·0153	1·0120	1·0122	1·0130	1·0156
4	1·0148	1·0212	1·0166	—	1·0175	1·0212
5	1·0190	1·0258	1·0200	—	1·0220	1·0269
6	1·0231	1·0311	1·0237	—	1·0264	1·0327
7	1·0272	1·0363	1·0270	—	1·0310	1·0385
8	1·0313	1·0417	1·0300	—	1·0356	1·0443
9	1·0355	1·0470	—	—	1·0403	1·0503
10	1·0397	1·0525	—	—	1·0458	1·0563
12	1·0481	1·0634	—	—	1·0544	1·0684
14	1·0567	1·0744	—	—	1·0640	1·0807
16	1·0655	1·0856	—	—	1·0736	1·0930
18	1·0745	1·0968	—	—	1·0833	1·1053
20	1·0837	1·1080	—	—	1·0930	1·1179
22	1·1032	1·1196	—	—	1·1031	1·1307
24	1·1153	1·1317	—	—	1·1135	1·1438
26	1·1283	1·1447	—	—	1·1241	1·1571
28	1·1436	1·1569	—	—	1·1349	1·1724
30	1·1600	1·1700	—	—	1·1460	1·1840
32	1·1801	1·1838	—	—	—	1·1989
34	—	1·1978	—	—	—	1·2142
36	—	1·2118	—	—	—	1·2304
38	—	1·2259	—	—	—	1·2478
40	—	1·2400	—	—	—	1·2660
42	—	1·2547	—	—	—	1·2882
44	—	1·2696	—	—	—	—
46	—	1·2861	—	—	—	—
48	—	1·3015	—	—	—	—
50	—	1·3180	—	—	—	—
52	—	1·3351	—	—	—	—
54	—	1·3527	—	—	—	—
56	—	1·3507	—	—	—	—
58	—	1·3902	—	—	—	—
60	—	1·4120	—	—	—	—

This table is so simple as scarcely to require any expla- nation. Suppose we have a solution of nitrate of zinc, of the specific gravity 1·4050, at the temperature of 55°; by inspecting the table, we see immediately that such a solution contains half its weight of crystallized nitrate of zinc.

When the specific gravity of our solution is not to be found exactly in the preceding table, we may obtain the quantity of salt which it contains pretty nearly by the following method: suppose we have a solution of American potash of the specific gravity 1·1900, at the temperature 55°. By inspecting the table, we find that the quantity of salt which our solution contains lies between 30 and 32 per cent. Now the specific gravity of a solution containing 30 per cent. is 1·1840, and that of one containing 32 per cent. is 1·1989. If we can find a number such that it will have the same ratio to 30 and 32, as 1·1900 has to 1·1840, and 1·1989, that number will give us very nearly the quantity of salt per cent. which our solution contains. The following operation gives us a number x, which, when added to 80, makes the number required:

$$32 - 30 : 1·1989 - 1·1840 :: x : 1900 - 1840;$$

Or, which is the same thing,

$$2 : 149 :: x : 60, \text{ and } x = \frac{2 \times 60}{149} = 0·81.$$

The number required of course is 30·81.

Suppose we have a saturated saline solution of any salt, and that we wish to reduce it by the addition of water till it contains only a given quantity of salt per cent. the quantity of water to be added may be found by the following operation. Let D be the weight of a saturated solution which we wish to dilute, S the quantity of salt which it contains, x the quantity of water to be added, S′ the quantity of salt contained in 100 parts of the new mixture; then we have $\frac{D + x}{S} = \frac{D}{S'}$: Hence $x = \frac{SD - S'D}{S'}$. Suppose the solution which we have to be nitre and D = 100. From the table we see that a saturated solution of nitre contains 24·88 per cent. of salt; therefore S = 24·88. Let it be required to reduce it so that it shall contain only 10 per cent. of salt. Here S′ = 10. We have therefore $x = \frac{2488 - 1000}{10} = 148·8.$

So that to 100 parts of the saturated solution if we add 148·8 parts of water by weight, we shall form a new solution, containing only 10 per cent. of salt.*

Effect of temperature.

7. The quantity of salt soluble in water in most cases increases with the temperature. Hence both the proportions and the specific gravity must vary with every temperature. The preceding table applies only to the temperature of 55°. Hitherto no exact set of experiments has been made to enable us to ascertain what allowance is to be made for changes of temperature. Hassenfratz has promised to publish a treatise on the subject; but hitherto he has not fulfilled that promise.

Action of water on different solids at once.

8. Water has the property of dissolving more than one solid body at a time; we may present to a saturated aqueous solution of one substance another substance soluble in water. In that case, the result varies exceedingly according to the substances used; but the different cases may be reduced to three : 1. Sometimes none of the solid is dissolved : thus, a saturated solution of muriate of lime is incapable, at the temperature of 60°, of dissolving any common salt. In that case the temperature of the liquid suffers no change. 2. Sometimes the saturated solution dissolves the whole or a part of the new solid, without losing any part of the solid with which it is already combined. Thus a saturated solution of nitrate of potash, in the temperature of 51°, dissolves a considerable quantity of common salt, and thus has its density greatly increased. In that case the temperature of the solution always sinks when the new solid is in the state of a hydrate. 3. Sometimes the saturated solution dissolves the new solid, but at the same time lets go a portion or the whole of the substance with which it was formerly combined. Thus when a saturated solution of sal ammoniac, in the temperature of 61°, is mixed with a sufficient quantity of common salt, this last substance is dissolved, but at the same time the whole of the muriate of ammonia precipitates. In this case the temperature of the solution often rises.

Action of common salt on saline solutions.

We are indebted to Mr. Vauquelin for the most curious set of experiments on this subject which has hitherto appeared. I shall present the result of them under the form

* Hassenfratz, Ann. de Chim. xxvii. 132.

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of a table. They were made by mixing muriate of soda in powder with saturated solutions of various salts. The portion of liquid used in each experiment was 2304 grains (4 oz. French,) and the quantity of common salt mixed with it was always 576 grains, or ¼th of the weight of the liquid. The first column of the following table gives the temperature of the saline solution employed; the second, the name of the solution; the third, its specific gravity, wherever that has been noted by Mr. Vauquelin; the fourth column gives the weight of common salt in grains, taken up by the solution; the fifth, the quantity of the salt previously in solution, which precipitated when the common salt dissolved; the sixth column gives the temperature of the liquid immediately after the solution of the common salt; and the seventh the amount of the change of temperature.*

Temperature before Mixture.	Saline Solution used.	Specific Gravity of Ditto.	Portion of Salt dissolved.	Portion of Salt precipitated from the Solution.	New Temperature produced.	Change of Temperature.
47°	Pure water	1·00	542	0	43·25	—3·75
51	Nitrate of lime		0	0	51	0
61·25	Muriate of lime		0	0	61·25	0
51·1	Nitrate of potash	1·114	540	0	51·1	0
47·75	Alum	1·048	556	0	45·25	— 2·5
49	Nitrate of barytes		533	0	45·5	— 3·5
47	Sulphate of lime	1·006	Almost all	0	43·25	— 3·75
47·75	Sulphate of potash		Almost all	44	46·75 / 48·75	— 1 / + 1

* See Vauquelin, Ann. de Chim. xiii. 86.

Tempera-ure before Mixture.	Saline Solution used.	Specific Gravity of Ditto.	Portion of Salt dissolved.	Portion of Salt precipitated from the Solution.	New temperature produced.	Change of Temperature.
52·25°	Nitrate of magnesia	1·307	Almost all	A little	55	+ 2·75
47	Sulphate of soda		Almost all	186	52·25	+ 5·75
61·25	Muriate of barytes		Almost all	Many crystals	67	+ 5·75
47·75	Sulphate of magnesia		536	396	54·5	+ 6·25
61·25	Muriate of ammonia		Almost all	The whole	70·25	+ 9·00
51·1	Nitrate of soda		The whole	648	61·25	+ 10·15
61·25	Muriate of potash		Greater part	A great deal	72·5	+ 11·25
47·75	Sulphate of ammonia	1·240	The whole	720	65·75	+ 18·25*

From this table it appears that a saturated solution of nitrate of lime dissolves *no* common salt; that a saturated solution of nitrate of potash dissolves *more* common salt than the same weight of pure water; and that, a saturated solution of nitrate of soda likewise dissolves *more* common salt than pure water, but at the same time allows the *greatest* part of the nitrate of soda to precipitate.

These curious phenomena obviously depend upon the mutual action which certain salts exert upon each other, which by dimishing the cohesion of each, enables the water to act upon them with more energy; and upon their relative affinity for water. This affinity we know varies with the temperature, and every salt follows a particular law of its own. Hence it happens, that the phenomena above de-

* The residue not precipitated formed with the muriate of soda a triple salt.

scribed succeed only at the temperature in which the experiments were made. In high temperatures, the affinity of muriate of soda for water is much feebler than that of most of the salts. At a boiling heat, therefore, it is separated by those very salts which it throws down at a low temperature.

The heat evolved, even when the quantity of salt precipitated was much less than of the common salt dissolved, shows us that muriate of soda absorbs but little heat during its solution in water. A circumstance probably connected with the small quantity of water of crystallization which it contains.

9. When a portion of the water holding a solid body in solution is removed by evaporation, the particles of the solid being brought nearer each other, their tendency to cohesion increases, and more than counterbalances their affinity for the liquid. Hence a portion separates and assumes the solid form. If different bodies be in solution at once, that substance separates first which has the greatest tendency to cohesion. But in general, the different substances dissolved act upon each other to a certain extent, and prevent or retard their returning to the solid form. Hence the *mother liquor*, as it is called, which almost always remains when compound saline liquors are evaporated.

By evaporation, a saturated solution of a solid may be concentrated to a considerable degree, without depositing any of the dissolved solid; because the cohesion being now destroyed, cannot resist the action of the water on account of the equilibrium of the particles, unless some cause intervene to destroy that equilibrium. Thus if a crystal of the substance dissolved be introduced into the solution, immediately the particles in solution begin to deposite themselves.*

II. The action of alcohol upon solids is more limited than that of water. There are, however, a considerable number of bodies on which it acts. We are not acquainted with any solid combinations into which alcohol enters similar to the hydrates. The following is a list of the solid substances which it is capable of dissolving:

Action of alcohol on solids.

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* Berthollet has explained this subject at great length, and with his usual sagacity. See Statique Chimique, i. 34 and 35.

1. Sulphur.

2. Phosphorus, and several compounds into which it enters.

3. Fixed alkalies.

4. Some of the alkaline earths in minute proportions.

5. Most of the solid acids.

6. Many salts.

7. Alkaline sulphurets.

8. Alkaline soaps.

9. Many vegetable substances.

Water and alcohol together appear to act upon several solid bodies with more energy than either of them separately.

III. The action of ether seems still more circumscribed than that of alcohol; but the experiments hitherto made upon the action of ether, petroleum, volatile oils, and fixed oils, upon solids, are neither sufficiently numerous nor precise to warrant any general deduction.

Action of mercury on metals.

IV. The action of mercury is confined entirely to the metals. With these it forms compounds called *amalgams*. The energy of the action depends obviously upon the strength of its affinity, and upon the cohesive force of the particles of the metal with which it is to combine.

There are seven metals upon which mercury acts spontaneously; and if applied in sufficient quantity, dissolves them completely. These are,

Gold,	Lead,	Bismuth,	Osmium.
Silver,	Tin,	Zinc,	

Upon five metals it may be made to act either by trituration or by destroying the cohesion of the metal by means of heat. These are,

Platinum,	Tellurium,	Antimony.
Copper,	Arsenic,	

With iron it may be made to combine; but its affinity for that metal being very weak, the iron must be presented in a particular state.

There are five metals with which mercury cannot be made to combine. These are,

Nickel,	Rhodium,	Molybdenum.
Cobalt,	Manganese,	

Its action upon the other metals has not been tried.

When several of the metals are dipped into mercury, they come out moistened with it just as a piece of wood does when plunged into water. The adhering portion has obviously begun a combination. Hence the mercury adheres to the metal with a considerable force. We learn from the experiments of Morveau, that this force varies in different metals. He constructed cylinders of different metals, perfectly round, an inch in diameter and the same in thickness, and having a small ring in their upper surface, by which they might be hung exactly in equilibrium. He suspended these cylinders, one after another, to the beam of a balance; and after counterpoising them exactly, applied them to a quantity of mercury placed about two lines below them, making them slide along its surface, to prevent any air from lodging between them and the mercury. He then marked exactly the weight necessary to overcome their adhesion, taking care to change the mercury after every experiment. The table of the results is as follows:

Gold adheres to mercury with a force of 446 gr.
Silver 429
Tin... 418
Lead 397
Bismuth 372
Platinum 282*
Zinc 204
Copper 142
Antimony 126
Iron 115
Cobalt 8

These numbers may be considered as proportional to the affinity of each metal for mercury. They obviously depend upon the quantity of mercury that adhered to each surface; and that of course would be regulated by the affinity. But the supposition that the numbers in the table are proportional to the affinity is altogether gratuitous.

* Morveau, Ann. de Chim. xxv. 10.

CHAP. IV.

OF SOLIDS.

SOLID bodies are much more numerous than either liquids or elastic fluids. Many of them when heated become liquids, while others are decomposed before they acquire the temperature necessary to produce fluidity. In this chapter we shall consider, in the first place, the constitution of solid bodies, and afterwards their combinations with each other. Solid bodies consist of an indefinite number of homogeneous particles aggregated together in masses, and so constituted that they cannot, like liquids, move among themselves. In considering the constitution of solid bodies, there are two things which claim particular attention. The first is the force by means of which the particles are united together. It is called *cohesion*. The second is the way in which these particles arrange themselves with regard to each other. It produces those regular shapes in solid bodies well known by the name of *crystals*. We shall treat of each of these separately: this chapter, then, will be divided into three sections; treating respectively,

1. Of cohesion.
2. Of crystallization.
3. Of the combination of solids with each other.

SECT. I.

OF COHESION.

THE force called *cohesion* is inherent in all the particles of solid bodies; for all solid bodies exist in masses composed of an indefinite number of particles united together.

1. It acts only at insensible distances; for whenever we remove the particles of a body to a perceptible distance from each other, they cease to cohere altogether.

Cohesion varies in different bodies.

2. Cohesion is exceedingly various in different bodies; though in the same body, if other things be equal, it is always the same. Thus an iron rod is composed of particles of iron cohering so strongly, that it requires an enormous

force to separate them. A smaller force is necessary to overcome the cohesion of lead, and a still smaller to separate the particles of chalk from each other. In short, there are scarcely two bodies whose particles cohere with the same force. The force of cohesion in solid bodies is measured by the weight necessary to break them, or rather to pull them asunder. Thus if a rod of glass be suspended in a perpendicular direction, and weights be attached to its lower extremity till the rod is broken by them, the weight attached to the rod just before it broke is the measure of the cohesive force of the rod. We are indebted to Muschenbroeck for the most complete set of experiments hitherto made upon the cohesive force of solid bodies. Sickengen has also examined the cohesion of several of the metals with much accuracy. The results of the labours of the first of these philosophers may be seen in the following table:*

I. METALS.

Steel, bar	135,000	Tin, cast	4,440
Iron, bar	74,500	Bismuth	2,900
Iron, cast	50,100	Zinc	2,600
Copper, cast	28,600	Antimony	1,000
Silver, cast	41,500	Lead, cast	860
Gold, cast	22,000		

II. ALLOYS.

Gold 2 parts, silver 1 part	28,000	Brass	51,000
		Tin 3, lead 1	10,200
Gold 5, copper 1	50,000	Tin 8, zinc 1	10,000
Silver 5, copper 1	48,500	Tin 4, antimony 1	12,000
Silver 4, tin 1	41,000	Lead 8, zinc 1	4,500
Copper 6, tin 1	55,000	Tin 4, lead 1, zinc 1	13,000

III. WOODS.

Locust tree	20,100	Alder	13,900
Jujeb	18,500	Elm	13,200
Beech, oak	17,300	Mulberry	12,500
Orange	15,500	Willow	12,500

* In this table the numbers denote the pounds avoirdupois which are just sufficient to tear asunder a rod of each of the bodies whose base is an inch square.

Book III.

Ash	12,000	Walnut	8,130
Plum	11,800	Pitch pine	7,656
Elder	10,000	Quince	6,750
Pomegranate	9,750	Cypress	6,000
Lemon	9,250	Poplar	5,500
Tamarind	8,750	Cedar	4,880
Fir	8,330		

IV. BONES.

Ivory	16,270	Whalebone	7,500
Bone	15,250	Tooth of sea calf	4,075
Horn	8,750		

Explained by Boscovich.

3. The nature of cohesion has been more happily explained by Boscovich than by any other philosopher. Indeed it forms the most beautiful and satisfactory part of his theory. According to him, the particles of bodies cohere together when they are placed in the limit of repulsion and attraction. Two particles, when situated at a certain distance from each other, repel each other mutually; this repulsion gradually diminishes as the distance between the particles increases, till at last, when the distance reaches a certain magnitude, the repulsion ceases altogether. If the distance be increased ever so little, the particles now, instead of repelling, attract each other; and this attraction increases with the distance, till at last it reaches its maximum. From this point it gradually diminishes, till at last, when the particles have acquired a certain distance, it vanishes altogether. If the distance be increased ever so little beyond that distance, the particles now again repel each other. He supposes that the insensible distance between two particles is divided into an indefinite number of portions of alternate repulsions and attractions.

Let the line A H represent the insensible distance between two particles; and let the ordinates of the curve I Q q q' q'' represent the attracting and repelling forces of the two particles, as the second moves along the line A B while the first remains in the point A. The ordinates of the curves situated above the line A H represent repulsive forces, and

1

those below the line represent attracting forces. The points B, C, D, E, F, G, H, where the curve cuts the axis, represent the limits between repulsion and attraction. While the second particle is in any part of the line A B it is repelled: the repulsion increases as the particle approaches A; and at the point A it is infinite, because the line A a is to be considered as an asymptote to the curve. At the point B the second particle is neither repelled nor attracted. In every part of the line B C it is attracted; and the attraction is a maximum at P, because there the ordinate P Q is a maximum. At the point C it is neither attracted nor repelled. In every part of C D it is repelled; in D it is neither attracted nor repelled; in D E it is attracted; and so on.

Now the points B, D, F, and H, are called by Boscovich limits of cohesion, because particles placed in these points remain unaltered, and even resist any force which endeavours to displace them. If they are driven nearer each other, they are again repelled to their former limit: on the other hand, if they are driven to a greater distance, they are again attracted to their former situation.

Boscovich supposes, that in all cases of cohesion the particles of the cohering body are so situated as to be in these limits of cohesion with respect to each other. According to this very ingenious theory, cohesion is not, properly speaking, a force, but the interval between two forces. And even if we were to modify the theory a little, still we must consider cohesion as the balancing of two opposite forces, either of which becomes prevalent according as the cohering particles are urged nearer each other or forced to a greater distance. Consequently, if we were to speak with precision, *cohesion* is not itself a force, but the absence of a force. What has been hitherto called the *force of cohesion*, is the attraction which prevents the cohering particles from separating from each other, and which begins to act, or, more precisely, which becomes prevalent, when the particles are urged to a greater distance from each other.

4. Boscovich has shown, in a very satisfactory manner, how all the varieties of cohesion may be produced by the differences in the size, figure, and density, of the cohering particles.* It deserves attention, that in most cases the co-

* See his Theoria Philosophiæ Naturalis, Part iii. Sect. 406, p. 185.

hesive force of undecompounded solid bodies is very consi-
derable.   All the metals cohere very strongly ; the diamond
probably coheres with no less force, if we can judge from its
hardness ; and the cohesion of sulphur is also great.   The
sapphire or crystallized alumina, and rock crystal or crystal-
lized silica, are always very hard.   In the metals the cohe-
sion is very often increased considerably by alloying them
together.   Thus the cohesion of copper is doubled by alloy-
ing it with one-sixth of its weight of tin, though the cohe-
sion of the tin is scarcely one-sixth of that of the copper.
The cohesion of metals is greatly increased by forging them,
and by drawing them out into wire.   By this last operation
gold, silver, and brass, have their cohesion nearly tripled,
copper and iron more than doubled.

SECT. II.

OF CRYSTALLIZATION.

THE word *crystal* (κρυσ7αλλος) originally signified *ice ;* but
it was afterwards applied by the ancients to crystallized
silica, or *rock crystal ;* because, as Pliny informs us, they
considered that body as nothing else than water congealed
by the action of cold.   Chemists afterwards applied the
word to all transparent bodies of a regular shape; and at
present it is employed to denote, in general, the regular
figures which bodies assume when their particles have full
liberty to combine according to the laws of cohesion.   These
regular bodies occur very frequently in the mineral king-
dom, and have long attracted attention on account of their
great beauty and regularity.   By far the greater number of
the salts assume likewise a crystalline form ; and as these
substances are mostly soluble in water, we have it in our
power to give the regular shape of crystals in some measure
at pleasure.

1. Most solid bodies either occur in the state of crystals,
or are capable of being made to assume that form.   Now
it has long been observed by chemists and mineralogists,
that there is a particular form which every individual sub-
stance always affects when it crystallizes : this indeed is con-

sidered as one of the best marks for distinguishing one sub-
stance from another. Thus common salt is observed to as-
sume the shape of a cube, and alum that of an octahedron,
consisting of two four-sided pyramids, applied base to base.
Saltpetre affects the form of a six-sided prism; and sulphate
of magnesia that of a four-sided prism; and carbonate of
lime is often found in the state of a rhomboid. Not that
every individual substance always uniformly crystallizes in
the same form; for this is liable to considerable variations
according to the circumstances of the case: but there are a
certain number of forms peculiar to every substance, and
the crystals of that substance, in every case, adopt one or
other of these forms, and no other; and thus common salt,
when crystallized, has always either the figure of a cube or
octahedron, or some figure reducible to these.

2. As the particles of bodies must be at liberty to move
before they crystallize, it is obvious that we cannot reduce
any bodies to the state of crystals, except those which we
are able to make fluid. Now there are two ways of render- Crystals
ing bodies fluid, namely, solution in a liquid, and fusion by formed by
heat. These of course are the only methods of forming
crystals in our power.

Solution is the common method of crystallizing salts. Solution,
They are dissolved in the water: the water is slowly eva-
porated, the saline particles gradually approach each other,
combine together, and form small crystals; which become
constantly larger by the addition of other particles, till at
last they fall by their gravity to the bottom of the vessel.
It ought to be remarked, however, that there are two kinds
of solution, each of which presents different phenomena of
crystallization. Some salts dissolve in very small propor-
tions in cold water, but are very soluble in hot water; that
is to say, water at the common temperature has little effect
upon them, but water combined with caloric dissolves them
readily. When hot water saturated with any of these salts
cools, it becomes incapable of holding them in solution:
the consequence of which is, that the saline particles gra-
dually approach each other and crystallize. Sulphate of
soda is a salt of this kind. To crystallize such salts, nothing
more is necessary than to saturate hot water with them, and
set it by to cool. But were we to attempt to crystallize
them by evaporating the hot water, we should not succeed;

Book III. nothing would be procured but a shapeless mass. Many of the salts which follow this law of crystallization combine with a great deal of water; or, which is the same thing, many crystals formed in this manner contain a great deal of water of crystallization.

There are other salts again which are nearly equally soluble in hot and cold water; common salt for instance. It is evident that such salts cannot be crystallized by cooling; but they crystallize very well by evaporating their solution while hot. These salts generally contain but little water of crystallization.

Fusion. There are many substances, however, neither soluble in water nor other liquids, which, notwithstanding, are capable of assuming a crystalline form. This is the case with the metals, with glass, and some other bodies. The method employed to crystallize them is *fusion*, which is a solution by means of caloric. By this method the particles are separated from one another; and if the cooling goes on gradually, they are at liberty to arrange themselves in regular crystals.

3. To obtain large artificial crystals, of a regular shape, requires considerable address and much patient attention. This curious branch of practical chemistry has been much improved by Mr. Leblanc; who has not only succeeded in obtaining regular crystals of almost any size at pleasure, but has made many interesting observations on crystallization in general.* His method is as follows: The salt to be crystallized is to be dissolved in water, and evaporated to such a consistency that it shall crystallize on cooling. Set it by, and when quite cold pour the liquid part off the mass of crystals, at the bottom, and put it into a flat-bottomed vessel. Solitary crystals form at some distance from each other, and these may be observed gradually increasing. Pick out the most regular of these, and put them into a flat-bottomed vessel at some distance from each other, and pour over them a quantity of liquid obtained in the same way, by evaporating a solution of the salt till it crystallizes on cooling. Alter the position of every crystal once at least every day with a glass rod, that all the faces may be alternately exposed to the action of the liquid; for

* Jour. de Phys. lv. 300.

the face on which the crystal rests never receives any increment. By this process the crystals gradually increase in size. When they have acquired such a magnitude that their form can easily be distinguished, the most regular are to be chosen, or those having the exact shape which we wish to obtain; and each of them is to be put separately in a vessel filled with a portion of the same liquid, and turned in the same manner several times a day. By this treatment they may be obtained of almost any size we think proper. After the crystal has continued in the liquid for a certain time, the quantity of salt held in solution becomes so much diminished, that the liquid begins to act upon the crystal and redissolve it. This action is first perceptible on the angles and edges of the crystal. They become blunted, and gradually lose their shape altogether. Whenever this begins to be perceived, the liquid must be poured off, and a portion of new liquid put in its place; otherwise the crystal is infallibly destroyed. Mr. Leblanc has observed, that this singular change begins first at the surface of the liquid, and extends gradually to the bottom; so that a crystal, if large, may be often perceived in a state of increase at its lower end, while it is disappearing as its upper extremity. Mr. Leblanc even affirms that saline solutions almost always increase in density according to their depth from the surface.

4. The phenomena of crystallization seem to have attracted but little of the attention of the ancient philosophers. Their theory, indeed, that the elements of bodies possess certain regular geometrial figures, may have been suggested by these phenomena; but we are ignorant of their having made any regular attempt to explain them. The schoolmen ascribed the regular figure of crystals to their substantial forms; without giving themselves much trouble about explaining the meaning of the term. This notion was attacked by Boyle; who proved, that crystals are formed by the mere aggregation of particles.* But it still remained to explain, why that aggregation took place; and why the particles united in such a manner as to form regular figures.

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* Treatise on the Origin of Forms and Qualities,

The aggregation is evidently the consequence of that attractive force which has been examined in the last section. But to explain the cause of the regular figures is a more difficult task. Newton has remarked, that the particles of bodies, while in a state of solution, are arranged in the solvent in regular order and at regular distances; the consequence of which must be, that when the force of cohesion becomes sufficiently strong to separate them from the solvent, they will naturally combine in groups, composed of those particles which are nearest each other. Now all the particles of the same body must be supposed to have the same figure; and the combination of a determinate number of similar bodies must produce similar figures. Haüy has made it exceedingly probable that these integrant particles always combine in the same body in the same way, that is to say, that the same faces, or the same edges, always attach themselves together; but that these differ in different crystals. This can scarcely be accounted for, without supposing that the particles of bodies are endowed with a certain polarity which makes them attract one part of another particle and repel the other parts. This polarity would explain the regularity of crystallization; but it is itself inexplicable.

It is remarkable that crystals not only assume regular figures, but are always bounded by plane surfaces. It is very rarely indeed that curve surfaces are observed in these bodies; and when they are, the crystals always give unequivocal proofs of imperfection. But this constant tendency towards plane surfaces is inconceivable, unless the particles of which the crystals are composed are themselves regular figures, and bounded by plane surfaces.

5. If the figure of crystals depends upon the figure of their integrant particles, and upon the manner in which they combine, it is reasonable to suppose that the same particles, when at full liberty, will always combine in the same way, and consequently that the crystals of every particular body will be always the same. Nothing at first sight can appear farther from the truth than this. The
All crystals have a primitive form.
different forms which the crystals of the same body assume are often very numerous, and exceedingly different from each other. Carbonate of lime, for instance, has been
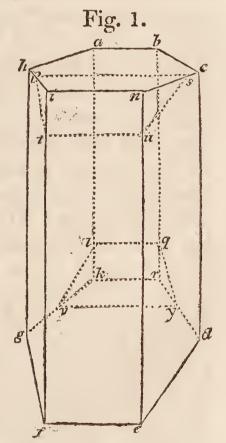
observed crystallized in no fewer than forty different forms, fluate of lime in eight different forms, and sulphate of lime in nearly an equal number.

But this inconsistency is not so great as might at first sight appear. Romé de Lisle has shown that every body susceptible of crystallization has a particular form which it most frequently assumes, or at least to which it most frequently approaches. Bergman has demonstrated, that this primitive form, as Haüy has called it, very often lies concealed in those very crystals which appear to deviate farthest from it. And Haüy has demonstrated, that all crystals either have this primitive form, or at least contain it as a nucleus within them; for it may be extracted out of all of them by a skilful mechanical division.

Happening to take up a hexangular prism of calcareous spar, or carbonate of lime, which had been detached from a group of the same kind of crystals, he observed that a small portion of the crystal was wanting, and that the fracture presented a very smooth surface. Let $a\,b\,c\,d\,e\,f\,g\,h$ (Fig. 1) be the crystal; the fracture lay obliquely as the trapazium $p\,s\,u\,t$, and made an angle of 135°, both with the remainder of the base $a\,b\,c\,s\,p\,h$ and with $t\,u\,e\,f$, the remainder of the side $i\,n\,e\,f$. Observing that the segment $p\,s\,u\,t\,i\,n$ thus cut off had for its vertex $i\,n$, one of the edges of the base $a\,b\,c\,n\,i\,h$ of the prism, he attempted to detach a similar segment in the part to which the next edge $c\,n$ belonged; employed for that purpose the blade of a knife, directed in the same degree of obliquity as the trapezium $p\,s\,u\,t$, and assisted by

Fig. 1.
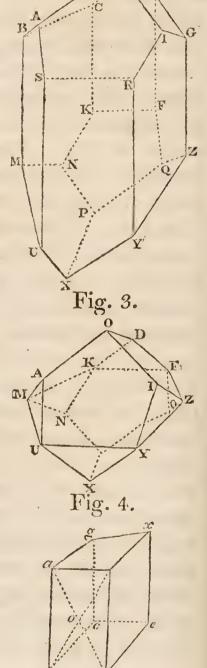
the strokes of a hammer. He could not succeed: but upon making the attempt upon the next edge $b\,c$, he detached another segment, precisely similar to the first, and which had for its vertex the edge $b\,c$. He could produce no effect on the next edge $a\,b$; but from the next following, $a\,h$, he cut a segment similar to the other two. The sixth edge likewise proved refractory. He then went to the other

base of the prism *d e f g k r*, and found, that the edges which admitted sections similar to the preceding ones were not the edges *e f*, *d r*, *g k*, corresponding with those which had been found divisible at the opposite base, but the intermediate edges *d e*, *k r*, *g f*. The trapezium *l q y v* represents the section of the segment which had *k r* for its vertex. This section was evidently parallel to the section *p s u t*; and the other four sections were also parallel two and two. These sections were, without doubt, the natural joinings of the layers of the crystal; and he easily succeeded in making others parallel to them, without its being possible for him to divide the crystal in any other direction. In this manner he detached layer after layer, approaching always nearer and nearer the axis of the prism, till at last the bases disappeared altogether, and the prism was converted into a solid O X (Fig. 2) terminated by twelve pentagons, parallel two and two: of which those at the extremities, that is to say, A S R I O, I G E D O, B A O D C at one end, and F K N P Q, M N P X U, Z Q P X Y at the other, were the results of mechanical division, and had their common vertices O, P, situated at the entrance of the bases of the original prism. The six lateral pentagons R S U X Y, Z Y R I G, &c. were the remains of the six sides of the original prism.

Fig. 2.

But continuing sections parallel to the former ones, the lateral pentagons diminished in length; and at last, the points R, G, coinciding with the points Y, Z, the points S, R, with the points U, Y, &c. there remained nothing of the lateral pentagons but the triangles Y I Z, U X Y, &c. (Fig. 3). By continuing the same sections, these triangles at last disappeared, and the prism was converted into the rhomboid *a e* (Fig. 4).

Fig. 3.

Fig. 4.

So unexpected a result induced him to make the same attempt upon more of these crystals; and he found that all of them could be reduced to similar rhomboids. He found also, that the crystals of other substances could be reduced in the same manner to certain primitive forms: always the same in the same substances, but every substance having its own peculiar form. The primitive form of fluate of lime, for instance, was an octahedron; of sulphate of barytes, a prism with rhomboidal bases; of felspar, an oblique angled parallelopiped, but not rhomboidal; of adamantine spar, a rhomboid, somewhat acute; of blende, a dodecahedron, with rhomboidal sides; and so on.

These primitive forms must depend upon the figure of the integrant particles composing these crystals, and upon the manner in which they combine with each other. Now, by continuing the mechanical division of the crystal, by cutting off slices parallel to each of its faces, we must at last reduce it to so small a size that it shall contain only a single integrant particle. Consequently this ultimate figure **Integrant** of the crystal must be the figure of the integrant particles of **particles** which it is composed. The mechanical division, indeed, **of three** cannot be continued so far, but it may be continued till it **figures.** can be demonstrated that no subsequent division can alter its figure. Consequently it can be continued till the figure which it assumes is similar to that of its integrant particles.

Haüy has found that the figure of the integrant particles of bodies, as far as experiment has gone, may be reduced to three; namely,

1. The parallelopiped, the simplest of the solids, whose faces are six in number, and parallel two and two.

2. The triangular prism, the simplest of prisms.

3. The tetrahedron, the simplest of pyramids. Even this small number of primitive forms, if we consider the almost endless diversity of size, proportion, and density, to which particles of different bodies, though they have the same figure, may still be liable, will be found fully sufficient to account for all the differences in cohesion and heterogeneous affinity, without having recourse to different absolute forces.

These integrant particles, when they unite to form the primitive crystals, do not always join together in the same

way. Sometimes they unite by their faces, and at other times by their edges, leaving considerable vacuities between each. This explains why integrant particles, though they have the same form, may compose primitive crystals of different figures.

Primitive crystalline forms, six. Mr. Haüy has ascertained that the primitive forms of crystals are six in number; namely,

1. The parallelopiped, which includes the cube, the rhomboid, and all solids terminated by six faces, parallel two and two.

2. The regular tetrahedron.

3. The octahedron with triangular faces.

4. The six-sided prism.

5. The dodecahedron, terminated by rhombs.

6. The dodecahedron, with isosceles triangular faces.

Each of these may be supposed to occur as the primitive form or the nucleus in a variety of bodies; but those only which are regular, as the cube and the octahedron, have hitherto been found in any considerable number.

But bodies, when crystallized, do not always appear in the primitive form; some of them indeed very seldom affect that form; and all of them have a certain latitude and a certain number of forms which they assume occasionally Secondary crystals owing to as well as the primitive form. Thus the primitive form of fluate of lime is the octahedron; but that salt is often found crystallized in cubes, in rhomboidal dodecahedrons, and in other forms. All these different forms which a body assumes, the primitive excepted, have been denominated by Haüy *secondary forms.* Now what is the reason of this latitude in crystallizing? why do bodies assume so often these secondary forms?

6. To this it may be answered:

Differences in the composition; 1st. That these secondary forms are sometimes owing to variations in the ingredients which compose the integrant particles of any particular body. Alum, for instance, crystallizes in octahedrons; but when a quantity of alumina is added, it crystallizes in cubes; and when there is an excess of alumina, it does not crystallize at all. If the proportion of alumina varies between that which produces octahedrons and what produces cubic crystals, the crystals become figures with fourteen sides; six of which are parallel to

those of the cube, and eight to those of the octahedron; and according as the proportions approach nearer to those which form cubes or octahedrons, the crystals assume more or less of the form of cubes or octahedrons. What is still more, if a cubic crystal of alum be put into a solution that would afford octahedral crystals, it passes into an octahedron: and, on the other hand, an octahedral crystal put into a solution that would afford cubic crystals becomes itself a cube.* Now, how difficult a matter it is to proportion the different ingredients with absolute exactness must appear evident to all.

2d. The secondary forms are sometimes owing to the solvent in which the crystals are formed. Thus if common salt be dissolved in water, and then crystallized, it assumes the form of cubes; but when crystallized in urine, it assumes the form, not of cubes, but of regular octahedrons. On the other hand, muriate of ammonia, when crystallized in water, assumes the octahedral form, but in urine it crystallizes in cubes.†

3d. But even when the solvent is the same, and the proportion of ingredients, as far as can be ascertained, exactly the same, still there are a variety of secondary forms which usually make their appearance. These secondary forms have been happily explained by the theory of crystallization, for which we are indebted to the sagacity of Mr. Haüy; a theory which, for its ingenuity, clearness, and importance, must ever rank high, and which must be considered as one of the greatest acquisitions which mineralogy, and even chemistry, have hitherto attained.

According to this theory, the additional matter which envelopes the primitive nucleus consists of thin slices or layers of particles laid one above another upon the faces of that nucleus, and each layer decreasing in size, in consequence of the abstraction of one or more rows of integrant particles from its edges or angles.

In the solvents; and

To the different decrements of the crystalline laminæ.

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* Leblanc, Ann. de Chim. xiv. 149.
† Fourcroy and Vauquelin, Ibid. xiv. 149.
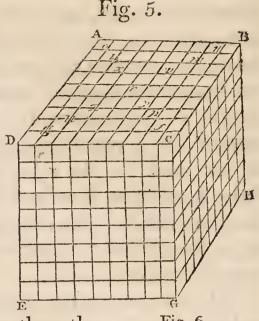
Let us suppose that A B F G (fig. 5) is a cube composed of 729 small cubes: each of its sides will consist of 81 squares, being the external sides of as many cubic particles, which to- gether constitute the cube. Upon A B C D, one of the sides of this cube, let us apply a square lamina, composed of cubes equal to those of which the primitive crystal consists, but which has on each side a row of cubes less than the outermost layer of the primitive cube. It will of course be composed of 49 cubes, 7 on each side; so that its lower base $o\,n\,f\,g$ (fig. 6) will fall exactly on the square marked with the same letters in (fig. 5)
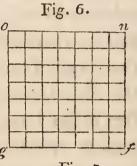
Fig. 5.

Fig. 6.

Above this lamina let us apply a second, $l\,m\,p\,u$ (fig. 7), composed of 25 cubes; it will be situated exactly above the square mark- ed with the same letters (fig. 5). Upon this second let us apply a third lamina, $v\,x\,y\,z$ (fig. 8), consisting only of 9 cubes; so that its base shall rest upon the letters $v\,x\,y\,z$ (fig. 5). Lastly, on the middle square r let us place the small cube r (fig. 9), which will represent the last lamina.

Fig. 7.

Fig. 8.

Fig. 9.

It is evident that by this process a quadran- gular pyramid has been formed upon the face A B C D (fig. 5) the base of which is this face, and the vertex the cube r (fig. 9). By continuing the same operation on the other five sides of the cube, as many similar pyramids will be formed; which will envelope the cube on every side.

It is evident, however, that the sides of these pyramids will not form continued planes, but that, owing to the gra- dual diminution of the laminæ of the cubes which compose them, these sides will resemble the steps of a stair. We can suppose, however (what must certainly be the case), that the cubes of which the nucleus is formed are exceed- ingly small, almost imperceptible; that therefore a vast
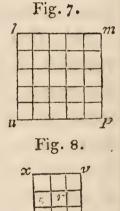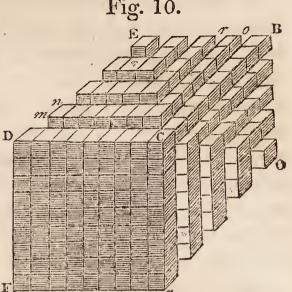
number of laminæ are required to form the pyramids, and consequently that the channels which they form are imperceptible. Now D C B E (fig. 10) being the pyramid resting upon the face A B C D (fig. 5), and C B O G (fig. 10) the pyramid applied to the next face B C G H (fig. 5) if we consider that every thing is uniform from E to O (fig. 10.), in the manner in which the edges of the *laminæ of superposition* (as the Abbé Haüy calls the laminæ which

Fig. 10.

compose the pyramids) mutually project beyond each other, it will readily be conceived that the face C E B of the first pyramid ought to be exactly in the same plane with the face C O B of the adjacent pyramid; and that therefore the two faces together will form one rhomb E C O B. But all the sides of the six pyramids amount to 24 triangles similar to C E B; consequently they will form 12 rhombs, and the figure of the whole crystal will be a dodecahedron.

Thus we see that a body which has the cube for the primitive form of its crystals, may have a dodecahedron for its secondary form. The formation of secondary crystals, by the superposition of laminæ gradually decreasing in size, was first pointed out by Bergman. But Haüy has carried the subject much farther: He has not only ascertained all the different ways by which these decrements of the laminæ may take place, but pointed out the method of calculating all the possible variety of secondary forms which can result from a given primitive form; and consequently of ascertaining whether or not any given crystal can be the secondary form of a given species.

The decrements of the laminæ which cover the primitive nucleus in secondary cystals are of four kinds.

1. *Decrements on the edges;* that is, on the edges of the slices which correspond with the edges of the primitive nucleus.

2. *Decrements on the angles;* that is to say, parallel to the diagonals of the faces of the primitive nucleus.

3. *Intermediate decrements;* that is to say, parallel to

lines situated obliquely between the diagonals and edges of the faces of the primitive nucleus.
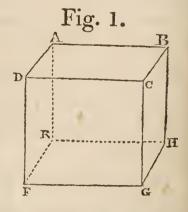
4. *Mixed decrements.* In these the superincumbent slices, instead of having only the thickness of one integrant particle, have the thickness of two or more integrant particles; and the decrement, whether parallel to the edges or angles, consists not of the abstraction of one row of particles, but of two or more. Haüy denotes these decrements by fractions, in which the numerator indicates the number of rows of particles which constitutes the decrement, and the denominator represents the thickness of the laminæ. Thus $\frac{2}{3}$ denotes laminæ of the thickness of three integrant particles, decreasing by two rows of particles.

An example of the first law of decrement, or of *decrement on the edges*, has been given above in the conversion of the cubic nucleus to a rhomboidal dodecahedron. In that example the decrement consisted of one row of particles, and it took place on all the edges. But these decrements may be more rapid; instead of one, they may consist of two, three, four, or more rows: and instead of taking place on all the edges, they may be confined to one or two of them, while no decrement at all takes place on the others. Each of these different modifications must produce a different secondary crystal. Besides this, the laminæ may cease to be added before they have reached their smallest possible size; the consequence of which must be a different secondary form. Thus, in the example given above, if the superposition of laminæ had ceased before the pyramids were completed, the crystal would have consisted of 18 faces, 6 squares parallel to the faces of the primitive nucleus, and 12 hexahedrons parallel to the faces of the secondary dodecahedron. This is the figure of the borate of magnesia found at Luneburg.

The second law in which the decrement is on the angles, or parallel to the diagonals of the faces of the primitive nucleus, will be understood from the following example: Let it be proposed to construct around the cube A B G F (fig. 1) considered as a nucleus, a secondary solid, in which the laminæ of superposition shall decrease on all sides by single rows of cubes,
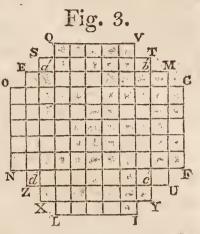
Fig. 1.
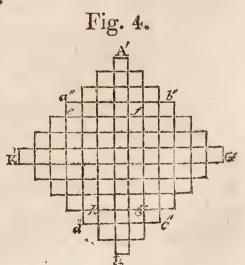
but in a direction parallel to the diagonals. Let A B C D (fig. 2), the superior base of the nucleus, be divided into 81 squares, representing the faces of the small cubes of which it is composed. Fig. 3 represents the superior surface of the first lamina of superposition, which must be placed above A B C D (fig. 2) in such a manner, that the points a', b', c', d', (fig. 3) answer to the points a, b, c, d (fig. 2). By this disposition the squares A a, B b, C c, D d (fig. 2) which compose the four outermost rows of squares parallel to the diagonals A C, B D, remain uncovered. It is evident also, that the borders Q V,

Fig. 2. Chap. IV.

Fig. 2.

Fig. 3.

O N, I L, G F, (fig. 3) project by one range beyond the borders A B, A D, C D, B C (fig. 2), which is necessary, that the nucleus may be enveloped towards these edges: For if this were not the case, re-entering angles would be formed towards the parts A B, B C, C D, D A of the crystal; which angles appear to be excluded by the laws which determine the formation of simple crystals, or, which comes to the same thing, no such angles are ever observed in any crystal. The solid must increase, then, in those parts to which the decrement does not extend. But as this decrement is alone sufficient to determine the form of the secondary crystal, we may set aside all the other variations which intervene only in a subsidiary manner, except when it is wished, as in the present case, to construct artificially a solid representation of a crystal, and to exhibit all the details which relate to its structure.

The superior face of the second lamina will be A' G' L' K' (fig. 4). It must be placed so that the points a'' b'' c'' d'' correspond to the points a', b', c', d', (fig. 3), which will leave uncovered a second row of cubes at each angle, parallel to the diagonals A C and B D. The solid still increases towards the sides. The large faces

Fig. 4.

of the laminæ of superposition, which in fig. 3 were octagons, in fig. 4 arrive at that of a square; and when they pass that term they decrease on all sides; so that the next lamina has for its superior face the square R′M′ L′ S′ (fig. 5), less by one range in every direction than the preceding lamina (fig. 4). This square must be placed so that the points e′, f′, g′, h′ (fig. 5) correspond to the points e, f, g, h, (fig. 4). Figures 6, 7, 8, and 9, represent the four laminæ which ought to rise successively above the preceding; the manner of placing them being pointed out by corresponding letters, as was done with respect to the three first laminæ. The last lamina z′ (fig. 10) is a single cube, which ought to be placed upon the square z (fig. 9).

The laminæ of superposition, thus applied upon the side A B C D (fig. 2) evidently produce four faces, which correspond to the points A, B, C, D, and form a pyramid. These faces having been formed by laminæ, which began by increasing, and afterwards decreased, must be quadrilaterals of the figure represented in fig. 11; in which the inferior angle C is the same point with the angle C of the nucleus (fig. 1 and 2); and the diagonal L Q represents L′ G′ of the lamina A′ G′ L′ K′ (fig. 4). And as the number of laminæ composing the triangle L Q C (fig. 11) is much smaller than that of the laminæ forming the triangle Z L Q, it is evident that the latter triangle will have a much greater height than the former.

The surface, then, of the secondary crystal, thus produced, must evidently consist of 24 quadrilaterals (for pyramids are raised on the other five sides of the primary cube exactly in the same manner), disposed three and three around each solid angle of the nucleus. But in consequence of the decre-

Fig. 5.
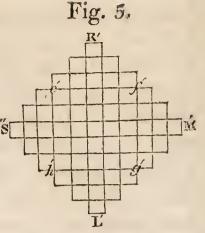
Fig. 6.

Fig. 7.

Fig. 8.

Fig. 9.

Fig. 10.

Fig. 11.
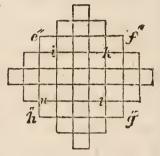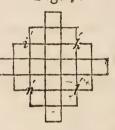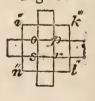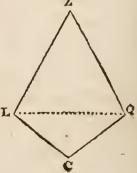
ment by one range, the three quadrila-
terals which belong to each solid angle,
as C (fig. 1), will be in the same plane,
and will form an equilateral triangle Z I N
(fig. 12). The 24 quadrilaterals, then,
will produce eight equilateral triangles;
and consequently the secondary crystals
will be a regular octahedron. This is
the structure of the octahedral sulphuret of lead and of
muriate of soda.

Fig. 12.

Chap. IV.

The third law is occasioned by the
abstraction of double, triple, &c. par-
ticles. Fig. 13 exhibits an instance
of the subtractions in question; and
it is seen that the moleculæ which compose the range repre-
sented by that figure are assorted in such a manner as if of
two there were formed only one; so that we need only to
conceive the crystal composed of parallelopipedons having
their bases equal to the small rectangles *a b c d*, *e d f g*,
h g i l, &c. to reduce this case under that of the common
decrements on the angles.

Fig. 13.

Third and
fourth de-
crements.

This particular decrement, as well as the fourth law, which
requires no farther explanation, is uncommon. Indeed
Haüy has only met with mixed decrements in some me-
tallic crystals.

These different laws of decrement account for all the dif-
ferent forms of secondary crystals. But in order to see the
vast number of secondary forms which may result from
them, it is necessary to attend to the different modifications
which result from their acting separately or together. These
modifications may be reduced to seven.

1. The decrements take place sometimes on all the edges,
or all the angles, at once.

2. Sometimes only on certain edges, or certain angles.

3. Sometimes they are uniform, and consist of one, two,
or more rows.

4. Sometimes they vary from one edge to another, or
from one angle to another.

5. Sometimes decrements on the edges and angles take
place at the same time.

6. Sometimes the same edge or angle is subjected succes-
sively to different laws of decrement.

7. Sometimes the secondary crystal has faces parallel to those of the primitive nucleus, from the superposition of laminæ not going beyond a certain extent.

Hence Mr. Haüy has divided secondary forms into two kinds, namely, *simple* and *compound*. Simple secondary crystals are those which result from a single law of decrement, and which entirely conceal the primitive nucleus. Compound secondary crystals are those which result from several laws of decrement at once, or from a single law which has not reached its limit, and which of course has left in the secondary crystal faces parallel to those of the primitive nucleus.

Such is a general view of Haüy's theory of crystallization, which has led already to several very important discoveries in mineralogy, and may be expected to lead to still more important ones hereafter. The evidence for its truth is the complete manner in which it explains the phenomena, and the exact coincidence of matter of fact, in every instance, with the result of calculation. But as it cannot be shown that the secondary forms are actually crystallized according to the theory, we must consider it in the light of a mathematical hypothesis; an hypothesis, however, of very great importance, because it serves to link together a vast number of otherwise unconnected facts; because it enables us to subject all the forms of crystals to calculation; and because it puts it in our power to ascertain the nature of a body with the utmost certainty, from an accurate examination of the figure of its crystals. Such hypotheses may be considered as the clues which lead us through the otherwise impenetrable mazes of error, and conduct us at last, though after a tedious journey, to the goal of certainty and truth.

SECT. III.

OF THE COMBINATION OF SOLIDS WITH EACH OTHER.

1. The following table exhibits a list of the principal solids, arranged according to their composition:

I. UNDECOMPOUNDED.

| Sulphur | Carbon | Metals |
| Phosphorus | Boron | |

II. COMPOUNDS.

1. Charcoal.
   Metallic oxides.
2. Sulphurets of metals.
   Sulphureted oxides.
3. Phosphurets of carbon.
                   metals.
                   oxides.
4. Carburets of iron.
5. Alloys.
6. Solid acids.
7. Oxides with oxides.
8. Salts and hydrosulphurets.
   Metallic oxides with alkalies.
9. Bitumens, solid oils, tannin.
10. Soaps.
11. Most vegetable substances.
12. Many animal substances.

Their numbers are very great; for if all the individuals were reckoned they would amount to many thousands.

2. Their specific gravity varies more than either that of liquids or elastic fluids, as will appear from the following table, in which they are arranged according to their density.

Specific Gravity.

	Specific Gravity.
Charcoals	0·223 to 1·526
Vegetable bodies	0·240 to 1·354
Salts.	0·273 to 7·176
Earths	0·346 to 4·842
Solid acids.	0·667 to 3·391
Earths with earths	0·680 to 4·815
Bitumens and solid oils	0·892 to 1·357
Fixed alkalies	1·336 to 1·708
Phosphorus	1·770 —
Carburets of iron	— 7·840
Sulphur	1·990 —
Earths with alkalies	2·732 to 3·329

Specific Gravity.

Carbon .... 1·987 to   3·531
Metallic sulphurets .... 3·225 to 10·000
Metals and alloys .... 0·600 to 21·65

The specific gravity of hammered platinum, which is the heaviest of the solid bodies, is nearly 100 times greater than that of common cork, which is one of the lightest.

3. Solid bodies, as far as regards their combinations with each other, may be divided into three classes: namely, those which unite in any proportion; those which unite in certain determinate proportions; and those which cannot be made to combine with each other at all. Let us examine the action of each of these classes separately.

Solids that unite in any proportion. I. The action of solids upon each other has been so imperfectly examined, that it is not possible to give more than a partial view of the subject. The following table comprehends the principal solids hitherto ascertained to be capable of uniting in any proportion.

1. Sulphur with phosphorus.
2. Carbon with iron ?
3. Metals with most metals.
4. Protoxide of antimony with sulphuret of antimony.
5. Earths with earths.
6. Earths with some metallic oxides.
7. Some earths with fixed alkalies.
8. Solid oils with each other, and with bitumen.

All the products produced by these mutual combinations are solids, except those formed by the union of sulphur and phosphorus in certain proportions, which are liquid.

1. As far as is known at present, none of the solids contained in the preceding list combine spontaneously, even though placed in contact. The cohesion of their particles presents a resisting force which their affinity for each other cannot overcome. The usual method employed is, to mix the two substances to be united in the intended proportions, and to apply a degree of heat capable of melting one or both of them. Thus they are enabled to act upon each other in the same way as liquids, and of course the same explanation applies to their combinations. These combinations obviously belong to that class which have been distinguished by the name of dissolutions, and accordingly do not differ much in their properties from their constituents,

except the compounds of carbon and iron, and some of the earths with each other, which possibly may be found here-after to belong to that class of solids which combine only in certain proportions.

2. The combination is usually accompanied by a change of density. This is most apparent in the metallic alloys, most of which are either above or below the mean.

II. The following table exhibits the principal solids which have hitherto been observed to unite only in deter-minate proportions.

Solids that unite only in certain propor-tions.

    Sulphur with metals.

            some metallic oxides.

            earths.

            fixed alkalies.

    Phosphorus with carbon.

            metals.

            some earths.

    Acids with alkalies.

            earths.

            metallic oxides, &c.

These combinations are more intimate than the preceding; they have been more closely examined, and are better known.

1. As far as is known at present, none of these bodies act upon each other while both continue in the solid state, except sulphur and the fixed alkaline hydrates, some acids, and a few hydrates of metallic oxides, and perhaps some of the acids and the fixed alkaline hydrates. With these ex-ceptions, it may be laid down as a general rule, that in all cases of the combination of these bodies with each other, one at least of the two which combine must have its cohe-sion destroyed, or at least diminished, by being reduced to a liquid state. Now there are two ways of bringing these solids to this state: 1. Fusion by means of fire. In this way sulphur is made to combine with metals, earths, and fixed alkalies, and phosphorus with metals. Sometimes the affinity is so weak, that it is necessary, in the first place, to reduce one of the constituents to the state of vapour. Thus phosphorus combines with lime, barytes, and strontian, only at a red heat. 2. Solution in water or some other liquid menstruum. In this way the acids are combined with the alkalies, earths, and metallic oxides, and in this

One of the bodies must be fluid.

Book III. way may sulphur and phosphorus be combined with metals.

2. As the union of these bodies with each other resembles that of liquids with solids in every respect, it would be unnecessary, after the details contained in the preceding chapter, to enter into any farther particulars respecting the theory of the combination. The points of most importance are, the *proportions* in which they unite, and the change of density which they undergo.

Sulphur with the metals.

3. Though the combinations of sulphur with the metals have been examined with very particular attention by chemists, there are many things connected with them that require elucidation. Mr. Berthollet is still of opinion that sulphur is capable of uniting indefinitely to the metals, and he has brought a number of examples of native sulphurets of lead, copper, and iron, analysed by the most accurate chemists, in which the proportion of sulphur varied indefinitely.* It is very likely that various doses of sulphur are capable of uniting with most metals: but the experiments hitherto made upon the artificial union of these bodies do not warrant us to conclude that they unite indefinitely; for when sulphur and a metal are fused together, we obtain always the two bodies combined in determinate proportions. As far as we know at present sulphur combines only in two proportions with metallic bodies. One atom of metal is capable of uniting with 1 atom of sulphur, and in some cases with 2 atoms. This will be seen by inspecting the table of sulphurets given in Vol. I. p. 525 of this work.

Sulphurets rarer than the mean.

4. Almost all the metallic sulphurets are rarer than the mean. The substances of course expand during their combination. In most cases this expansion is considerable, as will appear from the following table. The first column gives the real density of the compounds; the second the mean density, calculated on the supposition that no change of bulk had taken place by the combination.

Sulphurets of	Real density.	Calculated density.
Silver	7·2	9·22
Mercury	10	11·83

* Jour. de Phys. lx. 349.

Sulphurets of	Real density.	Calculated density.
Iron, 1st	4·518	5·62
—— 2d	4·830	4·73
Lead	7·	10·06
Bismuth	6·131	8·65
Antimony	4·368	5·53
Arsenic, 1st	3·225	} 7·05
—— 2d	5·315	
Molybdenum	4·73	5·97

In some of these examples the expansion is more than a fifth of the whole. Pyrites is the only instance known of a combination of sulphur and a metal, the specific gravity of which is greater than the mean.

5. The remaining compounds into which sulphur enters with solid bodies have not been sufficiently examined to admit of any additional observations. Neither do we know any thing precise respecting the combinations of phosphorus and solid bodies.

6. The case is very different with the acids; the compounds which they form with the alkalies, earths, and metallic oxides, have been examined with much attention, and have furnished chemists with most of the opinions which they entertain respecting affinity. The great facility with which these compounds are formed, the striking difference between their properties and those of their constituents, and the beautiful forms which many of them assume, were circumstances which excited the general interest of chemists.

7. If we take a given quantity of sulphuric acid diluted with water, and add to it slowly the solution of soda by little at a time, and examine the mixture after every addition, we shall find that for a considerable time it will exhibit the properties of an acid, reddening vegetable blues, and having a taste perceptibly sour: but these acid properties gradually diminish after every addition of the alkaline solution, and at last disappear altogether. If we still continue to add the soda, the mixture gradually acquires alkaline properties, converting vegetable blues to green, and manifesting an urinous taste. These properties become stronger and stronger the greater the quantity of soda is which is added. Thus it appears that when sulphuric acid and soda are mixed together, the properties either of the one or the

Neutralization explained.

other preponderate according to the proportion of each; but that there are certain proportions, according to which, when they are combined, they mutually destroy or disguise the properties of each other, so that neither predominates, or rather so that both disappear.

When substances thus mutually disguise each other's properties, they are said to *neutralize* one another. This property is common to a great number of bodies; but it manifests itself most strongly, and was first observed, in the acids, alkalies, and earths. Hence the salts which are combinations of these different bodies received long ago the name of *neutral salts*. When bodies are combined in the proportion which produces neutralization, they are often said to be *saturated*; but in this case the term is used improperly. It would be much better to confine the word *saturation* to the meaning assigned it in a former section, and to employ the term *neutralization* to denote the state in which the peculiar properties of the component parts mutually disappear; for very frequently neutrallization and saturation by no means coincide. Thus in *tartrate of potash* the acid and alkali neutralize each other: yet it cannot be said that the potash is saturated; for it is still capable of combining with more tartaric acid, and of forming supertartrate of potash, a compound in which the ingredients do not neutralize each other; for the salt has manifestly a preponderance of the properties of the acid.

8. It cannot but be obvious, that the same quantity of acid or alkali must be always employed to neutralize a given weight of alkali or acid; and that, therefore, the proportion in which these bodies unite to form neutral salts is fixed and determined. The acids and alkaline bases, indeed, may be capable of uniting with each other in various proportions; but the neutral combination must be constant: it must likewise be the most intimate. In general neutral salts are composed of 1 atom of acid united to 1 atom of base. In the carbonates, however, the alkaline base, though combined with an atom of acid, still continues to act as an alkali upon vegetable blues. Many bases are capable of combining with 2 atoms of acid; and sometimes with 4 atoms. Thus potash forms oxalate, binoxalate, and quadroxalate of potash. It forms likewise sulphate and bisulphate of potash. Sometimes an acid combines with 2 atoms

of the base. Thus boracic acid unites with 2 atoms of soda, forming *subborate of soda*. Perhaps it would be most accurate to denominate such compounds by prefixing the syllables *subbi*. In that case common borax will be denominated *subbiborate of soda*.

CHAP. V.

OF COMBINATION AND DECOMPOSITION.

THE great object of all chemical investigations is to separate bodies from each other which are chemically combined. But it is scarcely ever possible to separate a body from one substance without at the same time uniting it to another. Hence *decomposition* is almost always accompanied by *combination*. Every chemical analysis consists of a certain number of combinations and decompositions following each other in a regular order, and leading to the object desired, the knowledge of the constituents of the substance examined. It is accomplished by putting each constituent of the substance in succession into such a state of combination, that it shall not be acted upon nor dissolved by a given menstruum, which dissolves all the other constituents not already separated. But this cannot be done unless we are acquainted with the proper combinations, the method of forming them, and the requisite menstrua. Hence it is an accurate knowledge of the combinations which different substances are capable of forming, of the bodies best calculated for separating the constituents of compounds from each other, and of the peculiar solvent of each compound, which constitute the essential requisites for the practical chemist. In the three preceding chapters, we took a particular view of the mutual action of all the different chemical substances on each other, of the compounds which they form, and the various decompositions which they produce. In this chapter we shall take a general view of the subject. Three things claim our particular attention: namely, 1. The *proportions* in which bodies combine; 2. The *order* in which they decompose one another; and, 3. The way in which they separate from each other. Sometimes one of the ingredients assumes the form of gas or vapour; it is then said to be *volatilized* or

Importance of a knowledge of combination and decomposition.

evaporated: sometimes it falls to the bottom of the liquid compound, and is then said to be *precipitated*. These topics shall be considered in the following sections.

SECT. I.

OF COMBINATION.

WE have seen, in the preceding chapters that there are a variety of bodies which do not unite with each other; but that by far the greater number are capable of entering into combination, and of forming new compounds. These new compounds may he divided into two classes. Some differ but little in their properties from the constituents of which they are composed, while others assume properties that are extremely different. So little, indeed, are the first set altered by combination, that some persons have denied the combination altogether, and have supposed the bodies to be only mechanically mixed.

Com-
pounds of
two kinds.

Dissolu-
tions,

1. To the first set belong all those combinations which, after Berthollet, we have denominated *dissolutions*. In dissolutions, all the substances combining are sometimes in the *same* state. The mixed liquids, metallic alloys, and a few other solid compounds, comprehend the whole of such bodies. In them the proportions of all the constituents of the compound may vary indefinitely; or substances in the *same* state are capable of *dissolving any proportion* of each other.

The bodies dissolving each other are sometimes in different states. Water and many other liquids dissolve all the gases; and all the gases dissolve water and several other liquids. Water, &c. dissolve various solids, and many solids combine with water. In all these dissolutions there is a maximum quantity of one of the ingredients; and if it be exceeded, the surplus (supposing the quantity of the other ingredient fixed) will not be dissolved. When gases are dissolved in liquids, a given bulk of liquid can dissolve only a determinate portion of each gas. In like manner, a gas can dissolve only a determinate bulk of liquid. When a solid combines with a liquid, it can take up only a determinate

weight of it, provided it be not capable of assuming the liquid state; for every hydrate can contain only a determinate weight of water. When a liquid dissolves a solid, it takes up only a determinate quantity, and then loses the whole of its action on the remainder. Thus it appears, that when substances in different states dissolve one another, each of them has a maximum and a minimum quantity; but within these limits they are capable of dissolving each other in any proportions whatever.

Some liquids, whose cohesion or state differs very much, though in the same state, are capable of dissolving each other only in certain proportions. Thus water dissolves only $\frac{1}{10}$th of its weight of ether. Such liquids resemble substances in different states, and therefore follow the same law with regard to their mutual solutions.

2. Those bodies which form compounds differing very much from their constituents, have been more usually considered as chemical combinations, to the exclusion of the former. In all of them there is an obvious tendency to combine only in determinate proportions; and in the most striking examples these proportions are very few.

And chemical combinations.

The gases unite only in one, two, or at most three proportions; and it is very seldom that we can unite them directly in more than one. Thus oxygen and hydrogen, hydrogen and azote, unite only in one proportion. Oxygen and azote unite in five proportions; but we can unite them directly in only one. The other combinations are obtained by decomposing the compound formed directly.

They combine in certain proportions only.

In like manner, the combination of a gaseous and solid body is limited to certain proportions. Oxygen unites with carbon in two, and with phosphorus and sulphur in three proportions; but we seldom can unite them directly in more than one. With metals, also, it unites usually in a small number of proportions. Hydrogen unites with two proportions of carbon, and probably with the same proportions of phosphorus and sulphur.

When the substances that enter into combination are more than two, the proportions frequently increase in number; and indeed in many cases baffle our attempts to trace them. Thus azote, carbon, hydrogen, and oxygen, are almost the only elements out of which all the immense variety of animal and vegetable substances are formed.

But from each of these substances always affecting the same properties, there is reason to believe, that even in these complicated cases, the proportions are not absolutely unlimited, but fixed and determinate, as in the more simple cases which we are able to examine; for if it were not so, no two animal or vegetable bodies could be expected to possess precisely the same properties.

There are no liquid bodies, strictly so called, that enter into the intimate combination which we are now considering. All their combinations belong to the class of dissolutions.

The solid bodies which combine intimately appear at first sight to be capable of varying their proportions almost without limit. Thus we may melt together any proportion of sulphur with antimony, iron, or potash: we may add any proportion of liquid ammonia to nitric acid: But in all these cases the combination is not, strictly speaking, entitled to be ranked among those intimate ones which we are considering, unless we limit the quantity of each ingredient to certain determinate proportions. If the proportions be unlimited, the combination belongs to the class of dissolutions; the properties of the predominating constituent remaining unimpaired and unaltered. Whenever the combination is intimate, and the properties of the constituents concealed, then the proportions are not only limited, but in most cases do not exceed one or two. Thus, to constitute neutral salts, we must combine the acid and the base in one determinate proportion.

Thus we have found reason to conclude, that in cases of chemical dissolution, the ingredients unite in any proportion whatever, except when the proportion of one of the ingredients is limited by the difference of its state from that of its solvent; as, for example, when the solvent is liquid, and the substance dissolved gaseous or solid. But in cases of chemical combination, the ingredients affect determinate proportions: proportions which probably depend on the tendency which bodies have to combine atom to atom, or one atom of one with a determinate number of atoms of another.

SECT. II.

OF DECOMPOSITION.

IF into a solution of nitrate of silver we drop a quantity of liquid potash, a portion of the metallic oxide immediately separates from the solution, and falls to the bottom. Thus potash has the property of decomposing nitrate of silver by separating the oxide. The same experiment succeeds if we drop soda into a solution of sulphate of magnesia. The magnesia separates from the acid and falls to the bottom, while the soda takes its place. Just the reverse happens if barytes water be poured into a solution of sulphate of soda. The barytes and sulphuric acid separate in combination, while the soda remains in solution. We obtain the same result when we pour muriatic acid into nitrate of silver. The muriatic acid and the oxide of silver separate together, leaving the nitric acid. When muriate of barytes is mixed with sulphate of soda, the sulphuric acid and the barytes unite together, and separate from the solution, while the muriatic acid and soda, also combined together, remain dissolved. The same thing happens when oxalate of ammonia is mixed with nitrate of lime. The oxalic acid and lime separate in combination, while the nitric acid and the ammonia remain in solution.

Examples of decomposition.

Thus it appears that substances have the property of separating others from compounds of which they form a constituent. Now the great object of chemists is, to find a body x, capable of separating a body a from another body b. It is by this means that chemical analyses are effected. He accordingly, who is able to resolve the problem in the greatest variety of cases, is the most skilful practical chemist.

Chemists, at a very early period of the science, began to collect examples of these decompositions, and to endeavour to explain them. Mayow seems to have been one of the first who viewed the subject in the proper light. He has left a dissertation on the combination of the acids and bases, and of their decompositions, in which a considerable number of facts are stated with accuracy, though the imperfect knowledge of the substances frequently misled him in his explanations.* In 1718, Geoffroy thought of arranging

Ascribed to affinity.

* Mayow, Tract. I. c. xiv. p. 232. De Salium Congressu et Precipitatione.

the substances in a table, in the order in which they separate one another from a given body. This table was afterwards corrected and enlarged by different chemists, especially by Gellert and Limburg. But it was Bergman who first reduced the doctrine of decomposition to regular order, gave a luminous and satisfactory theory, exhibited a complete series of tables, and explained the anomalies or apparent exceptions to his theory, which had been pointed out by the experiments of Baumè, Marherr, and other chemists. His dissertation was first published in 1775, and afterwards in a more perfect form in 1783. The opinions adopted by this illustrious philosopher were universally acceded to, and, till within these few years, chemists considered them as the basis of the whole science, and were anxious only to fill up the chasms which he had left.

Berthollet, about the commencement of the present century advanced an opinion very different from that of Bergman. Affinity, according to him, always produces combination, and decomposition when it takes place must be ascribed to cohesion, elasticity, or some similar power, which tends to cause some of the constituents to separate from the rest. I think that Berthollet has succeeded in overturning all our pre-conceived opinions on the subject, but he has not been so successful in establishing his own.

As the tables of affinities (as they have been called) have been thus demonstrated not to indicate the real order of affinities, and as the decompositions on which they are founded are often illusory, and seldom complete, the tables themselves must be considered as of little value, and as tending, in most cases, rather to mislead than to convey accurate information. For that reason I have omitted them in the preceding part of this work.*

Tables of decomposi-tions. Tables of *decompositions*, indeed, even though only partial, would be of value, provided they could be constructed; but unfortunately it is only in a limited number of cases that we can ascertain the order in which bodies decompose each other: in most cases we must be contented with analogy. The following tables are constructed, partly

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* I shall place the most important part of Bergman's Table at the end of this chapter, as it is frequently referred to.

from the order of decomposition, and partly from the order of combination, when two bodies are presented at once to a third. They are of some value in a practical point of view, though they throw but little light on the strength of affinity.

I. OXYGEN.

1. Hydrogen	4. Phosphorus	7. Chlorine.
2. Carbon	5. Sulphur	
3. Boron	6. Azote	

Oxygen, and simple combustibles and incombustibles.

All these bodies unite to oxygen (if we consider the facility in all circumstances) nearly in the order of the table. None of them are capable of decomposing water, unless carbon be an exception. Charcoal decomposes water at a red heat; but hydrogen, in its turn, decomposes carbonic acid at the same temperature. Thus the power of decomposition is reciprocal: but I place hydrogen first, because, when carbureted hydrogen is mixed with an under proportion of oxygen, and fired by means of electricity, the hydrogen combines with the oxygen in preference to the carbon. Charcoal decomposes phosphoric acid at a red heat, and phosphorus decomposes carbonic acid at the same temperature; but I place carbon first, because the phosphorus does not seem capable of decomposing water like charcoal, and because its action on carbonic acid requires to be facilitated by the presence of a base. Sulphur does not seem to be capable of decomposing phosphoric acid, but phosphorus acts to a certain extent upon sulphuric. Sulphur is known to decompose nitric acid, at least partially; but azote has no sensible action on sulphuric acid. Though chlorine be placed last in order, it is known to be capable of separating a certain portion of oxygen from nitric acid; but nitrous gas when assisted by moisture converts chlorine into muriatic acid. Such are the reasons for placing the simple combustibles and incombustibles in the order of the preceding table.

II. OXYGEN AND ACID SOLUTIONS.

1. Zinc	6. Lead	11. { Palladium, Rhodium
2. Iron	7. Bismuth	{ Iridium, Osmium
3. Tin	8. Copper	12. Silver
4. Antimony	9. Platinum	13. Gold.
5. Arsenic	10. Mercury	

Metals from acid solutions.

Book III. This table exhibits the order in which the metals precipitate each other in the metallic state from acid and alkaline solutions. Zinc and iron throw down all the metals below them, either in the metallic state, or in the state of a black powder, as happens to antimony, arsenic, bismuth, and the four new metals discovered in crude plantina. Ritter has announced that these black powders are combinations of the metals with hydrogen. This assertion deserves to be verified. It would be of considerable importance, in explaining the nature of the precipitation, if it were to prove true. I am not certain whether antimony and arsenic precipitate the metals below them, but they are acted on more speedily by tin than either lead or copper. Lead precipitates copper. Bismuth and platinum are inserted only from analogy. Copper throws down mercury, and mercury silver and gold.

Mr. Sylvester has rendered it very probable that these precipitations are occasioned by the galvanic action of metals on each other. It has been shown by Volta, that metals differ in the avidity with which they absorb electricity; and that when two metals are placed in contact and separated, the one becomes *plus*, and the other *minus* electrified. In this respect they may be arranged in a regular series, zinc being at the one extremity, and gold at the other; all the metals which precede having the property of changing to minus the electricity of all the metals below them. Now, when metals are in different states of electricity, it has been shown, that when placed properly they decompose water, and produce all the other phenomena of galvanism. Mr. Sylvester has rendered it extremely probable, that it is the hydrogen evolved that produces the reduction of the metal.* If this opinion be correct, the order in which the metals precipitate each other ought to be precisely that of their tendency to take electricity from each other.

Were we to endeavour to unite the two preceding tables into one, these observations would indicate that hydrogen ought to be placed immediately after tin. Yet from the experiments of Priestley, we know that hydrogen is capable of reducing oxide of iron to the metallic state. Charcoal

* Nicholson's Jour. xiv. 94.

likewise decomposes the oxides of all metals; but, on the other hand, the oxides of zinc, iron, tin, and some others, have the property of decomposing carbonic acid. Phosphorus precipitates all the metals below lead, and perhaps even some above it. Even sulphur reduces most metallic oxides; but many of them in return decompose sulphuric acid when assisted by heat. Hence the relative places of the simple combustibles and incombustibles cannot well be ascertained. Probably we shall not err far if we place hydrogen after tin, carbon after antimony, phosphorus after lead, sulphur after copper, and azote and chlorine after mercury. Were we to complete the table from analogy, the refractory metals and manganese would be placed before zinc, and nickel just before platinum: But such analogies are very apt to mislead.

III. ACID SOLUTIONS.

1. Protoxide of iron
2. Peroxide of silver
3. Red oxide of mercury
4. Oxide of zinc
5. Oxide of manganese
6. Oxide of lead?
7. Peroxide of copper
8. Peroxide of iron.

Oxides from acids.

This table exhibits the order in which the metallic oxides precipitate each other from those acid solutions in which they are respectively soluble. It was drawn up from the experiments of Gay-Lussac. The relative order of several of the oxides is not quite certain, but they all precipitate peroxide of iron, and most of them peroxide of copper: while this last throws down peroxide of iron.*

IV. ACID SOLUTIONS.

Bases from acids.

1. Fixed alkalies
2. Barytes
3. Strontian
4. Lime
5. Ammonia
6. Magnesia
7. { Yttria
   { Glucina
8. Zirconia
9. Alumina
10. Metallic oxides.

This table represents the general order in which the bases precipitate each other from saline solutions; but there are many exceptions. Berthollet has even made it probable, that the order of precipitation varies with the proportion of the ingredients used. He has demonstrated, that the pre-

* Ann. de Chim. xlix. 21.

cipitation is rarely or never complete; that the bases divide the acid solvent between them in proportion to their relative quantities, and to the quantity of each necessary to neutrallize the acid. It is obvious that all those cases must be excepted, in which the acid and base or precipitant form an insoluble compound, because then they precipitate in combination. I place the fixed alkalies first, because, when muriate of barytes is dropped into potash so pure that it occasions no muddiness in barytes or lime water, a flaky precipitate constantly appears. No difference can be perceived in the action of potash and soda in this respect. These alkalies do not precipitate one another. Potash is placed first in the tables of Bergman, merely because it forms with acids less soluble salts than soda; and therefore (as Berthollet has shown), when a saline solution containing the two alkalies is evaporated, the salts of potash crystallize first. It has not been proved that barytes precipitates strontian and lime; even if it did, it could never, with propiety, be used as a precipitant of them. It is known that ammonia never occasions a precipitate in the solutions of the three alkaline earths that precede it in the table; but it precipitates all the bodies that follow it, if we except those metallic oxides which it is capable of holding in solution.

How far magnesia is capable of precipitating the earths placed below it in the table has not been examined; but it is probable that it is, as it is capable of forming neutral salts with acids, which is not the case with them. The marked attraction which magnesia shows for alumina would perhaps prevent it from taking the place of alumina; it would probably combine and form with it a substance insoluble nearly in potash. Zirconia is placed merely from analogy. Alumina is probably thrown down, at least partially, by glucina, which forms with acids a salt approaching more nearly to neutrallization. Several of the metallic oxides precipitate ammonia; but the relative power of the substances placed in the table below ammonia is not of much importance, as they cannot well be employed, except indirectly, as precipitants.

The acids do not precipitate each other from bases; therefore no table can be given of them. Many of them have the property of forming with bases insoluble compounds. Such acids separate bases from other acids, and

precipitate with them. It was from this circumstance that Bergman arranged the acids in his tables; but Berthollet has shown that the order is in many cases hypothetical, and that the nature of the precipitates varies with the proportion.

I shall now give a table of those substances which have the property of separating bodies either partially or completely from solutions, and which therefore are employed by chemists to ascertain the presence of the respective bodies, or to determine their quantity. Such a table can comprehend only the alkalies, earths, metallic oxides, acids, and a few other compound bodies. The simple substances are in general too intimately combined to admit of separation by such means.

V. GENERAL TABLE OF PRECIPITANTS.

1. Alalies.	Precipitants.
Potash	Tartaric acid
Soda	O
Ammonia	Fixed alkalies.

There are no substances known capable of precipitating the fixed alkalies. They are detected by separating other substances from them, combining them with acids, and ascertaining the properties of the salts formed. Tartaric acid detects potash in many cases, when dropped slowly into solutions containing it. Tartar is formed, which, being nearly insoluble, falls to the bottom in small crystals. Phosphoric acid forms with potash a salt nearly insoluble in cold water, but yet it cannot be used us a precipitant. We know of no substance capable of precipitating soda in this way. All the known salts of soda, except the fluate, oxalate, and camphorate, are very soluble. Though ammonia does not precipitate, yet it becomes perceptible by its odour, when solutions containing it are mixed with a fixed alkali.

2. Alkaline earths.	Precipitants.
Barytes........	Sulphuric acid
Strontian	Sulphuric acid
Lime	Oxalic acid
Magnesia	Phosphoric acid.

All the alkaline earths are precipitated completely by the alkaline carbonates, and they are commonly used for the

Book III. purpose. The acids indicated in the table likewise precipitate completely, provided they be combined with an alkaline base, and the proper precautions be taken to remove bodies that might impede the action. Sulphate of soda may be said to precipitate barytes completely from all solutions: but it does not act so powerfully upon strontian. Oxalate of ammonia acts with nearly the same energy on lime, provided there be no excess of acid present. But the oxalate of lime is soluble in most acids. We have no good precipitant of magnesia; it is usually detected by separating the other bodies, and then throwing it down by means of an alkali. Phosphoric acid has been proposed by Dr. Wollaston. His method is ingenious. He pours *carbonate of ammonia* (as nearly neutral as possible) into the magnesian solution. No precipitate appears, because the carbonic acid is sufficient to keep it in solution; but, on adding phosphate of soda, it falls down in an insoluble state combined with the phosphoric acid.

Earths,

3. Earths proper.   Precipitants.

Yttria . . . . . . Ammonia, ferrocyanate of potash
Glucina . . . . Ditto, ... ditto
Zirconia . . . . Ditto, hydrosulphuret of potash
Alumina . . . . Ditto, ditto.

All these earths are precipitated by the alkaline carbonates. None of them has an appropriate precipitate by means of which it is detected and separated. The separation is accomplished by more complicated means. If the solution be in sulphuric acid, indeed, alumina may be detected by means of potash, crystals of alum gradually separating.

Metallic oxides.

4. Metallic oxides.   Precipitants.

Gold . . . . $\begin{cases} \text{Sulphate of iron} \\ \text{Nitrate of mercury} \end{cases}$
Platinum . . . . . Sal ammoniac
Silver . . . . Common salt
Mercury . . . . . Common salt
Palladium. . . . . Prussiate of mercury
Rhodium . . . . O $\rbrace$ Zinc
Iridium . . . . . . O $\rbrace$
Osmium . . . . . . O, Mercury
Copper . . . . . . O, Iron

Metallic oxides.	Precipitants.
Iron	Succinate of soda, benzoate of soda
Nickel	O, sulphate of potash
Tin	Corrosive sublimate
Lead	Sulphate of soda
Zinc	O, alkaline carbonates
Bismuth	Water, muriate of soda
Antimony.....	Water, hydrosulphuret of potash
Tellurium	Water
Arsenic	Nitrate of lead
Cobalt	O, alkaline carbonates
Manganese ..	Tartrate of potash
Chromium ...	Nitrate of lead
Molybdenum..	O
Uranium	Prussiate of potash, alkalies
Tungsten	O, muriate of lime
Titanium	Infusion of galls
Columbium ...	Zinc, infusion of galls
Cerium	Oxalate of ammonia.

Almost all the metallic oxides may be thrown down either completely or partially by means of the alkalies, alkaline carbonates, or alkaline earths. Hydrosulphuret of potash likewise throws them almost all down; but many of them have, besides, particular precipitants, by means of which they may be separated from solutions. The precipitants usually employed are inserted in the preceding table.

The sulphate of iron throws down gold in the metallic state, and is commonly employed to separate that metal, except when the solution contains iron, and we wish to ascertain its quantity; in that case nitrate of mercury may be used.

Platinum is precipitated from nitro-muriatic acid in the state of a yellow powder by sal ammoniac. This is the precipitant commonly employed, because the ammonio-muriate of platinum is easily decomposed by heat.

Silver is completely precipitated from almost all solutions by common salt; the chloride of silver being insoluble in most liquids. It is one of the best precipitants with which we are acquainted.

Mercury is usually detected and separated by sublimation. There is no good precipitant of it except when in the

2

state of protoxide; then muriate of soda throws it down almost completely.

Dr. Wollaston has shown that palladium may be separated from nitro-muriatic solutions by means of prussiate of mercury. No good precipitant of rhodium is known. Dr. Wollaston obtained it in a separate state by means of common salt. Neither do we know any good precipitant of iridium or osmium; Mr. Tennant separated the first by means of zinc, and the second by means of mercury.

No saline precipitant of copper sufficiently accurate for use is known; the metal is usually thrown down by means of a plate of iron, or by sulphureted hydrogen.

Succinate or benzoate of soda or ammonia have been used with much advantage as a precipitant of iron.

No precipitant of nickel is known. Proust used sulphate of potash to separate it from cobalt by means of repeated crystallizations.

There is no good precipitant of tin; it may be thrown down, however, pretty completely, by means of corrosive sublimate. Zinc is commonly employed to separate it from solutions.

Lead is thrown down very completely from its solutions by sulphate of soda.

There is no good precipitant of zinc known. The method employed by chemists, when they wish to obtain it from solutions, is to separate, in the first place, all the earths and other metallic oxides that may be present, and then to throw down the zinc by means of an alkaline carbonate.

Bismuth is thrown down from its solution by water and by muriate of soda. The white precipitate does not blacken when exposed to the sun: neither is it soluble in nitric acid, which sufficiently distinguishes it from chloride of silver.

Antimony is precipitated by water. Hydrosulphuret of potash or ammonia may be necessary in order to detect the metal by the orange-coloured precipitate thrown down.

Tellurium, as appears from Klaproth's experiments, is thrown down by water. We know but little of its precipitants.

Arsenic in the state of white oxide is imperfectly precipitated by evaporation. Hydrosulphuret of potash throws

it down yellow; but the best method of ascertaining its quantity is to convert it into an acid, and then throw it down by means of nitrate of lead.

We have no good precipitant of cobalt. When tartrate of potash is put into a solution containing it, and set aside, red rhomboidal crystals form in it spontaneously, consisting of cobaltic tartrate of potash. This is not a bad way of obtaining the metal nearly pure, but it does not separate all the cobalt.

Neither have we any good precipitant of manganese. Richter has recommended tartrate of potash, which succeeds to a certain extent, especially if the solution does not contain an excess of acid.

Chromium, when in the state of an acid, is thrown down by nitrate of lead.

We have no good precipitant of molybdenum. By evaporation, it falls down spontaneously from acids in the state of an oxide.

Uranium is well characterized by the brown colour of the precipitate by prussiate of potash. The fixed alkalies throw it down completely from its solutions in the state of a brown powder.

We have no good precipitant of tungsten. It is usually obtained separate by combining its oxide with ammonia, evaporating to dryness, and then calcining.

Titanium is thrown down like coagulated blood by nutgalls; columbium in the state of a white powder by a plate of zinc; and cerium by oxalate of ammonia.

5. Acids.	Precipitants.
Sulphuric	Muriate of barytes
Sulphurous	Nitrate of lead
Phosphoric	Muriate of lime
Carbonic	Muriate of an alkaline earth
Fluoric	Muriate of lime
Boracic	Sulphuric acid
Nitric	O
Acetic	O
Benzoic	Muriatic acid
Succinic	Sulphate of iron
Moroxylic	Acetate of lead
Camphoric	O

Acids.	Precipitants.
Oxalic	Muriate of lime
Mellitic	Acetate of barytes
Tartaric	Potash
Citric	Acetate of lime
Saclactic	Ditto
Malic	O
Suberic	Muriatic acid.

This part of the table requires scarcely any explanation. When an alkali or neutral salt is indicated as a precipitant, the acid falls down in the state of an insoluble salt; when an acid is used, then the acid is precipitated in the state of small crystals. When no precipitant is indicated, in that case the acid forms no known insoluble salt, and is itself soluble in water.

When an acid forms an insoluble salt with any base, that acid, or its salts, almost always has the property of separating the base from the solutions which contain it. The base and its salt act in the same way when mixed with solutions containing the acid. Hence it is of importance to know the insoluble salts which the acids form with all the bases, because then we can always foretel the effect of mixing saline solutions together. If any acid and base be present, capable of forming an insoluble salt, they usually combine and precipitate. I shall, for that reason, insert the following table; it exhibits the solubility of most of the salts hitherto examined. The letter S indicates that the salt possesses a considerable degree of solubility; the letter I, that it is not sensibly soluble; and the letter L, that it is but little soluble, or possessed of a degree of solubility not exceeding one or two per cent.

Table of the solubility of salts.

ACIDS.	Sulphuric	Sulphurous	Phosphoric	Phosphorous	Carbonic	Fluoric	Boracic	Nitric	Muriatic	Chloric
Cerium.	S	S	I		I			S	S	—
Titanium.	S		I		I			S	S	
Uranium.	S			L		S		S	S	
Molybdenum.	S		S			S	I	S	S	
Manganese.	S		L		I	L	L	S	S	
Cobalt.	S		S			S	L	S	S	
Arsenic.	L		L			L	L	S	S	
Tellurium.	S							S	S	
Antimony.	L	I	S				I		S	
Bismuth.	L	I	S		I	I	I	S	S	
Zinc.	S	S	S		I	S	I	S	S	
Nickel.	S	S	L		I	S	L	S	S	
Yel. oxide of lead.	I	I	I		I	I	I	S	L	
Tin.	S	S	I			S	I	S	S	
Iron.	S	S	I		I	S	I	S	S	S
Perox. of copper.	S	S	I		I	S	L	S	S	S
Palladium.	S							S	S	
Mercury.	L		I		I	I	I	S	Sil	
Perox. of silver.	L	L	I	I	I	I	I	S	I	S
Perox. of plat.	S							S	S	
Perox. of gold.	S							S	S	
Zirconia.	I							S	S	
Alumina.	S	I	I	S	—	S	I	S	S	S
Glucina.	S		I		I			S	S	
Yttria.	S		I		I			S	S	
Magnesia.	S	S	S	L	I	I	L	S	S	S
Lime.	L	L	I	I	I	I	L	S	S	S
Strontian.	I	I	I		I		L	S	S	S
Barytes.	I	I	I	L	I	L	I	S	S	S
Ammonia.	S	S	S	S	S	S	S	S	S	S
Soda.	S	S	S	S	S	S	S	S	S	S
Potash.	S	S	L	S	S	S	S	S	S	S

ACIDS.	Arsenic	Tungstic	Molybdic	Chronic	Columbic	Acetic	Benzoic	Succinic	Moroxylic	Camphoric
Cerium.	I		I			S	I	L		
Titanium.	I									
Uranium.	I	I	L			S				
Molybdenum.						S		S		
Manganese.	L		I			S	S	S		
Cobalt.	S					S				
Arsenic.	I					S	S			
Tellurium.										
Antimony.	I		I			S	S	S		
Bismuth.	I		I			S	S	S		
Zinc.	I	I	I	I		S	S	S		
Nickel.	S		I			S				
Yel. oxide of lead.	I	I	I	I		S	S	L		
Tin.	I					S		S		
Iron.	I	I	I		I	S	S	I		
Perox. of copper.	S	I	I	I		S	S			
Palladium.										
Mercury.	I	I	L	I		S	I	S		
Perox. of silver.	I		I	I		S	S	S		
Perox. of plat.						S	L			
Peroxide of gold.						S				
Zirconia.						S				
Alumina.	I	I				S	S			L
Glucina.						S		I		
Yttria.	I					S		L		
Magnesia.		S	S			S	S	S		L
Lime.	I	I	I	S		S	S	L	S	L
Strontian.	I					S				
Barytes.	I	I		I		S	S	L		L
Ammonia.	S	S	S			S	S	S	S	L
Soda.	S	S	S	S		S	S	S	S	L
Potash.	S	S	S	S	S	S	S	S	S	L

Acids.	Oxalic	Mellitic	Tartaric	Citric	Saclactic	Malic	Suberic	Formic
Cerium.	I		I	S				
Titanium.	L		L					
Uranium.			L					
Molybdenum.	S		S					
Manganese.	I		S					
Cobalt.			S					
Arsenic.	S —		S					
Tellurium.								
Antimony.	L		S					
Bismuth.	L		I					
Zinc.			L	L		S		
Nickel.								
Yel. oxide of lead.	L	L	I	L	I	I	I	
Tin.	S		S					
Iron.	S	L	S	S	S	S	S	
Perox. of copper.	L	L	S	S	S	S	S	S
Palladium.								
Mercury.	L	I	I	L	I	I		
Perox. of silver.	L	S	S		I	L		
Perox. of plat.	S							
Perox. of gold.								
Zirconia.								
Alumina.	S	I	S		I	L	S	
Glucina.								
Yttria.	I		S					
Magnesia.	I	I	I		I	S	S	
Lime.	I	I	I	L	I	L	L	S
Strontian.	I		L	L		S		
Barytes.	I	I	L	L	I	L	L	
Ammonia.	S	S	S	S	S	S	S	S
Soda.	S	S	S	S	S	S	S	S
Potash.	S	S	S	S	S	S	S	S

Several of these salts, however, although insoluble in water, are still soluble in several saline or acid solutions. This prevents the precipitation from appearing in all cases of mixture as it otherwise would.

SECT. III.

OF PRECIPITATION.

FROM the tables and observations contained in the preceding section, it appears that certain substances only can be thrown down from solutions; namely, the earths and metallic oxides among the bases, and those acids which are nearly insoluble in water; while the alkalies and soluble acids cannot be precipitated at all. It remains for us to consider the state in which the precipitates are obtained, and the way in which they are produced.

According to the theory of elective attraction, a substance is precipitated when its affinity for the solvent is less than that of the precipitant. The precipitate therefore is pure; and if a sufficient quantity of the precipitant be employed, the precipitation is complete. Berthollet has overturned this notion by showing, that in all cases the acid is divided between the base with which it is already combined, and the base employed as a solvent, and that the quantity which unites to each depends upon the affinity and the quantity employed. If the first base happens to be insoluble, the portion thus disengaged will of course precipitate. By this separation the mass of the precipitant is augmented relatively to that of the base precipitated. It therefore acts with more energy. In this manner the quantity of the first base thrown down is increased. But it has not been proved, that by this method one substance is capable of precipitating every atom of another; though in some cases the decomposition is so nearly complete, that we may, without any sensible error, consider it as such: as when pure potash or soda is employed to throw down magnesia; or ammonia, to throw down alumina or peroxide of iron. In other cases the action is very limited. Thus potash does not seem capable of throwing down barytes or

strontian completely, nor ammonia magnesia, from acid
solutions.

When the base to be precipitated is capable of forming an insoluble compound with an under proportion of the acid to which it is combined, it is obvious that in that case the precipitation will commence whenever the compound is reduced by the action of the precipitant to that state of insolubility. Such precipitations cannot consist of the pure bases; they must all be in the state of subsalts. To know, therefore, whether a precipitate be a pure base or not, we have only to be acquainted with the nature of all the compounds which it is capable of forming with the acid which holds it in solution. If they be all very soluble, then we may conclude that the precipitate is in the state of a pure base, or nearly so; but if any of them be insoluble, we may expect to find at least a part of the precipitate in the state of a subsalt. The alkaline earths scarcely form insoluble subsalts, but alumina and many of the metallic oxides possess that property. Hence, when alumina and several of the metallic oxides are precipitated from an acid, we find the precipitate still containing united to it a certain portion of acid.

Several metallic oxides have such a tendency to form subsalts, that they are precipitated even by the affusion of water. This is the case particularly with bismuth and antimony, and with some of the oxygenized salts of mercury.

The precipitation of the metals from solutions by other metals has long puzzled chemists. Berthollet explained it by supposing the precipitate to be an alloy. This certainly is true in some cases, but it applies to the thin layer of the precipitate only which is next the precipitating metal. Thus when zinc precipitates copper, the layer next the cylinder of zinc always contains some zinc. Probably the same remark applies when copper is used to precipitate silver. But when iron precipitates copper, I can detect no mixture of iron in the precipitate, provided the iron has been polished and is not corroded unequally. Mr. Sylvester's opinion, that the metallic precipitates are always produced by the agency of galvanism, is much more probable than any other yet stated. In that case it is in reality hydrogen that reduces and precipitates the metals in all cases.

Hence they fall either pure, or in the state of a hydroguret, according as the metals have the property of combining with hydrogen or not.

Of acids.   When a base is employed to precipitate a soluble acid, the substance thrown down is always a compound consisting of the acid united to the base employed. In this case, like the preceding, the acid is sometimes completely separated, and sometimes not, according to the energy of the base employed, and the degree of insolubility of the salt formed. The same explanation applies as in the first case.

Precipitation by neutral salts.   When a neutral salt is employed as a precipitant, the substance which falls is always a compound. It is composed of one of the ingredients of the precipitating salt united to one ingredient of the salt in solution. Such salts alone can be employed as are known to form insoluble compounds with the acid or base which we wish to throw down. In these cases the separation is complete when the new salt formed is completely insoluble. Neutral salts perform the office of precipitants in general, much more readily and completely than pure bases or acids. Thus the alkaline carbonates throw down the earths much more effectually than the pure alkalies, and sulphate of soda separates barytes much more rapidly than pure sulphuric acid. This superiority is owing partly to the combined action of the acid and base, and partly to the comparatively weak action of a neutral salt upon the precipitate, when compared to that of an acid or alkali.

For the precipitation takes place, not because the salts are insoluble in water, but because they are insoluble in the particular solution in which the precipitate appears. Now if this solution happens to be capable of dissolving any particular salt, that salt will not precipitate, even though it be insoluble in water. Hence the reason why precipitates so often disappear when there is present in the solution an excess of acid, of alkali, &c.

Separation of salts from solutions.   When different salts are mixed together, they separate either spontaneously, or on evaporation, according to the order of their solubility. Those which are insoluble precipitate immediately on the mixture, and those which are least soluble crystallize first when the solution is evaporated. Potash forms with sulphuric acid a salt much less soluble than sulphate of soda. Hence the reason why it has been

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supposed to have a stronger affinity for sulphuric acid, and
by analogy for acids in general, than soda : For if sulphate
of soda be mixed with the greater number of the salts of
potash, sulphate of potash is obtained by evaporation.

But in cases where two salts are mixed together, the re-
sulting salts are much influenced by the proportions of
the ingredients. The same salts are not obtained if the in-
gredients be mixed in one proportion that would be ob-
tained if they were mixed in another proportion. This
will appear evidently from the following experiments of
Berthollet.

Book III.

Salts mixed.	Proportions.	Precipitate.	First evaporation.	Second evaporation.	Mother water.
Nitrate of lime Sulphate of potash	1 1	Sulphate of lime	Nitrate of potash Sulphate of lime	A little sulphate of potash	Little
Ditto	1 2	Ditto	Sulphate of potash Sulphate of lime	Nitrate of potash Sulphate of potash Sulphate of lime	Very little
Ditto	2 1	Ditto	Sulphate of lime Nitrate of potash	Nitrate of potash A very little sulphate of lime	Abundant*
Sulphate of soda Nitrate of lime	1 1	Sulphate of lime	Nitrate or soda	Nitrate of soda	Abundant†
Ditto	2 1	Ditto	Ditto	Ditto	Abundant‡

* Composed of nitrate of lime and nitrate of potash.　Composed probably of sulphate and nitrate of soda.
† Composed of nitrate of soda and of lime.

Salts mixed.	Propor- tions.	First evaporation.	Second evaporation.	Third evaporation.	Mother water.
Sulphate of soda Nitrate of potash	1 1	Sulphate of potash A little nitrate of potash	Nitrate of potash Some sulphate of potash	Nitrate of soda Some nitrate of potash	Considerable*
Ditto	2 1	Sulphate of potash	Sulphate of potash Some nitrate of potash	Sulphate of potash Nitrate of potash Nitrate of soda	Considerable*
Nitrate of potash Muriate of lime	1 1	Nitrate of potash	Muriate of potash Some nitrate of do.		Abundant†
Ditto	1 2	Muriate of potash			Abundant†
Muriate of potash Nitrate of lime	1 1	Nitrate of potash Some muriate of do.	Muriate of potash Some nitrate of do.		Abundant‡
Sulphate of potash Muriate of magnesia	1 1	Sulphate of potash	Sulphate of potash Muriate of do. Sulph. of pot. & mag.	Muriate of potash Sulph. of magnesia	Considerable‡
Ditto	1 2	Ditto	Muriate of potash Sulphate of potash- and-magnesia	Ditto	Ditto.

* Contained both salts. † Composed of nitrate and muriate of lime. ‡ Composed of all the saline ingredients.

The mother water, or the liquid which remains when mixtures of salts are separated by crystallization, always contains several salts, or rather their component parts, which are prevented from crystallization by their mutual action on each other. Hence the quantity of this mother water is always the greater the more soluble the salts are; that is to say, the less disposition they have to crystallize.

Such is a short sketch of Berthollet's ingenious doctrine of precipitation. For a more particular detail the reader is referred to the *Statique Chimique*.

SECT. IV.

OF VOLATILIZATION.

WE have seen, in the preceding section, that decomposition is produced in consequence of the insolubility of some of the ingredients. Berthollet has shown that it takes place equally when some of the ingredients possess elasticity. Thus when an acid is dropped into an alkaline carbonate, the carbonic acid assumes the gaseous form and flies off, and thus the decomposition is complete. In like manner, when an alkali is dropped into sal ammoniac, the ammonia becomes elastic, and is disengaged from the solution.

Effect of elasticity.
This separation, though precisely the reverse of the former, depends upon similar principles. When sulphuric acid is poured into carbonate of soda, the two acids divide the base between them according to their affinity and quantity : but when the proportion of base is diminished, a part of the carbonic acid is enabled to recover its elastic form. It flies off, and thus diminishes the quantity, and of course the action of the remaining carbonic acid. The sulphuric acid is enabled to act with more energy ; it takes a greater proportion of base ; more carbonic acid flies off. Thus the decomposition is gradually completed, not because carbonic acid has a weaker affinity for soda, but because it is elastic.

We may then lay it down as a general rule, that elastic acids are displaced by fixed ones, provided they are capable

of enduring a sufficient degree of heat without decompo-
sition. Hence the reason that the decompositions by the
dry way, as it is called, that is, when the ingredients are
made to act upon each other in a heat sufficient to produce
fusion in one of them, are very different from those pro-
duced when the substances are made to act upon each other
in water.

In like manner, ammonia is separated from acids by means
of the fixed alkalies and most of the earths, when a suffi-
cient heat is applied, and many of the metals separate sul-
phur from mecury.

To these general laws, however, there are several ex-
ceptions. They seem to depend upon the condensation of
the elastic fluid, upon the intimacy of its union with the
other body, upon the affinity of the substances employed to
separate; all of which have been investigated by Berthollet
with his usual sagacity. *

TABLE

OF CHEMICAL DECOMPOSITIONS.

I. ALKALIES.	II. BARYTES AND STRONTIAN.	III. LIME.	IV. MAGNESIA.	V. ALUMINA.
		Prussic	Nitrous	Sulphurous
			Carbonic	Nitrous
			Prussic	Carbonic
				Prussic
Sulphuric acid				
Nitric	Sulphuric			
Muriatic	Oxalic	Oxalic		
Phosphoric	Succinic	Sulphuric		
Fluoric	Fluoric	Tartaric	Oxalic	
Oxalic	Phosphoric	Succinic	Phosphoric	Sulphuric
Tartaric	Saclactic	Phosphoric	Sulphuric	Nitric
Arsenic	Nitric	Saclactic	Fluoric	Muriatic
Succinic	Muriatic	Nitric	Arsenic	Oxalic
Citric	Suberic	Muriatic	Saclactic	Arsenic
Formic	Citric	Suberic	Succinic	Fluoric
Benzoic	Tartaric	Fluoric	Nitric	Tartaric
Acetic	Arsenic	Arsenic	Muriatic	Succinic
Saclactic	Benzoic	Citric	Tartaric	Saclactic
Boracic	Acetic	Malic	Citric	Citric
Salphurous	Boracic	Benzoic	Malic	Phosphoric
Nitrous	Sulphurous	Acetic	Benzoic	Benzoic
Carbonic	Nitrous	Boracic	Acetic	Acetic
Prussic	Carbonic	Sulphurous	Boracic	Boracic

* Statique Chimique, i. 308.

Book III.

Sulphurous
Nitrous
Carbonic
Prussic

VI.
OXIDE OF GOLD.

Muriatic acid
Nitric
Sulphuric
Arsenic
Fluoric
Tartaric
Phosphoric
Prussic

VII.
OXIDE OF SILVER.

Muriatic acid
Oxalic
Sulphuric
Saclactic
Phosphoric
Sulphurous
Nitric
Arsenic
Fluoric
Tartaric
Citric
Formic
Acetic
Succinic
Prussic
Carbonic

VIII.
OXIDE OF MERCURY.

Muriatic
Oxalic
Succinic
Arsenic
Phosphoric
Sulphuric
Saclactic
Tartaric
Citric
Sulphurous
Nitric
Fluoric
Acetic
Boracic
Prussic
Carbonic

IX.
OXIDE OF COPPER.

Oxalic acid
Tartaric
Muriatic
Sulphuric
Saclactic
Nitric
Arsenic
Phosphoric
Succinic
Fluoric
Citric
Formic
Acetic
Boracic
Prussic
Carbonic

X.
OXIDE OF IRON.

Oxalic acid
Tartarous
Camphoric
Sulphuric
Saclactic
Muriatic
Nitric
Phosphoric
Arsenic
Fluoric
Succinic
Citric
Formic
Acetic
Boracic
Prussic
Carbonic

XI.
OXIDE OF NICKEL.

Oxalic acid
Muriatic
Sulphuric
Tartaric
Nitric
Phosphoric
Fluoric
Saclactic
Succinic
Citric
Formic
Acetic
Arsenic
Boracic

Prussic
Carbonic

XII.
OXIDE OF TIN.

Tartaric acid
Muriatic
Sulphuric
Oxalic
Arsenic
Phosphoric
Nitric
Succinic
Fluoric
Saclactic
Citric
Formic
Acetic
Boracic
Prussic

XIII.
OXIDE OF LEAD.

Sulphuric acid
Saclactic
Oxalic
Arsenic
Tartaric
Muriatic
Phosphoric
Sulphurous
Suberic
Nitric
Fluoric
Citric
Formic
Acetic
Boracic
Prussic
Carbonic

XIV.
OXIDE OF ZINC.

Oxalic acid
Sulphuric
Muriatic
Saclactic
Nitric
Tartaric
Phosphoric
Citric
Succinic
Fluoric
Arsenic
Formic
Acetic

Boracic
Prussic
Carbonic

XV.
OXIDE OF BISMUTH.

Oxalic acid
Arsenic
Tartaric
Phosphoric
Sulphuric
Muriatic
Benzoic
Nitric
Fluoric
Saclactic
Succinic
Citric
Formic
Acetic
Prussic
Carbonic

XVI.
OXIDE OF ANTIMONY.

Muriatic acid
Benzoic
Oxalic
Sulphuric
Nitric
Tartaric
Saclactic
Phosphoric
Citric
Succinic
Fluoric
Arsenic
Formic
Acetic
Boracic
Prussic
Carbonic

XVII.
OXIDE OF ARSENIC.

Muriatic acid
Oxalic
Sulphuric
Nitric
Tartaric
Phosphoric
Fluoric
Saclactic

Succinic
Citric
Formic
Arsenic
Acetic
Prussic

XVIII.
OXIDE OF COBALT.

Oxalic acid
Muriatic
Sulphuric
Tartaric
Nitric
Phosphoric
Fluoric
Saclactic
Succinic
Citric
Formic
Acetic
Arsenic
Boracic
Prussic
Carbonic

XIX.
OXIDE OF MANGANESE.

Oxalic acid
Citric
Phosphoric
Tartaric
Fluoric
Muriatic
Sulphuric
Nitric
Saclactic
Succinic
Tartaric
Formic
Acetic
Prussic
Carbonic

XX.
OXIDE OF TITANIUM.

Phosphoric acid
Arsenic
Oxalic
Sulphuric
Muriatic
Nitric
Acetic

XXI.
SULPHURIC ACID.

Barytes
Strontian
Potash
Soda
Lime
Magnesia
Ammonia
Glucina
Yttria
Alumina
Zirconia

XXII.
SULPHUROUS ACID.

Barytes
Lime
Potash
Soda
Strontian
Magnesia }
Ammonia }
Glucina
Alumina
Zirconia

XXIII.
PHOSPHORIC ACID.

Barytes
Strontian
Lime
Potash
Soda
Ammonia
Magnesia
Glucina
Alumina
Zirconia

XXIV.
PHOSPHOROUS ACID.

Lime
Barytes
Strontian
Potash
Soda
Ammonia
Glucina
Alumina
Zirconia

XXV.
CARBONIC ACID.

Barytes
Strontian
Lime
Potash
Soda
Magnesia
Ammonia
Glucina
Zirconia

XXVI.
NITRIC ACID.

Barytes
Potash
Soda
Strontian
Lime
Magnesia
Ammonia
Glucina
Alumina
Zireonia

XXVII. XXVIII.
MURIATIC AND ACETIC ACIDS.

Barytes
Potash
Soda
Strontian
Lime
Ammonia
Magnesia
Glucina
Alumina
Zirconia

XXIX.
OXYMURIATIC ACID.

Potash
Soda
Barytes
Strontian
Lime
Ammonia
Magnesia
Alumina

XXX. XXXI. XXXII. XXXIII.
FLUORIC, BORACIC, ARSENIC, AND TUNGSTIC ACIDS.

Lime
Barytes
Strontian
Magnesia
Potash
Soda
Ammonia
Glucina
Alumina
Zirconia

XXXIV.
OXALIC ACID.

Lime
Barytes
Strontian
Magnesia
Potash
Soda
Ammonia
Alumina

XXXV.
CITRIC ACID.

Lime
Barytes
Strontian
Magnesia
Potash
Soda
Ammonia
Alumina
Zirconia

XXXVI.
BENZOIC ACID.

Potash
Soda
Ammonia
Barytes
Lime
Magnesia
Alumina

XXXVII.
SUCCINIC ACID.

Barytes
Lime
Potash
Soda
Ammonia
Magnesia
Alumina

XXXVIII.
CAMPHORIC ACID.

Lime
Potash
Soda
Barytes
Ammonia
Alumina
Magnesia

XXXIX.
SUBERIC ACID.

Barytes
Potash
Soda
Lime
Ammonia
Magnesia
Alumina

XL.
PRUSSIC ACID.

Barytes
Strontian
Potash
Soda
Lime
Magnesia
Ammonia

XLI.
FIXED OILS.

Lime
Barytes
Fixed alkalies
Magnesia
Ammonia
Oxide of mercury
Other metallic oxides
Alumina

PART II.

CHEMICAL EXAMINATION OF NATURE.

HAVING, in the first part of this work, given a very full detail of the principles of Chemistry, and a description of the different Substances with which it is necessary for the Chemist to be acquainted, I propose, in this Second Part, to take a view of the different substances as they exist in nature, constituting the material world, that we may ascertain how far the science of chemistry will contribute towards explaining their nature, and accounting for the different changes which they produce on each other. Now the different substances of which the material world, as far as we have access to it, is composed, may be very conveniently arranged under the five following heads:

1. The Atmosphere. 3. Minerals. 5. Animals.
2. Waters. 4. Vegetables.

These five divisions will form the subject of the five following books.

BOOK I.

OF THE ATMOSPHERE.

Book I.

THE atmosphere is that invisible elastic fluid which surrounds the earth to an unknown height, and encloses it on all sides. It received its name from the Greeks, in consequence of the vapours which are continually mixing with it. When the chemist turns his attention to the atmosphere, his object is to determine the constituents of which it is composed. This will occupy our attention accordingly in the following chapter.

CHAP. I.

COMPOSITION OF THE ATMOSPHERE.

NEITHER the properties nor the composition of the atmosphere seen to have occupied much of the attention of the ancients. Aristotle considered it as one of the four elements, situated between the regions of *water* and *fire*, and mingled with two *exhalations*, the *dry* and the *moist*; the first of which occasioned thunder, lightning, and wind; while the second produced rain, snow, and hail. The ancients, in general, seem to have considered the blue colour of the sky as essential to the atmosphere; and several of their philosophers believed that it was the constituent principle of other bodies, or at least that air and other bodies are mutually convertible into each other.* But these opinions continued in the state of vague conjectures, till the matter was explained by the sagacity of Hales, and of those philosophers who followed his illustrious career.

It was not till the time of Bacon, who first taught mankind to investigate natural phenomena, that the atmosphere began to be investigated with precision. Galileo introduced the study by pointing out its weight; a subject which was soon after investigated fully by Torricelli, Paschal, &c. Its density and elasticity were ascertained by Boyle and the Florence Academicians. Mariotte measured its dilatibility; Hook, Newton, Boyle, Derham, pointed out its relation to light, to sound, and to electricity. Newton explained the effect produced upon it by moisture; from which Halley attempted to explain the changes in its weight indicated by the barometer. But a complete enumeration of the discoveries made upon the atmosphere in general belongs to *pneumatics*; a science which treats professedly of the mechanical properties of air.

The knowledge of the component parts of the atmosphere

Opinions of the ancients.

Discoveries of the moderns.

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* Thus Lucretius:
    Semper enim quodcunque fluit de rebus, id omne
    Aeris in magnum fertur mare : qui nisi contra
    Corpora retribuat rebus, recreetque fluenteis,
    Omnia jam resoluta forent, et in aera versa.
    Haud igitur cessat gigni de rebus et in res
    Recidere assidue, quoniam fluere omnia constat.   Lib. v. 274.

did not keep pace with the investigation of its mechanical properties. The opinions of the earlier chemists concerning it are too vague and absurd to merit any particular notice. Boyle, however, and his contemporaries, put it beyond doubt that the atmosphere contained two distinct *Component* substances. 1. An elastic fluid distinguished by the name *parts of the* of *air*. 2. Water in the state of vapour. Besides these *atmos-* two bodies, it was supposed that the atmosphere contained *phere.* a great variety of other substances, which were continually mixing with it from the earth, and which often altered its properties, and rendered it noxious or fatal. Since the discovery of carbonic acid gas by Dr. Black, it has been ascertained that this elastic fluid always constitutes a part of the atmosphere. The constituent parts of the atmosphere therefore are,

1. Air.	3. Carbonic acid gas.
2. Water.	4. Unknown bodies.

These shall form the subject of the four following Sections. But before proceeding to ascertain their properties, and the proportion in which they exist in air, it will be worth while to endeavour to calculate the amount of the whole of the atmosphere which surrounds the earth. This will put it in our power to state the amount of its different constituent parts, and of course to see how far the quantities of each agree with the different chemical theories which have been maintained concerning the influence of these bodies on the different kingdoms of nature.

Its absolute   Mechanical philosophers have demonstrated, that the *quantity.* weight of a column of the atmosphere, whose base is an inch square, is equal to a column of mercury of the same base, and balanced by the atmosphere in the barometrical tube. Now let us suppose the mean height of the barometer to amount to nearly 30 inches. Let R denote the radius of the earth, r the height of the mercury in the barometer, π the ratio between the circumference of a circle and its diameter. The solidity of the earth is $\dfrac{4 \pi R^3}{3}$; the solidity of the sphere composed of the earth, and a quantity of mercury surrounding it equal to the weight of the atmosphere, is $\dfrac{4 \pi (R + r)^3}{3}$. Consequently the solidity of the hollow sphere of mercury equal to the weight of the atmosphere is

$$\frac{4\,\pi\,(R + r)^3}{3} - \frac{4\,\pi\,R^3}{3} = 4\,\pi\,\left(R^2\,r + r^2\,R + \frac{r^3}{3}\right),$$ or, ne-
glecting the terms containing r^2 and r^3, $4\,\pi\,R^2\,r$. This
formula, by substituting for π, R^2, and r, their known
values, gives the solidity of the hollow sphere of mercury in
cubic feet. But a cubic foot of mercury is nearly equal to
13·5000 avoirdupois ounces. Hence the mean weight of the
atmosphere amounts to about 1,911,163,227,258,181,818 lbs.
avoirdupois.

SECT. I.

OF AIR.

THE word AIR seems to have been used at first to denote Air an elas-
the atmosphere in general; but philosophers afterwards re- tic fluid.
stricted it to the elastic fluid, which constitutes the greatest
and the important part of the atmosphere, excluding the
water and the other foreign bodies which are occasionally
found mixed with it. For many years all permanently
elastic fluids were considered as air, from whatever combina-
tions they were extricated, and supposed to possess exactly
the same properties with the air of the atmosphere. It is
true, indeed, that Van Helmont suspected that elastic fluids
possessed different properties; and that Boyle ascertained
that all elastic fluids are not capable of supporting combus-
tion like air. But it was not till the discoveries of Caven-
dish and Priestley had demonstrated the peculiar properties
of a variety of elastic fluids, that philosophers became sen-
sible that there existed various species of them. In conse-
quence of this discovery, the word *air* became generic, and
was applied by Priestley, and the British and Swedish
philosophers in general, to all permanently elastic fluids,
while the air of the atmosphere was distinguished by the
epithets of *common* or *atmospheric* air: but Macquer thought
proper to apply the term *gas*, first employed by Van
Helmont, to all permanently elastic fluids except common
air, and to confine the term *air* to this last fluid. This
innovation was scarcely necessary; but as it has now been
generally adopted, it will be proper to follow it. By the

word *air*, then, in this section, I mean only common *air*, or the fluid which forms by far the greatest part of the atmosphere.

The foreign bodies which are mixed or united with air in the atmosphere are so minute in quantity compared to it, that they have no very sensible influence on its properties. We may, therefore, consider atmospheric air, when in its usual state of dryness, as sufficiently pure for examination.

Specific gravity.

1. Air is an elastic fluid, invisible indeed, but easily recognized by its properties. Its specific gravity, when the barometer is at 30 inches, and the thermometer at 60°, is usually reckoned 1·000: it is 828 times lighter than water. One hundred cubic inches of air weigh 30·5 grains troy, according to the experiments of Sir George Shuckburgh.

Density.

But as air is an elastic fluid, and compressed at the surface of the earth by the whole weight of the incumbent atmosphere, its density diminishes according to its height above the surface of the earth. From the experiments of Pascal, Deluc, General Roy, &c. it has been ascertained, that the density diminishes in the ratio of the compression. Consequently the density decreases in a geometrical progression, while the heights increase in an arithmetical progression.

Bouguer had suspected, from his observations made on the Andes, that at considerable heights the density of the air is no longer proportional to the compressing force; * but the experiments of Saussure, junior, made upon Mount Rose, have demonstrated the contrary.†

Colour.

2. Although the sky is well known to have a blue colour, yet it cannot be doubted that air itself is altogether colourless and invisible. The blue colour of the sky is occasioned by the vapours which are always mixed with air, and which have the property of reflecting the blue rays more copiously than any other. This has been proved by the experiments which Saussure made with his *cyanometer* at different heights above the surface of the earth. This instrument consisted of a circular band of paper, divided into 51 parts, each of which was painted with a different shade of blue; beginning with the deepest mixed with black, to

* Mem. Par. 1753, p. 515.   † Jour. de Phys. xxxvi. 98.

the lightest mixed with white. He found that the colour of the sky always corresponds with a deeper shade of blue the higher the observer is placed above the surface; consequently, at a certain height, the blue will disappear altogether, and the sky appear black; that is to say, will reflect no light at all. The colour becomes always lighter in proportion to the vapours mixed with the air. Hence it is evidently owing to them.*

3. For many ages air was considered as an element or simple substance. For the knowledge of its component parts we are indebted to the labours of those philosophers in whose hands chemistry advanced with such rapidity during the last forty years of the 18th century. The first step was made by Dr. Priestley in 1774, by the discovery of oxygen gas. This gas, according to the prevailing theory of the time, he considered as air totally deprived of phlogiston; azotic gas, on the other hand, was air saturated with phlogiston. Hence he considered common air as oxygen gas combined with an indefinite portion of phlogiston, varying in purity according to that portion; being always the purer the smaller a quantity of phlogiston it contained.

While Dr. Priestley was making experiments on oxygen gas, Scheele proceeded to the analysis of air in a different manner. He observed that the liquid sulphurets, phosphorus, and various other bodies, when confined along with air, have the property of diminishing its bulk; and this diminution always amounts to a certain proportion, which he found to be between a third and a fourth part of the whole. The residuum was unfit for supporting flame, and was not diminished by any of the processes which diminish common air. To this residuum he gave the name of *foul air*. From these experiments, he concluded that air is a compound of two different elastic fluids: namely, *foul air*, which constitutes more than two thirds of the whole, and *another air*, which is alone capable of supporting flame and animal life. This last air he extricated from nitre by heat, from the black oxide of manganese, and from other substances, and gave it the name of *empyreal air*. He showed that a mixture of two parts of foul air and one part of empyreal air possesses the properties of common air.†

* Saussure, Voyages dans les Alpes, iv. 288.
† Scheele on Air and Fire, p. 7, &c. Eng. Trans.

The foul air of Scheae was the same with the phlogisti-cated air of Priestley, or with what is now known by the name of *azotic gas*. His empyreal air is the same with the dephlogisticated air of Priestley, or with what is at present called *oxygen gas*. According to him, therefore, air is a compound of two parts of azotic and one part of oxygen gas. He accounted for the diminution of air by the liquid sulphurets and other similar bodies by his theory of the composition of caloric, which he considered as a compound of phlogiston and oxygen gas. According to him, the phlogiston of the sulphuret combines with the oxygen of the air, and passes through the vessels in the state of caloric, while the azotic gas, which has no affinity for caloric, is left behind.

While Scheele was occupied with his experiments on air, Lavoisier was assiduously employed on the same subject, and was led by a different road to precisely the same conclusion as Scheele. By oxidizing mercury in a vessel filled with common air, and heated to the boiling point of mercury, he abstracted the greater part of its oxygen gas; and by heating the red oxide thus formed, he reconverted it into mercury, while at the same time a quantity of oxygen gas was extricated. The residuum in the first experiment possessed the properties of azotic gas; but when the oxygen gas extricated from the mercury was added to it, the mixture assumed again the properties of common air. Hence he concluded that air is composed of azotic gas and oxygen; and from a variety of experiments he determined the proportions to be 73 parts of azotic gas and 27 parts of oxygen gas. He demonstrated, too, that when air is diminished by liquid sulphurets, metals, &c. the oxygen gas which is abstracted combines with the sulphurets, &c. and converts them into acids or oxides according to their respective natures. But as all these experiments have been already detailed in the first part of this work, it is unnecessary to be more particular in this place.

Air, then, is a compound of oxygen and azotic gas: but it becomes a question of considerable consequence to determine the proportion of these two ingredients, and to ascertain whether that proportion is in every case the same. Since azotic gas, one of the component parts of that fluid, cannot be separated by any substance with which chemists

are acquainted, the analysis of air can only be attempted by exposing it to the action of those bodies which have the property of absorbing its oxygen. By these bodies the oxygen gas is separated, and the azotic gas is left behind, and the proportion of oxygen may be ascertained by the diminution of bulk; which being once known, it is easy to ascertain the proportion of azotic gas, and thus to determine the exact relative quantity of the component parts of air.

After the composition of the atmosphere was known Method of to philosophers, it was taken for granted that the pro-ascertaining portion of its oxygen varies at different times and in portion of different places; and that upon this variation depended its component the purity or noxious qualities of air. Hence it became parts. an object of the greatest importance to get possession of a method to determine readily the quantity of oxygen in a given portion of air. Accordingly various methods were proposed, all of them depending upon the property which many bodies possess, of absorbing the oxygen of the air without acting upon its azote. These bodies were mixed with a certain known quantity of atmospheric air in graduated glass vessels inverted over water, and the proportion of oxygen was determined by the diminution of bulk. These instruments received the name of *eudiometers*, because they were considered as measures of the purity of air. The eudiometers proposed by different chemists may be reduced to five.

1. The first eudiometer was made in consequence of Dr. Eudiometer Priestley's discovery, that when nitrous gas is mixed with of Priestley and Fontana. air over water, the bulk of the mixture diminishes rapidly, tana. in consequence of the combination of the gas with the oxygen of the air and the absorption of the nitric acid thus formed by the water. When nitrous gas is mixed with azotic gas, no diminution at all takes place. When it is mixed with oxygen gas in proper proportions, the absorption is complete. Hence it is evident, that in all cases of a mixture of these two gases the diminution will be proportional to the quantity of the oxygen. Of course it will indicate the proportion of oxygen in air; and by mixing it with different portions of air, will indicate the different quantities of oxygen which they contain, provided the component parts of air be susceptible of variation. Dr. Priest-

ley's method was to mix together equal bulks of air and nitrous gas in a low jar, and to transfer the mixture into a narrow graduated glass tube about three feet long, in order to measure the diminution of bulk. He expressed this diminution by the number of hundred parts remaining. Thus, suppose he had mixed together equal parts of nitrous gas and air, the sum total of this mixture was 200 (or 2·00): suppose the residuum when measured in the graduated tube to amount to 104 (or 1·04), and of course that 96 parts of the whole had disappeared, he denoted the purity of the air thus tried by 104. A more convenient instrument was invented by Dr. Falconer of Bath; and Fontana greatly improved this method of measuring the purity of air. A description of his eudiometer was published by Ingenhousz in the first volume of his Experiments; but it was Mr.

Improved by Cavendish. Cavendish who first brought this eudiometer to such a state of precision as to be enabled to ascertain correctly the con-stituents of air. His method was to put 125 measures of nitrous gas into a glass vessel, and to let up into it very slowly 100 measures of the air to be examined, agitating the vessel containing the nitrous gas during the whole time. The diminution of bulk when the process was conducted in this way was almost uniform. The greatest was 110, the least 106·8; the mean 108·2. The variation he found to depend, not upon the air examined, but upon the state of the water in which the experiment was made. If the experiment was reversed, by letting up the nitrous gas to common air, he used 100 measures of each, and the diminution in that case was only 90 measures.

This constancy in the diminution of the bulk of all the different specimens of common air examined, induced Mr. Cavendish to conclude that the proportion between the oxygen and azote in common air does not vary. To find the absolute quantity of oxygen in air, he mixed together oxygen gas and azote in various proportions, and at last found that a mixture of 10 measures of the purest oxygen which he could procure with 38 measures of azote, was just as much diminished by nitrous gas as the same bulk of common air. Hence he concluded that air is composed of 10 parts by bulk of oxygen and 38 of azote, which gives us for its composition per cent.

79·16 azote
20·82 oxygen
————
100·00

or very nearly 21 per cent. of oxygen gas.*

Other philosophers, who did not pay that rigid attention Dalton's method. to precision which characterises all Mr. Cavendish's experiments, obtained variable results from the nitrous gas eudiometer. Most of the circumstances which occasion the variation were pointed out by Cavendish; but they seem to have escaped the observation of succeeding chemists. Humboldt's attempt to render the eudiometer of Fontana accurate did not succeed.† But Mr. Dalton has explained the anomalies in a very luminous manner. According to this philosopher, oxygen gas and nitrous gas are capable of uniting in two proportions: 21 measures of oxygen gas uniting either with 36 measures of nitrous gas, or with twice 36, = 72 measures. Both of these compounds are soluble in water. If the tube be wide, a considerable portion of nitrous gas comes at once in contact with the oxygen. Hence the latter gas combines with a maximum of nitrous, especially if agitation be employed. In a narrow tube the oxygen combines with the minimum of nitrous gas, provided no agitation be employed, and the residue be poured soon into another vessel. When intermediate proportions are used, the absorption will be intermediate. Mr. Dalton recommends a narrow tube; the nitrous gas is to be only in the proportion requisite to form the minimum combination; no agitation is to be employed; and when the diminution is completed, the gas must be transferred to another tube. To 100 measures of air add about 36 of nitrous gas; note the diminution of bulk, and multiply it by $\frac{7}{19}$; the product gives the bulk of oxygen in the air examined.‡

In order to get rid of the anomalies which had perplexed Davy's method. former experimenters, Davy proposed to employ the nitrous gas in a different state. He caused sulphate or muriate of iron to absorb this gas to saturation, and employed the dark brown liquid thus obtained to deprive air of its

* Phil. Trans. 1783, p. 107.   † Ann. xxvii.
‡ Dalton, Phil. Mag. xxviii. 351.

oxygen.   A small graduated glass tube, filled with the air to be examined, is plunged into the nitrous solution, and moved a little backwards and forwards.   The whole of the oxygen is absorbed in a few minutes.   The state of greatest absorption ought to be marked, as the mixture afterwards emits a little gas, which would alter the result.   By means of this, Davy examined the air at Bristol, and found it always to contain about 0·21 of oxygen.   Air sent to Dr. Beddoes from the coast of Guinea gave exactly the same result.

2. For the second kind of eudiometer we are indebted to Scheele.   It is merely a graduated glass vessel, containing a given quantity of air exposed to newly prepared liquid alkaline or earthy sulphurets, or to a mixture of iron filings and sulphur, formed into a paste with water.   These substances absorb the whole of the oxygen of the air, which converts a portion of the sulphur into an acid.   The oxygen contained in the air thus examined, is judged of by the diminution of bulk which the air has undergone.   This method is not only exceedingly simple, but it requires very little address, and yet is susceptible of as great accuracy as any other whatever.   The only objection to which it is liable is its slowness; for when the quantity of air operated on is considerable, several days elapse before the diminution has reached its maximum.

But this objection has been obviated by Mr. De Marti, who has brought Scheele's eudiometer to a state of perfection.   He found that a mixture of iron filings and sulphur does not answer well, because it emits a small quantity of hydrogen gas, evolved by the action of the sulphuric acid formed upon the iron; but the hydrogureted sulphurets, formed by boiling together sulphur and liquid potash or lime water, answered the purpose perfectly.   These substances, indeed, when newly prepared, have the property of absorbing a small portion of azotic gas; but they lose this property when saturated with that gas, which is easily effected by agitating them for a few minutes with a small portion of atmospheric air.   His apparatus is merely a glass tube, ten inches long, and rather less than half an inch in diameter, open at one end, and hermetically sealed at the other.   The close end is divided into 100 equal parts, having an interval of one line between each division.   The

use of this tube is to measure the portion of air to be employed in the experiment. The tube is filled with water; and by allowing the water to run out gradually while the tube is inverted, and the open end kept shut with the finger, the graduated part is exactly filled with air. These hundred parts of air are introduced into a glass bottle filled with liquid sulphuret of lime previously saturated with azotic gas, and capable of holding from two to four times the bulk of the air introduced. The bottle is then to be corked with a ground glass stopper, and agitated for five minutes. After this the cork is to be withdrawn while the mouth of the phial is under water; and for the greater security, it may be corked and agitated again. After this, the air is to be again transferred to the graduated glass tube, in order to ascertain the diminution of its bulk.*

Air examined by this process suffers precisely the same diminution in whatever circumstances the experiments are made: no variation is observed whether the wind be high or low, or from what quarter soever it blows; whether the air tried be moist or dry, hot or cold; whether the barometer be high or low. Neither the season of the year, nor the situation of the place, its vicinity to the sea, to marshes, or to mountains, make any difference. Mr. De Marti found the diminution always between 0·21 and 0·23.

3. The third kind of eudiometer was proposed by Volta. Eudiometer of Volta. The substance employed by that philosopher to separate the oxygen from the air was hydrogen gas. His method was to mix given proportions of the air to be examined and hydrogen gass in a graduated glass tube; to fire the mixture by an electric spark; and to judge of the purity of the air by the bulk of the residuum. This method has been lately examined by Gay-Lussac and Humboldt. They have found it susceptible of great precision. It is one of the simplest and most elegant methods of estimating the proportion of oxygen in air. When 100 measures of hydrogen are mixed with 200, or any greater bulk of oxygen, up to 900 measures, the diminution of bulk after detonation is always 146 measures. The same diminution is obtained if the hydrogen be increased up to a certain quantity. The result of their trials is, that 100 measures of

* Jour. de Phys. lii. 176.

oxygen gas require 200 of hydrogen for complete combustion, which coincides very well with the trials previously made in this country. Hence the method of using this eudiometer is very simple : Mix together equal bulks of the air to be examined and of hydrogen gas, ascertain the diminution of bulk after combustion, divide it by three, the quotient represents the number of measures of oxygen in the air. A great number of trials, in different seasons of the year, of mixtures of 200 measures of air and as much hydrogen, gave almost uniformly a diminution of bulk amounting to 126 measures. Now the third of 126 is 42, the quantity of oxygen in 200 measures of air. Hence 100 parts of air, according to these trials, contain 21 of oxygen.*

Eudiometer of Berthollet. 4. In the fourth kind of eudiometer, the abstraction of the oxygen of air is accomplished by means of phosphorus. This eudiometer was first proposed by Achard.† It was considerably improved by Reboul, ‡ and by Seguin and Lavoisier ; § but Berthollet ‖ brought it to a state of perfection.

Instead of the rapid combustion of phosphorus, this last philosopher has substituted its spontaneous combustion, which absorbs the oxygen of air completely ; and when the quantity of air operated on is small, the process is over in a short time. The whole apparatus consists in a narrow graduated tube of glass containing the air to be examined, into which is introduced a cylinder of phosphorus fixed upon a glass rod, while the tube stands inverted over water. The phosphorus should be so long as to traverse nearly the whole of the air. Immediately white vapours rise from the phosphorus and fill the tube. These continue till the whole of the oxygen combines with phosphorus. They consist of phosphorous acid, which falls by its weight to the bottom of the vessel, and is absorbed by the water. The residuum is merely the azotic gas of the air, holding a portion of phosphorus in solution. Berthollet has ascertained, that by this foreign body its bulk is increased $\frac{1}{40}$th part. Consequently the bulk of the residuum, diminished by $\frac{1}{40}$, gives us the bulk of the azotic gas of the air examined;

* Jour de Phys. lx. 129.   † Ibid. 1784, vol. i.
‡ Ann. de Chim. xiii. 38.   § Ann. de Chim. ix. 293.
‖ Ibid. xxxiv. 73. and Jour. de l'Ecole Polytechn. I. iii. 274.

which bulk, subtracted from the original mass of air, gives us the proportion of oxygen gas contained in it.*

All the different experiments which have been made by means of this eudiometer agree precisely in their result, and indicate that the proportions of the ingredients of air are always the same; namely, about 0·21 parts of oxygen gas, and 0·79 of azotic gas. Berthollet found these proportions in Egypt and in France, and I have found them constantly in Edinburgh and in London, in all the different seasons of the year.

Thus it appears, that whatever method is employed to abstract oxygen from air, the result is uniform, provided the experiment be precisely made. They all indicate that common air consists very nearly of 21 parts of oxygen and 79 of azote. Scheele and Lavoisier found 27 per cent. of oxygen, but their methods were not susceptible of precision. Air, then, does not vary in its composition; the proportion between its constituents is constant in all places and in all heights. Gay Lussac examined air brought from the height of more than 21,000 feet above Paris, and found it precisely the same as the air at the earth's surface.†

But 21 cubic inches of oxygen gas weigh 7·116 grains, Constitu- and 79 inches of azote weigh 23·425 grains. These added ents of air, together amount to 30·541 grains, which ought to be the weight of 100 inches of common air. But this is somewhat greater than the weight of 100 inches of air, according to Sir John Shuckburgh Evelyn's experiments, who found it only 30·5 grains. The difference is not great, and is probably owing to a small error in the specific gravities of the different gases. According to this estimate, 100 parts of air are composed by weight of

23·299 oxygen
76·701 azote

—————

100·000

In all the analyses of air, it is necessary to operate on Method of air of a determinate density, and to take care that the resi- ascertain-
ing the den
sity of the
air operated
on.

* A very convenient apparatus for making eudiometrical experiments, has been invented by Mr. Pepys, and described by him in Phil. Trans. for 1807.

† Phil. Mag. xxi. 225.

duum be neither more condensed nor dilated than the air was when first operated on. If these things are not attended to, no dependence whatever can be placed upon the result of the experiments, how carefully soever they may have been performed. Now there are three things which alter the volume of air and other elastic fluids: 1. A change in the height of the barometer. 2. An increase or diminution of their quantity; the vessel in which they are contained remaining the same, and standing in the same quantity of water or mercury. 3. A change in the temperature of the air.

How to re-
duce air to
a given ba-
rometrical
pressure.
1. The density of air and other elastic fluids is always proportional to the compressing force. Now they are compressed by the weight of the atmosphere, which is measured by the barometer. If that weight diminishes, their density diminishes in proportion, and of course their bulk increases: if the weight of the atmosphere increases, their density increases, and their bulk diminishes in the same proportion. Consequently, if the height of the barometer varies during an experiment, the bulk of the residuum will not be the same that it would have been if no such change had taken place. We shall therefore commit an error, unless we reduce the bulk of the residuum to what it would have been if no such alteration had taken place. This is easily done by a very simple formula.

It has been ascertained by philosophers, that the volumes of air are always inversely as the compressing forces. Therefore let m be the height of the barometer at the commencement of an experiment, n its height at the end, v the volume of the gas when the barometer is at n, and x its volume, supposing the barometer at m. We have $n : m :: x : v$. Consequently $x = \frac{n v}{m}$. So that to find the volume required, we have only to multiply the volume obtained by the actual height of the barometer, and divide by the height of the barometer at which we want to know the volume: and, in general, to reduce a volume of air to the volume it would occupy, supposing the barometer at 30 inches, we have only to use the above formula, substituting 30 in place of m.

To reduce
it to the
density of
2. When air is confined in a jar standing over water or mercury, its density is not the same with that of the atmos-

phere, unless its lower surface in the jar be exactly level with the surface of the liquid in the tub in which it stands. Let A be a jar containing air, and B C the surface of the water or mercury in the tub in which the jar is inverted; the air within the jar is not of the same density with the external air, unless it fills exactly that part of the jar above B C. If it fill only that part of it between A and D, while the water or mercury rises to D, the air will be more dilated than the external air, because it is compressed only by the weight of the atmosphere, diminished by the column of mercury or water D m. On the other hand, if the water or mercury only rise in the jar to E, the air within it will be denser than the external, because it is compressed by the weight of the atmosphere, and also by the column of water or air m E. It is proper, therefore, in all cases, to bring the lower surface of the air in the jar to the same level with the surface of the water or mercury in the trough. But in eudiometrical experiments this is often impossible; because part of the air being absorbed, though the water or mercury over which it stands at first only rose to m, yet the absorption which takes place occasions it to rise to some line D above m. Hence the air which remains after the experiment is in a state of dilatation, and must be reduced by calculation to the volume which it would occupy were it in the same state of compression as at the commencement of the experiment. This is easily done by the following formula.

Let us suppose the experiment is made over mercury. Let H be the height of the barometer at the commencement of the experiment, h the length of the column of mercury m D, v the volume of the air in A D, and x the volume required, or the volume which the air would have, supposing D to coincide with m. Then we have H : H $- h :: v : x$. And $x = \frac{(H - h)\, v}{H}$. Thus let H be 30 inches, $h = 5$ inches, and $v = 200$ cubic inches; then $x = 166\frac{2}{3}$ cubic inches; so that without this correction the error would amount to no less than $33\frac{1}{3}$ cubic inches, or about the sixth part of the whole. When the experiment is made over water, the same formula applies; only in that

case H must be multiplied by 13·6, because a column of water 13·6 times longer than mercury is necessary to produce the same pressure. In that case, supposing the numbers the same as before, x would be $= 197\frac{1}{2}$; so that the error over water is only $2\frac{1}{2}$ inches, or the 80th part of the whole.

Allowance for temperature.

3. A change in the temperature may be more easily guarded against in eudiometrical experiments, as they are usually made within doors: but when it does happen, it occasions an alteration in the volume of the air; an increase of temperature dilating it, and a diminution of temperature occasioning a condensation. This error may be easily corrected in air and all other gases, by increasing or diminishing their apparent bulk for every degree of change in the thermometer, according to the table of the dilatations of the gases formerly given.*

SECT. II.

OF WATER.

Water of the atmosphere.

THAT the atmosphere contains water has been always known. The rain and dew which so often precipitate from it, the clouds and fogs with which it is often obscured, and which deposite moisture on all bodies exposed to them, have demonstrated its existence in every age. Even when the atmosphere is perfectly transparent, water may be extracted from it in abundance by certain substances. Thus, if concentrated sulphuric acid be exposed to air, it gradually attracts so much moisture, that its weight is increased more than three times: it is converted into diluted acid, from which the water may be separated by distillation. Substances which have the property of abstracting water from the atmosphere have received the epithet of *hygroscopic*, because they point out the presence of that water. Sulphuric acid, the fixed alkalies, muriate of lime, nitrate of lime, and in general all deliquescent salts, possess this property. The greater number of animal and vegetable bodies likewise possess it. Many of them take water from

* See Vol. I. p. 66.

moist air, but give it out again to the air when dry. These
bodies augment in bulk when they receive moisture, and
diminish again when they part with it. Hence some of Detected
them have been employed as *hygrometers*, or measures of the by the hy-
grometer.
quantity of moisture contained in the air around them. This
they do by means of the increase or diminution of their
length, occasioned by the addition or abstraction of mois-
ture. This change of length is precisely marked by means
of an index. The most ingenious and accurate hygrometers
are those of Saussure, Deluc, and Wilson. In the first,
the substance employed to mark the moisture is a human
hair, which by its contractions and dilatations is made to
turn round an index. In the second, instead of a hair, a
very fine thin slip of whalebone is employed. The scale is
divided into 100°. The beginning of the scale indicates
extreme dryness, the end of it indicates extreme moisture.
It is graduated by placing it first in air made as dry
as possible by means of salts, and afterwards in air satu-
rated with moisture. This gives the extremes of the
scale, and the interval between them is divided into
100 equal parts. In Mr. Wilson's hygrometer, which
is the simplest of all, the hygrometrical substance is a rat's
bladder, which, by dilating or contracting, alters the
height of a column of mercury in a thermometrical tube
attached to it. The bladder and part of the tube being filled
with mercury.

Since it cannot be doubted that the atmosphere always
contains water, there are only two points which remain to
be investigated: 1. The state in which that water exists in
air; 2. The quantity which a given bulk contains.

I. With respect to the state in which water exists in air, State in
two opinions have been formed, each of which has been which wa-
ter exists in
supported by very able philosophers. 1. Water may be air.
dissolved in air in the same manner as a salt is held in solu-
tion by water. 2. It may be mixed with air in the state
of steam or vapour, after having been converted into vapour.

1. The first of these opinions was hinted at by Dr.
Hooke in his *Micrographia*, and afterwards proposed by
Dr. Halley; but it was much more fully developed by Mr.
Le Roy of Montpellier in 1751. Dr. Hamilton of Dublin
made known the same theory about the same time. The
phenomena in general coincide remarkably well with this
theory. The quantity of water which air is capable of hold-

ing in solution is increased by every augmentation of temperature, and diminished by cold, which is precisely analogous to almost all other solvents. These analogies, and several others which will easily suggest themselves to the reader, have induced by far the greater number of philosophers to adopt this opinion.

2. The second theory, namely, that water exists in air in the state of vapour, has been embraced by Deluc in his last treatise on Meteorology; at least his reasoning appears to me to lead to that conclusion. But it is to Mr. Dalton that we are indebted for the most precise information on the subject.* The following reasons put the truth of this opinion almost beyond the reach of controversy.

It is in the state of vapour. In the *first* place, It cannot be doubted that the water which exists in air is derived originally from the waters on the surface of the earth, which are exposed to the action of the atmosphere. Accordingly we find that water, when exposed to the air, suffers a gradual diminution of bulk, and at last disappears altogether. This diminution of the water may be owing, either to its gradual solution in air, or to its conversion into vapour. The last is the common opinion, as the phenomenon is in common language ascribed to the *evaporation* of the water. When water is placed in an exhausted receiver, it diminishes in bulk even more rapidly than in the open air. In this case, as no air is present, we can only ascribe the diminution of bulk to the conversion of the water into vapour. Accordingly we find, upon examination, that the receiver is actually filled with water in the state of vapour. The presence of this vapour very soon, by its elasticity, puts an end to the evaporation of the water. Now, since water disappears equally whether air be present or not, and exactly in the same manner, it is reasonable to ascribe its disappearing in both cases to the same cause. But in the exhausted receiver it is converted into vapour. Hence it is probable that it is converted into vapour also in the open air; and if so, it must exist in air in the state of vapour.

In the *second* place, If the disappearing of water exposed to the open air were owing to solution and not to evaporation, it ought certainly to disappear more rapidly when it is exposed to the action of a great quantity of air than when

* Manchester Memoirs, v. p. 571.

to a small quantity; for the quantity of any body dissolved is always proportional to the quantity of the solvent. But the very contrary is what actually takes place with respect to the water contained in the air. Saussure has proved that water evaporates much faster at great heights than at the surface of the earth, even when the temperature and the moisture of the air in both places are the same. By comparing a set of experiments made upon the Col-du-Geant, at the height of 11,275 feet above the level of the sea, with a similar set made at Geneva, 1324 feet above the level of the sea, he ascertained that, supposing the temperature and the dryness of the air in both places the same, the quantity of water evaporated at Geneva is to that evaporated on the Col-du-Geant in the same time and same circumstances as 37 to 84, or nearly as 3 : 7. Now the air on the Col-du-Geant is about $\frac{1}{3}$d rarer than at Geneva; so that the diminution of about $\frac{1}{3}$d in the density of the air more than doubles the rate of evaporation.* This is precisely what ought to be the case, provided the water which dissappears mixes with the air in the state of vapour only; but the very contrary ought to hold, if the water disappeared in consequence of the solvent power of air.

In the *third* place, It has been demonstrated by Dr. Black that vapour is water combined with a certain dose of caloric. Consequently when water is converted into vapour, a certain portion of caloric combines with it and disappears. If, therefore, there is the same waste of caloric whenever water passes from a liquid state, and enters into the atmosphere as a component part, we have reason to conclude that it enters into the atmosphere only in the state of vapour. But it is a well known fact that cold is always generated during spontaneous evaporation; that is to say, that the water as it dissappears carries off with it a quantity of caloric. It is well known, that when a wet body is exposed to the air, its temperature is lowered by the evaporation which takes place upon its surface. Hence, in warm countries water is cooled by putting it into porous vessels, and exposing it to the air. The water penetrates through the vessels, evaporates from their surface, and carries off so much heat, as even in some cases to freeze the water in the vessels. Saussure observed, that the evaporation from the surface of

* Saussure's Voyages dans les Alpes, iv. 263.

<div style="text-align: right">Book I.</div>

melting snow caused it to freeze again when the temperature of the surrounding air was 4·5° above the freezing point. Dr. Black has rendered it probable that the quantity of caloric which disappears during spontaneous evaporation is as great as that which is necessary to convert water into steam. We have a right then to conclude, that water, when it evaporates spontaneously, is always converted into vapour, and of course that it is only in that state that it enters into the atmosphere.

In the *fourth* place, Mr. Dalton has demonstrated, that the water which exists in air possesses precisely the same degree of elasticity that it does when in the state of vapour in a vacuum at the same temperature. Hence it follows irresistibly that it exists in air, not in the state of water, but of an elastic fluid or vapour.

We are authorised to conclude, then, that the water which exists in the atmosphere is in the state of vapour.

Quantity of vapour in air.

II. Many attempts had been made to measure the quantity of water contained in air; but Saussure was the first who attained any thing like precision. This ingenious philosopher has shown, in his Hygrometrical Essays, that an English cubic foot of air, when saturated with water, at the temperature of 66°, contains only about eight grains troy of that liquid, or about $\frac{1}{67}$th of its weight.* But the experiments of Mr. Dalton were susceptible of more precision. As the greatest part of the water of the atmosphere is in the state of vapour, the elasticity of which depends upon the temperature, it is obvious that this elasticity, provided it can be ascertained, must measure the quantity of vapour which exists in the atmosphere, the temperature being the same. The elasticity or force of vapour was determined by this ingenious philosopher in the following manner, which

Dalton's method of ascertaining its elasticity.

had been originally contrived by Le Roy : He took a tall cylindrical glass jar, dry on the outside, and filled it with cold spring water fresh from the well: if dew was immediately formed on the outside, he poured the water out, let it stand a while to increase in temperature, dried the outside of the glass well with a linen cloth, and then poured the water in again. This operation was to be continued till the dew ceased to be formed, and then the temperature of the water was observed; and opposite to it in the table † was

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* Essais sur l'hygrometrie, p. 99.   † See Vol. I. p. 97.

found the force of vapour in the atmosphere. This experiment must be conducted in the open air, or at a window; because the air within is generally more humid than that without. Spring water is generally about 50°, and will mostly answer the purpose in the three hottest months of the year: in other seasons an artificial cold mixture is required.

From Dalton's experiments it follows that the quantity of vapour in the atmosphere is variable in quantity. In the torrid zone its force varies from 0·6 to one inch of mercury. In Britain it seldom amounts to 0·6, but is often as great as 0·5 during summer. In winter it is often as low as 0·1 of an inch of mercury.[*]

These facts would enable us to ascertain the absolute quantity of vapour contained in the atmosphere at any given time, provided we were certain that the density and elasticity of vapours follow precisely the same law as that of gases, as is extremely likely to be the case. If so, the vapour will vary from $\frac{1}{60}$th to $\frac{1}{300}$th part of the atmosphere. Dalton supposes that the medium quantity of vapour held in solution at once in the atmosphere may amount to about $\frac{1}{70}$th of its bulk.[†]

SECT. III.

OF CARBONIC ACID GAS.

THE existence of carbonic acid gas as a constituent part of the atmosphere was observed by Dr. Black immediately after he had ascertained the nature of that peculiar fluid. If we expose a pure alkali or alkaline earth to the atmosphere, it is gradually converted into a carbonate by the absorption of carbonic acid gas. This fact which had been long known, rendered the inference, that carbonic acid gas existed in the atmosphere, unavoidable, as soon as the difference between a pure alkali and its carbonate had been ascertained to depend upon that acid. Not only alkalies and alkaline earths absorb carbonic acid when exposed to the air, but several of the metallic oxides also. Hence the reason that we so often find the native oxides in the state of carbonates. Thus *rust* is always saturated with carbonic acid.

* Dalton, Manchester Memoirs, v. 547.   † Phil. Mag. xxxiii. 353.

Found at
great
heights.

Carbonic acid gas not only forms a constituent part of the atmosphere near the surface of the earth, but at the greatest heights which the industry of man has been able to penetrate. Saussure found it at the top of Mount Blanc, the highest point of the European continent ; a point covered with eternal snow, and not exposed to the influence of vegetables or animals. Lime-water diluted with its own weight of distilled water formed a pellicle on its surface after an hour and three quarters exposure to the open air on that mountain ; and slips of paper moistened with pure potash acquired the property of effervescing with acids after being exposed an hour and a half in the same place.* Now this was at a height no less than 15,668 feet above the level of the sea. Humboldt has more lately ascertained the existence of this gas in air brought by Mr. Garnerin from a height not less than 4280 feet above the surface of the earth, to which height he had risen in an air balloon.† This fact is a sufficient proof that the presence of carbonic acid in air does not depend upon the vicinity of the earth.

Its quantity.

The difficulty of separating this gas from air has rendered it difficult to determine with accuracy the relative quantity of it in a given bulk of air. From the experiments of Humboldt it appears to vary from 0·005 to 0·01.

Mr. Dalton's experiments give the quantity much smaller. He found, that if a glass vessel filled with 102,400 grains of rain water be emptied in the open air, and 125 grains of lime water be poured in, and the mouth then closed; by sufficient time and agitation, the whole of the lime water is just saturated with the carbonic acid which it finds in the inclosed volume of air : but 125 measures of lime water require 70 measures of carbonic acid gas to saturate them. Hence he concludes, that air contains only $\frac{1}{1400}$th of its bulk of carbonic acid.‡

From the previous experiments of Mr. Cavendish, however, we learn that lime water is not capable of depriving air of the whole of its carbonic acid. A portion still remains, which can only be separated either by milk of lime, or by repeated washings with new doses of lime water. Hence the quantity of carbonic acid in air must be considerably greater than it was found by Dalton. I do not know ex-

* Saussure's Voyages, iv. 199.   † Jour. de Phys. xlvii. 202.
‡ Phil. Mag. xxiii. 354.

actly the meaning of *lime water being just saturated*, unless it signifies that it refuses to absorb any more gas. In that case the whole of the lime is held in solution by the acid. It must be difficult to ascertain the exact point of saturation according to this sense of the word. We may conclude, however, from Dalton's experiment, that the bulk of carbonic acid in air does not much exceed $\frac{1}{1000}$th of the atmosphere; but it is liable to variation from different circumstances. Immense quantities of carbonic acid must be constantly mixing with the atmosphere, as it is formed by the respiration of animals, by combustion, and several other processes which are going on continually. The quantity, indeed, which is daily formed by these processes is so great, that at first sight it appears astonishing that the gas does not increase rapidly. The consequence of such an increase would be fatal, as air containing $0\cdot1$ of carbonic acid extinguishes light, and is noxious to animals. But we shall find reason afterwards to conclude, that this gas is decomposed by vegetables as rapidly as it is formed.

SECT. IV.

OF THE OTHER BODIES FOUND IN THE ATMOSPHERE.

From the three preceding sections, we see that the atmosphere consists chiefly of three distinct elastic fluids united together by chemical affinity; namely, air, vapour, and carbonic acid gas; differing in their proportions at different times and in different places; but that the average proportion of each is

<div align="center">

98·9 air
1·0 vapour
0·1 carbonic acid

———

100·0

</div>

Composition of the atmosphere.

But besides these bodies, which may be considered as the constituent parts of the atmosphere, the existence of several other bodies has been suspected in it. I do not mean in this place to include among those bodies electric matter, or the substance of clouds and fogs, and those other bodies

Other bodies contained in it.

which are considered as the active agents in the phenomena of meteorology, but to confine myself merely to those foreign bodies which have been occasionally found or suspected in air. Concerning these bodies, however, very little satisfactory is known at present, as we are not in possession of instruments sufficiently delicate to ascertain their presence. We can indeed detect several of them actually mixing with air, but what becomes of them afterwards we are unable to say.

Hydrogen gas.

1. Hydrogen gas is said to have been found in air situated near the crater of volcanoes, and it is very possible that it may exist always in a very small proportion in the atmosphere; but this cannot be ascertained till some method of detecting the presence of hydrogen combined with a great proportion of air be discovered. From the experiments of Gay-Lussac and Humboldt, it appears that air does not contain so much as $\frac{3}{1000}$th parts hydrogen.

2. Carbureted hydrogen gas is often emitted by marshes in considerable quantities during hot weather. But its presence has never been detected in air; so that in all probability it is again decomposed by some unknown process.

3. Oxygen gas is emitted by plants during the day. We shall afterwards find reason to conclude that this is in consequence of the property which plants have of absorbing and decomposing carbonic acid gas. Now, as this carbonic acid is formed at the expense of the oxygen of the atmosphere, as this oxygen is again restored to the air by the decomposition of the acid, and as the nature of atmospheric air remains unaltered, it is clear that there must be an equilibrium between these two processes; that is to say, all the carbonic acid formed by combustion must be again decomposed, and all the oxygen abstracted must be again restored. The oxygen gas which is thus continually returning to the air keeps its component parts always at the same ratio.

4. The smoke and other bodies which are continually carried into the air by evaporation, &c. are probably soon deposited again, and cannot therefore be considered with propriety as forming parts of the atmosphere. But there is another set of bodies which are occasionally combined with air, and which, on account of the powerful action which they produce on the human body, have attracted a great deal of

attention. These are known by the names of matters of contagion.

That there is a difference between the atmosphere in different places, as far as respects its effects upon the human body, has been considered as an established point in all ages. Hence some places have been celebrated as healthy, and others avoided as pernicious to the human constitution. It is well known that in pits and mines the air is often in such a state as to suffocate almost instantaneously those who attempt to breathe it. Some places are haunted by peculiar diseases. It is known that those who frequent the apartments of persons ill of certain maladies, are extremely apt to catch the infection; and in prisons and other places, where crowds of people are confined together, when diseases once commence, they are wont to make dreadful havoc. In all these cases, it has been supposed that a certain noxious matter is dissolved by the air, and that it is the action of this matter which produces the mischief.

This noxious matter is in many cases readily distinguished by the peculiarly disagreeable smell which it communicates to the air. No doubt this matter differs according to the diseases which it communicates, and the substance from which it has originated. Morveau attempted to ascertain its nature; but he soon found the chemical tests hitherto discovered altogether insufficient for that purpose. He has put it beyond a doubt, however, that the noxious matter which rises from putrid bodies is of a compound nature; and that it is destroyed altogether by certain agents, particularly by those gaseous bodies which readily part with their oxygen. He exposed air infected by putrid bodies to the action of various substances; and he judged of the result by the effect which these bodies had in destroying the fetid smell of the air. The following is the result of his experiments.

Contagious matter,

1. Odorous bodies, such as benzoin, aromatic plants, &c. have no effect whatever. 2. Neither have the solutions of myrrh, benzoin, &c. in alcohol, though agitated in infected air. 3. Pyrolignous acid is equally inert. 4. Gunpowder, when fired in infected air, displaces a portion of it; but what remains still retains its fetid odour. 5. Sulphuric acid has no effect; sulphurous acid weakens the odour, but

How destroyed.

does not destroy it. 6. Vinegar diminishes the odour, but its action is slow and incomplete. 7. Acetic acid acts instantly, and destroys the fetid odour of infected air completely. 8. The fumes of nitric acid, first employed by Dr. Carmichael Smith, are equally efficacious. 9. Muriatic acid gas, first pointed out as a proper agent by Morveau himself, is equally effectual. 10. But the most powerful agent is chlorine gas, first proposed by Mr. Cruikshanks, and now employed with the greatest success in the British Navy and Military Hospitals.

Thus there are four substances which have the property of destroying contagious matter, and of purifying the air: but acetic acid cannot easily be obtained in sufficient quantity, and in a state of sufficient concentration, to be employed with advantage.   Nitric acid may be attended with some inconvenience, because it is almost always contaminated with nitrous gas.   Muriatic acid and chlorine are not attended with these inconveniences; the last deserves the preference, because it acts with greater energy and rapidity. All that is necessary is to mix together two parts of common salt with one part of the black oxide of manganese, to place the mixture in an open vessel in the infected chamber, and to pour upon it two parts of sulphuric acid. The fumes of chlorine are immediately exhaled, fill the chamber, and destroy the contagion.   Or the oxymuriate of lime, sold for the purposes of the bleacher, may be mixed with sulphuric acid, and placed in the infected apartment.

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SECT. V.

OF THE STONES WHICH FALL FROM THE ATMOSPHERE.

NOTHING can be a more complete proof of the imperfect state of the science of meteorology, than the discovery of facts, for which not even a conjectural cause in the smallest degree probable can be assigned. Luminous bodies called *meteors, fire-balls, &c.* have in all ages been observed in the atmosphere, and many of them have been described by eye-witnesses. One of the most remarkable of these was the meteor which appeared in 1783. It was very luminous,

and its diameter could not be less than 1000 yards. It traversed Britain and a considerable part of the continent of Europe with very great velocity, and at the height of nearly 60 miles from the surface of the earth.* Almost all the meteors observed resembled each other. They were luminous, at a great height, moved very swiftly, and disappeared in a very short time. Their disappearance was usually accompanied by a loud explosion like a clap of thunder; and it was almost constantly affirmed, that heavy stony bodies fell from them to the earth. But though several well authenticated accounts of the fall of such stones had been from time to time published, little credit was given to them; nor did they indeed attract the attention of philosophers, till Dr. Chladni published a dissertation on the subject in 1794. Two years after Mr. King published a still more complete collection of examples, both ancient and modern; many of them supported by such evidence that it was impossible to reject it. These two dissertations excited considerable attention: but the opinion, that stones had really fallen from the atmosphere, was considered as so extraordinary, and so contrary to what we know of the constitution of the air, that most people hesitated or refused their assent. Meanwhile Mr. Howard took a different method of investigating the subject. He not only collected all the recent and well authenticated accounts of the fall of stony bodies, and examined the evidence of their truth, but procured specimens of the stones which were said to have fallen in different places, compared them together, and subjected them to a chemical analysis. The result was, that all these stony bodies differ completely from every other known stone; that they all resemble each other, and that they are all composed of the same ingredients. His dissertation on the subject was published in the Philosophical Transactions for 1802. The proofs which this admirable dissertation contains, that the stony bodies in question really fell from the atmosphere, are quite irresistible. Indeed their external characters and chemical analysis would alone decide the point: for it is quite inconceivable that in India, England, France, Germany, and Italy, in climates and in soils exceedingly different from

* See Cavallo's description of it, Phil. Trans. 1784.

each other, stones should have been pointed out which differed from every other mineral in the countries where they were found, and which exactly resembled one another, provided these had not had the same origin. The chemical analysis of Howard was soon after repeated and verified by Vauquelin * and Klaproth.†

Table of the best authenticated instances of the fall of stones.

1. Most of the stones which have fallen from the atmosphere have been preceded by the appearance of luminous bodies or meteors. These meteors burst with an explosion, and then the shower of stones falls to the earth. Sometimes the stones continue luminous till they sink into the earth ; but most commonly their luminousness disappears at the time of the explosion. These meteors move in a direction nearly horizontal, and they seem to approach the earth before they explode. The following table, drawn up by Mr. Izarn, exhibits a collection of the best authenticated instances of the falling of stones from the atmosphere hitherto observed, together with the time when they fell, and the persons on whose evidence the fact rests.‡

* Ann. de Chim. xlv. 225.   † Phil. Mag. xv. 182.   ‡ Ibid. xvi. 298.

Substances.	Places where they fell.	Period of their Fall.	Testimony.
Shower of stones	At Rome	Under Tullus Hostilius	Livy
Shower of stones	At Rome	Consuls C. Martius and M. Torquatus	J. Obsequens
Shower of iron	In Lucania	Year before the defeat of Crassus	Pliny
Shower of mercury	In Italy	—	Dion
A very large stone	Near the river Negos, Thrace	Second year of the 78th Olympiad	Pliny
Three large stones	In Thrace	Year before J. C. 452	Ch. of Count Marcellin
Shower of fire	At Quesnoy	January 4th, 1717	Geoffroy le Cadet
Stone of 72 lbs.	Near Larissa, Macedonia	January, 1706	Paul Lucas
About 1200 stones—one of 120 lbs.	Near Padua in Italy	In 1510	Carden, Varcit
Another of 60 lbs.	On Mount Vasier, Provence	November 27th, 1627	Gassendi
Another of 59 lbs.	In the Atlantic	April 6th, 1719	Pere la Feuillée
Shower of sand for 15 hours	Sodom and Gomorrah	—	Moses
Shower of sulphur	In the Duchy of Mansfield	In 1658	Spangenberg
Sulphureous rain	Copenhagen	In 1646	Olaus Wurmius
The same	Brunswick	October 1721	Siegesber
Shower of sulphur	Ireland	In 1695	Muschenbroeck
Ditto of a viscid unknown matter	Liponas in Bresse	September 1753	Delalande
Two large stones weighing 20 lbs.	Niort, Normandy	In 1750	Delalande
A stony mass	At Luce in Le Maine	September 13th, 1768	Bachelay
A stone of 7½ lbs.	At Aire in Artois	In 1768	Gurson de Boyaval
A stone	In Le Gotentin	In 1768	Morand
A stone	Environs of Agen	July 24th, 1790	St. Amand, Baudin, &c.
Extensive shower of stones	Sienna, Tuscany	July 1794	Earl of Bristol
About 12 stones	Wold-Cottage, Yorkshire	December 13th, 1795	Captain Topham
A large stone of 56 lbs	Salé, Department of the Rhone	March 17th, 1798	Lelievre and De Drée
A stone of about 20 lbs.	In Portugal	February 19th, 1796	Southey
A stone of 10 lbs.	Benares, East Indies	December 19th, 1798	J. Lloyd Williams, Esq.
Shower of stones	At Plann, near Tabor, Bohemia	July 3d, 1753	B. de Born
Shower of stones	America	April 5th, 1800	Philosophical Magazine
Mass of iron 70 cubic feet	Abakank, Siberia	Very old	Pallas, Chladni, &c.
Mass of ditto, 14 quintals	Barboutan, near Roquefort	July 1789	Darcet, jun. Lomet, &c.
Shower of stones	Ensisheim, Upper Rhine	November 7th, 1492	Butenschoen
Large stone 260 lbs.	Near Verona	In 1762	Acad. de Bourd.
Two stones 200 and 300 lbs.	Sales, near Ville-Franche	March 12th, 1798	De Drée
A stone of 20 lbs.	—	—	Fourcroy
Several ditto from 10 to 17 lbs.	Near L'Aigle, Normandy	April 26, 1803	—

Stones usually covered with a black crust.

2. The stony bodies when they fall are always hot. They commonly bury themselves some depth under ground. Their size differs from a few ounces to several tons. They are usually roundish, and always covered with a black crust. In many cases they smell strongly of sulphur. The black crust, from the analysis of Howard, consists chiefly of oxide of iron.

Their composition.

3. The outer surface of these stones is rough. When broken, they appear of an ash-grey colour, and of a granular texture like a coarse sandstone. When examined with a microscope, four different substances may be discovered of which the stone is composed: 1st, A number of spherical bodies, varying in size from a pin-head to a pea, of a greyish-brown colour, opaque, breaking easily in every direction, of a compact texture, capable of scratching glass, and of giving a few feeble sparks with steel. 2d, Fragments of pyrites of an indeterminate shape, of a reddish-yellow colour, granular, and easily reduced to powder. The powder has a black colour. 3d, Grains of iron in the metallic state, scattered like the pyrites through the stone. 4th, The three substances just mentioned are cemented together by a fourth of an earthy consistence, and so soft that all the other substances may be easily separated by the point of a knife or the nail, and the stone itself crumbled to pieces between the fingers. This cement is of a grey colour.* The proportion and size of these different constituents vary considerably in different specimens; but all of them bear a striking resemblance to each other. Their specific gravity varies from $3 \cdot 352$ to $4 \cdot 281$.†

Their chemical analysis.

4. From the analysis of Howard, which was conducted with much precision and address, and which has been fully confirmed by Vauquelin and Klaproth, we learn that the black crust consists of a compound of iron and nickel, partly metallic, and partly oxidized. The pyrites consist of iron, nickel, and sulphur. The metallic grains consist of iron, combined with about $\frac{1}{3}$d of its weight of nickel, and the yellow globules are composed of silica, magnesia, iron, and nickel. The Count Bournon observes, that these globules resemble the chrysolite of Werner, and that their chemical analysis corresponds exactly with Klaproth's ana-

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* Bournon, Phil. Trans. 1802.   † Ibid.

lysis of that mineral. The earthy cement consists of the very same substances, and nearly in the same proportions as the globular substances. But it will be necessary to exhibit a specimen of some of the analyses, as published by the philosophers to whom we are indebted for them. A stone which fell at Benares in India was analysed by Howard. The pyrites consisted of

$$
\begin{aligned}
&2\cdot0 \quad \text{sulphur} \\
&10\cdot5 \quad \text{iron} \\
&1\cdot0 \quad \text{nickel} \\
&2\cdot0 \quad \text{earths and foreign bodies} \\
&\overline{} \\
&15\cdot5
\end{aligned}
$$

The spherical bodies of
$$
\begin{aligned}
&50\cdot0 \quad \text{silica} \\
&15\cdot0 \quad \text{magnesia} \\
&34\cdot0 \quad \text{oxide of iron} \\
&2\cdot5 \quad \text{oxide of nickel} \\
&\overline{} \\
&101\cdot5
\end{aligned}
$$

The earthy cement of
$$
\begin{aligned}
&48\cdot0 \quad \text{silica} \\
&18\cdot0 \quad \text{magnesia} \\
&34\cdot0 \quad \text{oxide of iron} \\
&2\cdot5 \quad \text{oxide of nickel} \\
&\overline{} \\
&102\cdot5
\end{aligned}
$$

A stone which fell in Yorkshire, deprived as much as possible of its metallic particles, gave Mr. Howard from 150 grains

$$
\begin{aligned}
&75 \quad \text{silica} \\
&37 \quad \text{magnesia} \\
&48 \quad \text{oxide of iron} \\
&2 \quad \text{oxide of nickel} \\
&\overline{} \\
&162
\end{aligned}
$$

The increase of weight was owing to the oxidizement of the metallic bodies.

Stones which fell at Laigle in France, in 1803, yielded, by the analyses of Vauquelin and Fourcroy,

54 silica
36 oxide of iron
9 magnesia
3 oxide of nickel
2 sulphur
1 lime

———

105 *

The following table exhibits the result of the most re-markable analyses of such stones, which have been made since the publication of Howard's paper on the subject.

	†	‡	§	‖
Iron	29·00	17·60	23·00	——
Nickel	0·50	0·40	——	——
Chromium	——	——	——	2·
Oxide of iron	——	25·00	——	31·00
Sulphur	3·50	3·00	——	——
Silica	43·00	38·00	48·50	33·90
Magnesia	22·00	14·25	2·00	32·00
Lime	0·50	0·75	9·50	——
Alumina	1·25	1·00	14·50	——
Magnesia	0·25	——	——	——

Stromeyer has lately announced the discovery of cobalt in the meteoric iron from the Cape of Good Hope.**

From the preceding analyses, it is obvious that there are several different kinds of meteoric stones ; so that if we were to arrange them according to their composition, they might be divided into at least three or four species. It deserves attention that the metals found in them are iron, nickel, chromium, and cobalt. Now these constitute the whole of the magnetic metals.

Conjectures respecting their origin.   5. The experiments of Howard, thus confirmed by others, and supported by the most respectable historical evidence, having demonstrated that these stony bodies really do fall from the heavens, it was natural to expect that

* Phil. Mag. xvi. 302.

† Klaproth, v. 252. The stone fell at Lissa in 1808.

‡ Ibid. p. 255. The stone fell at Smolensk in 1807.

§ Ibid. p. 261. The stone fell at Stannern in 1808.

‖ Vauquelin, Ann. de Chim. et Phys. i. 53. The stone fell at Langres in 1815.   ** Annals of Philosophy, ix. 249.

various attempts would be made to account for their appear- ance. But such is the obscurity of the subject, so little progress have we made in the science of meteorology, that no opinion in the slightest degree probable has hitherto been advanced. It was first supposed that the bodies in question had been thrown out of volcanoes; but the immense distance from all volcanoes at which they have been found, and the absence of all similar stones from volcanic productions, render this opinion untenable. Chladni endeavoured to prove that the meteors from which they fell were bodies floating in space, unconnected with any planetary system, attracted by the earth in their progress, and kindled by their rapid motion through the atmosphere. But this opinion is not susceptible of any direct evidence, and can scarcely be believed, one would think, even by Dr. Chladni himself. Laplace suggests the probability of their having been thrown off by the volcanoes of the moon: but the meteors which almost always accompany them, and the swiftness of their horizontal motion, militate too strongly against this opinion. The greater number of philosophers consider them, with Mr. King and Sir William Hamilton, as concretions actually formed in the atmosphere. This opinion is undoubtedly the most probable of all; but in the present state of our knowledge, it would be absurd to attempt any explanation of the manner in which they are formed. The masses of native iron found in South America, in Siberia, and near Agnam, contain nickel, as has been ascertained by Proust, Howard, and Klaproth, and resemble exactly the iron found in the stones fallen from the atmosphere. We have every reason therefore to ascribe to them the same original: and this accordingly is almost the uniform opinion of philosophers. Klaproth has shown that real native iron is distinguished from meteoric iron by the absence of nickel.*

Upon the whole, we may consider these stony and metallic masses as fragments of fire-balls which have burst in the atmosphere; but the origin and cause of these fire-balls will perhaps for ages baffle all the attempts of philosophers to explain them.

* Gehlen's Jour. i. 8.

BOOK II.

OF WATERS.

Waters,   MANKIND must have observed very early, that the waters which exist in such abundance in almost every part of the earth, differ considerably from each other in their taste and transparency, and in their fitness for serving as vehicles for food, and for the various purposes of domestic economy. These differences are occasioned by the foreign bodies which the aqueous fluid holds in solution or suspension; for water is never found native in a state of complete purity. In some cases the quantity of these foreign matters is so minute as to have but little influence on the taste or the other properties of water; but in other cases, the foreign bodies alter its properties altogether, and render it noxious, or medicinal, or unfit for the preparation of food. In the present book I shall take a general view of the different springs and collections of water; and give an account of their properties and component parts, as far as they have been hitherto ascertained. Now waters may be very conveniently divided
Divisible into three classes: 1. Waters which may be used for dressing food, and the other purposes of domestic economy to which water is usually applied. These, for want of a better name, may be called *common water*. 2. Sea water. 3. Those waters which have been called *mineral*, in consequence of the notable quantity of mineral substances which they contain.—These three classes of waters shall form the subject of the three following chapters.

Divisible into three classes.

CHAP. I.

OF COMMON WATERS.

GOOD water is as transparent as crystal, and entirely colourless. It has no smell, and scarcely any taste; and in general the lighter it is so much the better. If we compare the different waters which are used for the common purposes of life with each other, and judge of them by the above

standard, we shall find them to differ considerably from each other, according to the circumstances of their situation. These waters may be reduced under four heads; namely, 1. Rain water; 2. Spring and river water; 3. Well water; 4. Lake water.

1. Rain water, unless when near a town, or when col- Rain water. lected at the commencement of the rain, possesses the properties of good water in perfection, and is as free from foreign ingredients as any native water whatever. The substances which it holds in solution are *air, carbonic acid, carbonate of lime,* and, according to Bergman, it yields some traces of *nitric acid,* and a little of *muriate of lime.** The existence of air in water was first pointed out by Boyle. Scheele first observed that this air contained a greater proportion of oxygen than common air. The quantity of air in good water does not exceed $\frac{1}{28}$th of the bulk. One hundred cubic inches of water contain generally about one cubic inch of carbonic acid gas. It is to the presence of these two elastic fluids that water owes its taste, and many of the good effects which it produces on animals and vegetables. Hence the vapidness of newly boiled water from which these gases are expelled. Snow water, when newly melted, is also desti- Snow water. tute of all gaseous bodies.† Hence the reason that fish cannot live in it, as Carradori has ascertained.‡ Hassenfratz, indeed, has endeavoured to prove that snow water holds oxygen gas in solution; but in all probability the water which he examined had absorbed air from the atmosphere.

The quantity of muriate of lime contained in rain water How purified. must be exceedingly minute; provided Morveau's assertion, that rain water may be rendered sufficiently pure for chemical purposes by dropping into it a little barytes water, and then exposing it for some time to the atmosphere, and allowing the precipitate formed to deposite, be well founded. According to this philosopher, the rain water which drops from the roofs of houses, after it has rained for some time, contains only a little sulphate of lime, which it has dissolved as it trickled over the slates.§

If meteoric stones be really formed in the atmosphere

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* Bergman, i. 87. † Bergman, i. 87.
‡ Jour. de Phys. xlviii. 226. § Ann. de Chim. xxiv. 321.

we have reason to expect a greater proportion of foreign bodies in rain water at some seasons than others. It is not unlikely that some light might be thrown upon the decompositions going on in the atmosphere, by examining the solid substances left behind when rain water is evaporated.

Spring water. 2. The water of springs is nothing else than rain water, which, gradually filtering through the earth, collects at the bottom of declivities, and makes its way to the surface. It is, therefore, equally pure with rain water, provided it does not meet with some soluble body or other in its passage through the soil. But as this is almost always the case, we generally find, even in the purest spring water, a little carbonate of lime and common salt, besides the usual proportion of air and carbonic acid gas. Sometimes also it contains muriate of lime or a little carbonate of soda.* Dr. Henry expelled the air from a portion of spring water by boiling; 100 cubic inches of the water yielded 4·76 inches of gas. This gas he found a mixture of 3·38 inches of carbonic acid, and 1·38 of atmospheric air.† Bergman found the springs about Upsala, which are reckoned exceedingly pure, to contain the following foreign bodies:

1. Oxygen gas,	5. Common salt,
2. Carbonic acid,	6. Sulphate of potash,
3. Carbonate of lime,	7. Carbonate of soda,
4. Silica,	8. Muriate of lime.

The whole of these ingredients amounted at an average to 0·0004 parts; and the proportion of each of the solid bodies was as follows:

Carbonate of lime .. 5·0	Muriate of lime .... 0·5
Common salt...... 3·0	Sulphate of potash.. 0·25
Silica .... 0·5	Carbonate of soda .. 0·25

River water. River waters may be considered as merely a collection of spring and rain water, and therefore are usually possessed of a degree of purity at least equal to these. Indeed, when their motion is rapid, and their bed siliceous sand, they are generally purer than spring water; depositing during their motion every thing which was merely mechanically suspended, and retaining nothing more than the usual propor-

* Bergman, i. 88.   † Nicholson's Jour. v. 237.

tion of air and carbonic acid gas, and a very minute quan-
tity of carbonated lime and common salt. When their
bed is clayey, they are usually opal-coloured, in conse-
quence of the particles of clay which they hold in suspension.

3. By well water is meant the water which is obtained by Well wa-
digging deep pits, which is not in sufficient quantity to ter.
overflow the mouth of the well; but which may be obtained
in abundance by pumping. It is essentially the same with
spring water, being derived from the very same source; but
it is more liable to be impregnated with foreign bodies from
the soil, in consequence of its stagnation or slow filtration.
Hence the reason that well water is often of that kind which
is distinguished by the name of *hard water*, because it does Hard wa-
not dissolve soap, and cannot be used for dressing several ters.
kinds of food. These properties are owing to the great pro-
portion of earthy salts which it holds in solution. The most
common of these salts is sulphate of lime. These earthy
salts have the property of decomposing common soap: their
acid unites with the alkali of the soap, while the earthy
basis forms with the oil a soap not soluble in water, which
envelopes the soap and gives it a greasy feel. These waters
may be in general cured by dropping into them an alkaline
carbonate. Mr. Sennebier has shown that well water usually
contains a greater proportion of carbonic acid gas than spring
or river water.

4. The water of lakes is merely a collection of rain water, Water of
spring water, and river water, and of course contains pre- lakes.
cisely the same heterogeneous salts: but it is seldom so
transparent as river water, being usually contaminated with
the remains of animal and vegetable bodies which have
undergone putrefaction in it. For as lake water is often
nearly stagnant, it does not oppose the putrefaction of these
bodies, but rather promotes it; whereas in river water,
which is constantly in motion, no putrefaction takes place.
Hence the reason of the slimy appearance and the brownish
colour which often distinguishes lake water.

Marsh water contains a still greater proportion of animal
and vegetable remains than lake water, because it is alto-
gether stagnant. Moss water is strongly impregnated with
those vegetable bodies which constitute mosses, and usually
also contains iron.

When water is kept in casks during sea voyages, it soon
becomes putrid and offensive. This is owing to the action

of the water upon the cask, a portion of which it dissolves. Berthollet suggested the charring of the inside of the cask as an effectual remedy. The experiment has been successfully tried in a long sea voyage of Krusenstern, a Russian captain. Charcoal powder acts effectually, but it is troublesome, and soon loses its property.*

CHAP. II.

OF SEA WATER.

The ocean is the great reservoir of water into which the lakes and rivers empty themselves, and from which is again drawn by evaporation that moisture which, falling in showers of rain, fertilizes the earth, and supplies the waste of the springs and rivers. This constant circulation would naturally dispose one to believe, *a priori*, that the waters of the ocean do not differ much from the waters of rivers and lakes : but nothing would be more erroneous than such a conclusion ; for the sea water, as every one knows, differs materially from common water in its taste, specific gravity, and other properties. It contains a much greater proportion of saline matter, particularly of common salt, which is usually extracted from it. Indeed, if the sea were not impregnated with these saline bodies, the putrefaction of the immense mass of animal and vegetable matter which it contains would in a short time prove fatal to the whole inhabitants of the earth.

Quantity of sea water.   The absolute quantity of sea water cannot be ascertained, as its mean depth is unknown. Mr. De la Place has demonstrated, that a depth of four leagues is necessary to reconcile the height to which the tides are known to rise in the main ocean with the Newtonian theory of the tides.† If we suppose this to be the mean depth, the quantity of water in the ocean must be immense. Even on the supposition that its mean depth is not greater than the fourth part of a mile, its solid contents (allowing its surface to be three-fourths of that of the superficies of the earth) would be $32,058,939\frac{3}{4}$ cubic miles.

Its properties.   Sea water has a very disagreeable bitter taste, at least

* Ann. de Chim. lix. 96, and Gehlen's Jour. 2d series, i. 645.
† Mem. Par. 1776, p. 213.

when taken from the surface or near the shore; but when brought up from great depths, its taste is only saline.* Hence we learn that this bitterness is owing to the animal and vegetable substances with which it is mixed near the surface. It specific gravity varies from 1·0269 to 1·0285.† It does not freeze till cooled down to 28·5° ‡ of Fahrenheit's scale.

Sea water has been examined by many chemists, and various accurate sets of experiments made to determine its constituents. The following table exhibits the quantity of salts contained in 10,000 parts of sea water. According to the result of these experiments:

	§	‖	**	††	‡‡	§§
Common salt	137·59	284·19	55·75	72·91	106·04	251
Sulphate of magnesia.. ..	{ 6·18	—	2·3	—	0·86	57·8
Sulphate of soda........			2·79	—	—	
Muriate of magnesia	15·62	67·65	10·41	7·81	48·17	35
Muriate of lime	20·38	—	—	31·25	—	—
Sulphate of lime........	3·47	8·01	2·08	7·81	5·21	1·5

	§§	§§	‖‖	‖‖	‖‖
Common salt............	251	251	242·51	245·04	220·01
Sulphate of magnesia	57·8	62·5	7·86	17·04	—
Sulphate of soda........	—	—	9·99	2·66	33·16
Muriate of magnesia.....	35	32·5	34·49	28·63	42·08
Muriate of lime..........	—	—	—	—	7·84
Sulphate of lime........	1·5	1·5	9·45	9·72	—

* Bergman, i. 180.　　† Bladh, Kirwan's Geological Essays, p. 355.

‡ Nairne, Phil. Trans. 1776, Part First.

§ Lavoisier, Mem. Par. 1772, p. 555. The analysis occurs in a dissertation on the use of alcohol in the analysis of mineral waters.

‖ Bergman, Opusc. i. 182.

** Lichtenberg, Schweigger's Journal, ii. 256. It was water of the Baltic. He found, likewise, carbonate of lime 0·83, carbonate of magnesia 0·41, and 2·6 cubic inches of carbonic acid gas.

†† Pfaff, ibid. It was also Baltic water. He obtained, likewise, 1·3 of carbonate of lime.

‡‡ Link, ibid. It was also Baltic water which he analysed. He obtained, likewise, 0·41 of resinous matter.

§§ Bouillon, Lagrange, and Vogel, Annals of Philosophy, iv. 206. The first was water from the English Channel, the second from the Bay of Biscay, and the third from the Mediterranean. The first two contained 2, and the last 1 of carbonates of lime and magnesia. The first two contained 2·3, and the last 1·1 of carbonic acid gas.

‖‖ Murray, Edin. Trans. viii. 205. The first analysis was performed

The analyses of Lichtenberg, Pfaff, and Link were of the Baltic Sea near the island of Zealand, where it merely tastes brackish, and has a specific gravity of 1·00701. Bergman's analysis was of water from the latitude of the Canaries, brought by Sparrman for the purpose of analysis. The specific gravity of the sea water, in that latitude, is nearly a maximum; yet the quantity of common salt found by Bergman was unusually great. The water examined by Lavoisier was from the English channel. The experiments of Dr. Murray demonstrate that the salts obtained from sea water vary according to the mode of analysis. Hence it follows obviously that the real constituents cannot be detected by evaporation and the crystallization of the salts. His supposition that all the constituents of sea water are muriates, except sulphate of soda, and that when the salts are concentrated by evaporation the muriates of lime and magnesia decompose the sulphate of soda, forming sulphates of lime and of magnesia, is very plausible and probable. We may, therefore, consider the last column of the preceding table as exhibiting pretty correctly the saline constituents of sea water in the neighbourhood of the British islands. The proportion of salt, therefore, amounts to about $\frac{1}{33}$ of the weight of the water, or about 3 per cent.

In different places.   As far as experiment has gone, the proportion of saline contents does not differ much, whatever be the latitude in which the water of the ocean is examined. Lord Mulgrave, in north latitude 80°, and 60 fathoms under ice, found the saline contents of sea water 0·0354; in latitude 74°, he found them 0·036; in latitude 60°, 0·034. Pages found sea water taken up in north latitude 45° and 39° to contain 0·04 of saline contents; and Baumé obtained by analysis, from water taken up by Pages in north latitude 34° and 14°, exactly the same proportions of saline matter. In southern latitudes Pages found the following proportions of saline matters:

Latitude.	Saline matter.
49° 50′	0·0416
46 0	0·045

according to the mode followed by Lavoisier; the second, according to the common mode; and the third exhibits what Dr. Murray considers as the true constituents of sea water. The water analysed was of the Frith of Forth, of the specific gravity 1·029.

Latitude.	Saline matter.
40° 30′	0·04
25 54	0·04
20 0	0·039
1 16	0·035

From the experiments made by Bladh on the specific gravity of sea water in different latitudes it appears that the water contains more salt at the tropics than towards the equator.

If we were acquainted with the proportion between the saline contents of sea water and its specific gravity, it would be easy in all cases to ascertain the quantity of saline matter merely by taking the specific gravity of water we wish to examine. This would require a set of experiments on purpose; dissolving in pure water different quantities of the salts contained in sea water in the proportions which they bear to each other, and ascertaining the specific gravity of every such solution. Dr. Watson has given us a table for ascertaining that point, as far as common salt is concerned; and as the salt which he used was not perfectly pure, but contained a mixture of the different salts usually found in the sea, we may consider it as very nearly determining the proportion of saline contents in sea water as far as it goes. This table therefore I shall here insert.*

(marginal note: Specific gravity of water holding different proportions of salt in solution.)

Propor. of salt.	Specific gravity.	Propor. of salt.	Specific gravity.	Propor. of salt.	Specific gravity.
0	1·000	$\frac{1}{21}$	1·032	$\frac{1}{84}$	1·007
$\frac{1}{2}$	1·206	$\frac{1}{24}$	1·029	$\frac{1}{108}$	1·006
$\frac{1}{4}$	1·160	$\frac{1}{27}$	1·027	$\frac{1}{126}$	1·005
$\frac{1}{5}$	1·121	$\frac{1}{28}$	1·025	$\frac{1}{144}$	1·004
$\frac{1}{6}$	1·107	$\frac{1}{30}$	1·024	$\frac{1}{162}$	1·003
$\frac{1}{7}$	1·096	$\frac{1}{32}$	1·023	$\frac{1}{192}$	1·0029
$\frac{1}{8}$	1·087	$\frac{1}{36}$	1·020	$\frac{1}{256}$	1·0023
$\frac{1}{9}$	1·074	$\frac{1}{39}$	1·019	$\frac{1}{320}$	1·0018
$\frac{1}{12}$	1·059	$\frac{1}{42}$	1·015	$\frac{1}{448}$	1·0017
$\frac{1}{14}$	1·050	$\frac{1}{48}$	1·014	$\frac{1}{512}$	1·0014
$\frac{1}{15}$	1·048	$\frac{1}{54}$	1·013	$\frac{1}{848}$	1·0008
$\frac{1}{16}$	1·045	$\frac{1}{56}$	1·012	$\frac{1}{1024}$	1·0006
$\frac{1}{18}$	1·040	$\frac{1}{72}$	1·009		

* Watson's Chemical Essays, v. 91.

This table was calculated at a temperature between 46°
and 55°; but Mr. Kirwan has reduced part of it to the
temperature of 62°, in order to compare it with the specific
gravities of sea water taken at that temperature, or at least
reduced to it. The specific gravities, thus altered by
Kirwan, are as follows:

Propor. of Salt.	Spec. Grav. at 62°.
$\frac{1}{24}$	1·0283
$\frac{1}{25}$	1·0275
$\frac{1}{26}$	1·0270
$\frac{1}{27}$	1·0267
$\frac{1}{28}$	1·0250
$\frac{1}{30}$	1·0233
$\frac{1}{39}$	1·0185
$\frac{1}{44}$	1·0133
$\frac{1}{56}$	1·0105
$\frac{1}{108}$	1·004
$\frac{1}{162}$	1·0023

This table will enable us to ascertain the saline contents
of sea water in different parts of the Atlantic and Indian
Oceans, from the following table of the specific gravity of
sea water in different parts of these oceans, constructed by
Bladh, and reduced by Kirwan to the temperature of
62°.*

Specific
gravity of
sea water
in different
places.

Latitude. North.		Longitude.† East.		Sp. Gr. at 62°.
59° 39′	....	8° 48′	....	1·0272
57 18	....	18 48	....	1·0269
		West.		
57 01	....	1 22	....	1·0272
54 00	....	4 45	....	1·0271
44 32	....	2 04	....	1·0276
		East.		
44 07	....	1 00	....	1·0276
40 41	....	0 30	....	1·0276
34 40	....	1 18	....	1·0280
29 50	....	0 00	....	1·0281

* Kirwan's Geol. Essays, p. 350.
† The Lon. is counted from Teneriffe.

Latitude. North.	Longitude. West.	Sp. Gr. at 62°.
24° 00′	2° 32′	1·0284
18 28	3 24	1·0281
16 36	3 37	1·0277
14 56	3 46	1·0275
10 30	3 49	1·0272
5 50	3 28	1·0274
2 20	3 26	1·0271
1 25	3 30	1·0273
South.		
0 16	3 40	1·0277
5 10	6 00	1·0277
10 00	6 05	1·0285
14 40	7 00	1·0284
20 06	5 30	1·0285
25 45	2 22	1·0281
East.		
30 25	7 12	1·0279
37 37	68 13	1·0276

From this table, compared with the last, we learn that the ocean contains most salt between south latitude 10° and 20°; the saline contents amounting to rather more than $\frac{1}{24}$th. The quantity of salt between north latitude 18° and 34° is rather less than $\frac{1}{24}$th: at the equator it is nearly $\frac{1}{25}$th. The proportion of salt is least of all in north latitude 57°, where it amounts to little more than $\frac{1}{27}$th.

From the experiments of Wilcke, we learn that the Baltic contains much less salt than the ocean; that the proportion of its salt is increased by a west wind, and still more by a north-west wind. The specific gravity of the Baltic water, ascertained by this philosopher under these different circumstances, and reduced by Mr. Kirwan to the temperature of 62°, is exhibited in the following table: *Of the Baltic.*

Specific Gravity.
1·0039 Wind at E.
1·0067 Ditto at W.
1·0118 Storm at W.
1·0098 Wind at N. W.

From this table it appears that the proportion of salt in

the Baltic, when an east wind prevails, is only $\frac{1}{108}$; and that this proportion is doubled by a westerly storm: a proof not only that the saltness of the Baltic is derived from the neighbouring ocean, but that storms have a much greater effect upon the waters of the ocean than has been supposed.* The Euxine and Caspian Seas, if we believe Tournefort, are less salt than the ocean; † but it is probable that the Mediterranean is at least as salt as the Atlantic.

The water of the *Dead Sea* differs exceedingly from sea water. Its specific gravity is 1·211; ‡ and it is saturated with salt, containing no less than 24·6 per cent. of saline matter. According to the analysis of Lavoisier, it is composed of

> 55·60 water
> 38·15 muriate of lime and of magnesia
> 6·25 common salt
> ————
> 100·00 §

But by the late very accurate analysis of Dr. Marcet, the constituents contained in 100 parts of the water of this lake, are in the following proportions :

> 3·920 muriate of lime
> 10·246 muriate of magnesia
> 10·360 muriate of soda
> 0·054 sulphate of lime
> 75·420 water
> ————
> 100·000 ‖

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* Kirwan's Geological Essays, p. 356. I found the specific gravity of water taken from the Baltic in calm weather, as follows :

> Taken up at Tunaberg ...... 1·00476
> the Sound ..... 1·00701
> the Scaw point . 1·02037

Water from Tunaberg contains just one-seventh of the salt contained in the water of the Frith of Forth.

† Tournefort's Voyages, ii. 410.   ‡ Marcet.

§ Mem. Par. 1778, p. 69.

‖ Nicholson's Jour. xx. 25. The constituents of sulphate of lime, and of sulphate of barytes, being taken by Dr. Marcet from the erroneous analysis of Chenevix, will make a small error in the quantity of sulphate of lime ; but the quantity of this salt contained in the water

The water of this lake, therefore, ought to be distin- Chap. III. guished from sea water; and might with propriety be included among *mineral* waters. Dr. Marcet found the constituents of the river Jordan, which flows into the Dead Sea, similar, but the salts do not exceed $\frac{1}{800}$th part of the solid contents.

CHAP. III.

OF MINERAL WATERS.

ALL waters which are distinguished from common water Mineral by a peculiar smell, taste, colour, &c. and which in con- waters explained. sequence of these properties cannot be applied to the purposes of domestic economy, have been distinguished by the appellation of *mineral waters*. These occur more or less frequently in different parts of the earth, constituting wells, springs, or fountains; sometimes of the temperature of the soil through which they pass, sometimes warm, and in some cases even at the boiling temperature. Many of these mineral springs attracted the attention of mankind in the earliest ages, and were resorted to by those who laboured under diseases, and employed by them either externally or internally as a medicine. But it was not till towards the end of the 17th century that any attempt was made to detect the ingredients of which these waters were composed, or to discover the substances to which they owed their properties.

Mr. Boyle may be considered as the first person who Attempts pointed out the method of examining water. He first as- to analyse them. certained the existence of air in it, and pointed out a number of tests, by means of which conjectures might be made concerning the saline bodies which the water examined held in solution. In 1665, Dominic du Clos attempted to examine the different mineral waters in France. He employed almost all the re-agents recommended by Boyle, and likewise added several of his own. In 1680,

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is so small, that the error may be reckoned immaterial. I have omitted Klaproth's analysis as less accurate than Marcet's. See Annals of Philosophy, i. 36.

Book II. Hierne published a set of experiments on the mineral waters of Sweden. Soon after various improvements were introduced by Regis, Didier, Burlet, and Homberg; and in 1726 Bouldoc pointed out a method of precipitating several of the saline contents of water by means of alcohol. But it was not till after the discovery of carbonic acid by Dr. Black, that any considerable progress was made in ascertaining the composition of mineral waters. That subtile acid which is so often contained in them, and which serves as a solvent to many of the earths and even metallic bodies, had thwarted all the attempts of former chemists to detect the composition of these liquids. Since the discovery of that acid, the analysis of mineral waters has advanced with great rapidity, in consequence chiefly of the admirable dissertation on the analysis of mineral waters published by Bergman in 1778. Since that period much has been done by the labours of Gioanetti, Black, Klaproth, Westrumb, Fourcroy, Brezé, Kirwan, and many other eminent chemists. So that notwithstanding the difficulty of the subject, scarcely any branch of chemistry has made greater progress, or is farther advanced than the knowledge of mineral waters. Of late indeed Dr. Murray of Edinburgh has published a general formula, applicable to the analysis of mineral waters in general, and considerably simplifying the labour of analysis.

Constituents. The substances hitherto found in mineral waters amount to about 38, and may be reduced under the four following heads: 1. Air and its component parts, oxygen and azotic gas. 2. Acids. 3. Alkalies and earths. 4. Salts.

1. Air. I. 1. Air is contained in by far the greater number of mineral waters: its proportion does not exceed $\frac{1}{28}$th of the bulk of the water.

2. Oxygen gas was first detected in waters by Scheele. Its quantity is usually inconsiderable; and it is incompatible with the presence of sulphureted hydrogen gas or iron.

3. Azotic gas was first detected in Buxton water by Dr. Pearson. Afterwards it was discovered in Harrowgate waters by Dr. Garnet, and in those of Limington Priors by Dr. Lambe.

2. Acids. II. The only acids hitherto found in waters, except in

combination with a base, are the four following: carbonic, sulphurous, boracic, and sulphureted hydrogen gas.

1. Carbonic acid was first discovered in Pyrmont water by Dr. Brownrigg. It is the most common ingredient in mineral waters, 100 cubic inches of the water generally containing from 6 to 40 cubic inches of this acid gas. According to Westrumb, 100 cubic inches of Pyrmont water contain 187 cubic inches of it, or almost double its own bulk.

2. Sulphurous acid has been observed in several of the hot mineral waters in Italy, which are in the neighbourhood of volcanoes.

3. The boracic acid has also been observed in some lakes in Italy.

4. Sulphureted hydrogen gas constitutes the most conspicuous ingredient in those waters which are distinguished by the name of hepatic or sulphureous.

III. The only alkali which has been observed in mineral waters, uncombined, is soda; and the only earthy bodies are silica and lime.

1. Dr. Black detected soda in the hot mineral waters of Geyzer and Rykum in Iceland; but in most other cases the soda is combined with carbonic acid. 3. Alkalies and earths.

2. Silica was first observed in waters by Bergman. It was afterwards detected in those of Geyzer and Rykum by Dr. Black, and in those of Carlsbad by Klaproth. Hassenfratz observed it in the waters of Pougues, and Brezé in those of Pu. It has been found also in many other mineral waters.

3. Lime is said to have been found uncombined in some mineral waters: but this has not been proved in a satisfactory manner.

IV. The only salts hitherto found in mineral waters are the following, *sulphates, nitrates, muriates, carbonates,* and *hydrosulphurets :* 4. Salts.

1. Sulphate of soda	9. Nitrate of lime
2. ....ammonia	10. .... magnesia
3. ....lime	11. Muriate of potash
4. ....magnesia	12. .... soda
5. ....alumina	13. .... ammonia
6. ....iron	14. .... barytes
7. ....copper	15. .... lime
8. Nitrate of potash	16. .... magnesia

17. Muriate of alumina   23. Carbonate of magnesia
18. .... manganese   24. .... alumina
19. Carbonate of potash   25. .... iron
20. .... soda   26. Hydrosulph. of lime
21. .... ammonia   27. .... potash
22. .... lime   28. And likewise borax

Of these genera the carbonates and muriates occur by far most commonly, and the nitrates most rarely.

1. Sulphate of soda is not uncommon, especially in those mineral waters which are distinguished by the epithet *saline.*

2. Sulphate of ammonia is found in mineral waters near volcanoes.

3. Sulphate of lime is exceedingly common in water. Its presence seems to have been first detected by Dr. Lister in 1682. It would seem to be generally formed during the evaporation of mineral waters by the action of sulphate of soda on muriate of lime.

4. Sulphate of magnesia is almost constantly an ingredient in those mineral water which have purgative properties. It was detected in Epsom waters in 1610, and in 1696 Dr. Grew published a treatise on it.

5. Alum is sometimes found in mineral waters, but it is exceedingly rare.

6 and 7. Sulphate of iron occurs sometimes in volcanic mineral waters, and has even been observed in other places. But sulphate of copper is only found in the waters which issue from copper mines.

8. Nitre has been found in some springs in Hungary; but it is exceedingly uncommon.

9. Nitrate of lime was first detected in water by Dr. Home of Edinburgh in 1756. It is said to occur in some springs in the sandy deserts of Arabia.

10. Nitrate of magnesia is said to have been found in some springs.

11. Muriate of potash is uncommon; but it has been discovered in the mineral springs of Uhleaborg in Sweden by Julin.

12. Muriate of soda is so exceedingly common in mineral waters, that hardly a single spring has been analysed without detecting some of it.

13. Muriate of ammonia is uncommon; but it has been found in some mineral springs in Italy and in Siberia.

14. Muriate of barytes is still more uncommon; but its presence in mineral waters has been announced by Bergman.

15 and 16. Muriates of lime and magnesia are common ingredients.

17. Muriate of alumina has been observed in waters by Dr. Withering; but it is very uncommon.

18. Muriate of manganese was mentioned by Bergman as sometimes occurring in mineral waters. It has lately been detected by Lambe in the waters of Lemington Priors; but in an extremely limited proportion, and by Dr. Scudamore in the water of Tunbridge Wells.

19. The presence of carbonate of potash in mineral waters has been mentioned by several chemists: if it does occur, it must be in a very small proportion.

20. But carbonate of soda is, perhaps, the most common ingredient of these liquids, if we except common salt and carbonate of lime.

21. Carbonate of ammonia has been discovered in waters; but it is uncommon.

22. Carbonate of lime is found in almost all waters, and is usually held in solution by an excess of acid. It appears from the different experiments of chemists, as stated by Mr. Kirwan, and especially from those of Berthollet, that water saturated with carbonic acid is capable of holding in solution 0·002 of carbonate of lime. Now water saturated with carbonic acid, at the temperature of 50°, contains very nearly 0·002 of its weight of carbonic acid. Hence it follows that carbonic acid, when present in such quantity as to saturate water, is capable of holding its own weight of carbonate of lime in solution. Thus we see that 1000 parts by weight of water, when it contains two parts of carbonic acid, is capable of dissolving two parts of carbonate of lime. When the proportion of water is increased, it is capable of holding the carbonate of lime in solution, even when the proportion of carbonic acid united with it is diminished. Thus 24,000 parts of water are capable of holding two parts of carbonate of lime in solution, even when they contain only one part of carbonic acid. The greater the proportion of water, the smaller proportion of carbonic acid is necessary to keep the lime in solution; and when the water is increased to a certain proportion, no sensible excess of

carbonic acid is necessary to keep the lime in solution; and when the water is increased to a certain proportion, no sensible excess of carbonic acid is necessary. It ought to be remarked also, that water, how small a quantity soever of carbonic acid it contains, is capable of holding carbonate of lime in solution, provided the weight of the carbonic acid present exceed that of the lime.* These observations apply equally to the other earthy carbonates held in solution by mineral waters.

23. Carbonate of magnesia is also very common in mineral waters, and is almost always accompanied by carbonate of lime.

24. Carbonate of alumina is said to have been found in waters; but its presence has not been properly ascertained.

25. But carbonate of iron is by no means uncommon; indeed it forms the most remarkable ingredient in those waters which are distinguished by the epithet of *chalybeate*.

26 and 27. The hydrosulphurets of lime and of soda have been frequently detected in those waters which are called sulphureous or hepatic.

28. Borax exists in some lakes in Persia and Thibet; but the nature of these waters has not been ascertained.†

5. Vegetable and animal matter. Besides these substances, certain vegetable and animal matters have been occasionally observed in mineral waters. But in most cases these are rather to be considered in the light of accidental mixtures than of real component parts of the waters in which they occur.

From the above enumeration, we are enabled to form a pretty accurate idea of the substances which occur in mineral waters; but this is by no means sufficient to make us acquainted with these liquids. No mineral water contains all of these substances. Seldom are there more than five or six of them present together, and hardly ever do they exceed the number of eight or ten. The proportion too, in which they enter into mineral waters is generally small, and in many cases extremely so. Now in order to understand the nature of mineral waters, it is necessary to know the substances which most usually associate together, and the proportion in which they commonly associate. In the

* Kirwan on Mineral Waters, p. 15.   † Ibid. p. 8, &c.

greater part of mineral waters there is usually some sub-stance present, which, from its greater proportion, or its greater activity, stamps, as it were, the character of the water, and gives it those properties by which it is most readily distinguished. This substance of course claims the greatest attention, while the other bodies which enter in a smaller proportion may vary, or even be absent altogether, without producing any sensible change in the nature of the water. This circumstance enables us to divide mineral waters into classes, distinguished by the peculiar substance which predominates in each. Accordingly they have been divided into four classes ; namely,

Mineral waters divided into four classes.

1. Acidulous,
2. Chalybeate,
3. Hepatic,
4. Saline.

Let us take a view of each of these classes.

1. The acidulous waters contain a considerable propor-tion of carbonic acid. They are easily distinguished by their acid taste, and by their sparkling like champaign wine when poured into a glass. They contain almost constantly some common salt, and in general also a greater or smaller pro-portion of the earthy carbonates.

1. Acidulous.

2. The chalybeate waters contain a portion of iron, and are easily distinguished by the property which they have of striking a black with the tincture of nutgalls. The iron is usually held in solution by carbonic acid. It very often happens that this acid is in excess; in which case the waters are not only chalybeate but acidulous. This is the case with the waters of Spa and Pyrmont. In some instances the iron is in the state of a sulphate; but this is uncommon. Waters containing the sulphate of iron may be readily dis-tinguished by the property which they have of continuing to strike a black with tincture of nutgalls even after being boiled and filtered; whereas boiling decomposes the car-bonate of iron, and causes its base to precipitate.

2. Chalybeate.

3. The hepatic or sulphureous waters are those which contain sulphureted hydrogen gas. These waters are easily distinguished by the odour of sulphureted hydrogen gas which they exhale, and by the property which they have of blackening silver and lead. The nature of the waters be-longing to this class long puzzled chemists. Though they often deposite sulphur spontaneously, yet no sulphur could

3. Hepatic.

Book II.   be artificially separated from them.   The secret was at last
discovered by Bergman.   These waters are of two kinds:
in the first the sulphureted hydrogen is uncombined; in
the second it is united to lime or an alkali.   They are fre-
quently also impregnated with carbonic acid, and usually
contain some muriates or sulphates.

4. Saline.   4. Saline waters are those which contain only salts in
solution, without iron or carbonic acid in excess.   They
may be distinguished into four different orders.   The waters
belonging to the first order contain salts whose base is lime,
and generally either the carbonate or the sulphate.   They
are known by the name of hard waters, and have but a
slight disagreeable taste.   The waters belonging to the se-
cond order are those in which common salt predominates.
They are readily recognised by their salt taste, and like sea
water usually contain some magnesian and calcareous salts.
The waters of the third order contain sulphate of magnesia.
They have a bitter taste and are purgative.   Finally, the
waters of the fourth order are alkaline, containing carbonate
of soda.   They are easily distinguished by the property
which they have of tinging vegetable blues green.

Such is a short view of the different classes of mineral
waters.   A particular description of each particular spring
would be inconsistent with the plan of this work.*   But a
pretty accurate notion may be formed of the salts which
most commonly associate, and of the proportions of each,
from the following Table, which exhibits a synoptical view
of the component parts of a considerable number of mineral
waters, as analysed by different chemists.

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* The reader will find an accurate account of the properties and con-
stituents of the most celebrated mineral springs, both British and fo-
reign, in Dr. Saunders's Treatise on the Chemical History and Medical
Powers of the most celebrated Mineral Waters.   From this excellent
work I have borrowed several of the analyses which appear in the ensu-
ing table in the text.

			Gases, Cubic inches.			Carbonates of				Muriates of				Sulphates of					
	Water.	Oxygen	Carbonic acid.	Sulph. hydrog.	Azotic.	Soda.	Lime.	Mag.	Iron.	Soda.	Lime.	Mag.	Pot-ash.	Soda.	Lime.	Mag.	Silica.	Alumina.	Resin.
Seltzer[1]	8949	·435	13·068	—	—	5·22	78·3	6·32	—	13·74	—	—	—	—	—	—	—	—	—
Spa[1]	8933	—	9·8	—	—	1·85	1·85	4·35	0·70	0·21	—	—	—	—	—	—	—	—	—
Pyrmont[1]	8950	—	19·6	—	—	—	4·3	9·8	0·70	1·7	—	—	—	—	8·38	5·44	—	—	—
Aix la Chapelle[1]	8940	—	—	13·06	—	15·25	5·98	—	—	6·21	0·11	—	—	—	—	—	—	—	—
Medvi[1]	8933	—	6·53	8·71	—	38·5	—	—	0·92	—	—	—	—	66·75	—	—	2·25	—	—
Carlsbad[2]	25320	—	50·	—	—	—	12·5	—	0·14¼	32·5	—	11·5	—	15·2	112·	—	—	—	—
Leming Priors[3]	5816	—	·5	—	3·5	—	—	—	·75	430·	—	—	—	—	—	—	3·2	0·35	—
Pouges[4]	9216	—	16·7	—	—	10·4	12·4	1·2	—	2·2	—	—	—	—	33·3	—	—	—	—
Enghien[5]	92160	—	18·5	70·	—	—	21·4	1·35	—	2·4	—	8·0	—	—	14·03	5·8	—	0·48	—
Lu[6]	36864	—	5·	2·	—	—	10·22	—	—	36·74	9·25	—	—	—	—	—	0·23	—	—
Geyzer[7]	10000	—	—	—	—	0·95*	1·9	—	1·2	2·46	—	—	—	1·46	0·8	—	5·4	—	·6
Uhleaborg[8]	42250	—	0·	—	—	—	16·5	—	—	5·7	—	—	—	—	—	—	1·7	—	—
Teplisz[9]	22540	—	—	—	—	13·25	2·4	1·25	32·5	61·3	28·5	12·8	—	28·2	13·0	—	15·1	—	—
Kilburu[10]	138240	—	84·	36·	—	—	13·5	—	·3⅜	6·0	0·6	—	—	11·25	11·75	91·0	—	—	—
Bristol[11]	103643	3·	30·	—	—	—	—	—	—	4·	—	7·25	—	—	1·25	—	—	—	—
Tunbridge[12]	103643	1·4	10·6	—	4·	—	—	—	1·	0·5	—	2·25	—	480·‡	40·	—	—	—	—
Cheltenham[13]	103643	—	30·368	—	15·	—	—	—	5·	5·	13·	25·†	—	—	—	—	—	—	—
Harrowgate[14]	103643	—	8·	19·	7·	—	18·5	5·5	—	615·5	—	9·	—	—	—	0·5	—	—	—
Moffat[14]	103643	—	1·	10·	4·	—	—	—	—	3·6	—	—	—	—	—	—	—	—	—
Bath[15]	15360	—	2·4	—	—	—	1·6	—	0·004	6·6	—	—	—	3·	18·	—	0·4	—	—

1 Bergman.   2 Kiaproth.   3 Lambe, Man. Mem. v. 174.   4 Hassenfratz, Ann. de Chim. i. 81.   9 Fourcroy, ibid. vi. 172.

5 Breezé, ibid. x. 44.   7 Black.   8 Julin, Crell's Annals, 1797, ii. 373.   9 Jahn, ibid. i. 331.   10 Schmeisser, Phil. Trans. lxxxii. 127.

11 Dr. Carrick, Saunders on Miner. Waters, p. 118.   12 Dr. Babington, ibid. p. 241.   13 Fothergill, ibid.

14 Garnet, ibid. p. 524 and 33.   15 Philips, Phil. Mag. xxiv, 342.   * Pure soda.   † And sulphate of magnesia.   ‡ And carbonate.

CHAP. IV.

OF THE METHOD OF ANALYSING WATERS.

THE analysis of waters, or the art of ascertaining the different substances which they hold in solution, and of determining the proportion of these substances, is one of the most difficult things in chemistry. The difficulty arises not only from the diversity of the bodies which occur in waters, but from the very minute quantities of some of the ingredients. Though many attempts had been made to analyse particular waters, and several of these were remarkably well conducted, no general mode of analysis was known till Bergman published his Treatise on Mineral Waters in 1778. This excellent tract carried the subject all at once to a very high degree of perfection. The Bergmannian method has been followed by succeeding chemists, to whom we are indebted not only for a great number of very accurate analyses of mineral waters, but likewise for several improvements in the mode of conducting the analysis. Mr. Kirwan has in 1799 published an essay on the general analysis of waters, no less valuable than that of Bergman; containing all that has hitherto been done on the subject, and enriched by the numerous experiments of Mr. Kirwan himself. Mr. Kirwan has given a new method of analysis, which will probably be adopted hereafter; not only because it is shorter and easier than the Bergmannian, but because it is susceptible of a greater degree of accuracy. I propose in this chapter to give an account of this method, modified however by our recent improved knowledge of the constituents of the salts.

The analysis of waters resolves itself into two different branches: 1. The method of ascertaining all the different bodies contained in the water which we are examining. 2. The method of determining the exact proportion of each of these ingredients. These two branches form the subject of the two following sections.

SECT. I.

METHOD OF DETERMINING THE INGREDIENTS OF WATERS.

THE different bodies which are dissolved and combined in water, are discovered by the addition of certain substances to the water which is subjected to examination. The consequence of the addition is some change in the appearance of the water; and this change indicates the presence or the absence of the bodies suspected. The substances thus employed are distinguished by the name of *tests*, and are the instruments by means of which the analysis of water is accomplished. They were first introduced into chemistry by Boyle, and were gradually increased by succeeding chemists: but Bergman was the first who ascertained with precision the degree of confidence which can be placed in the different tests. They still continued rather uncertain and precarious, till Mr. Kirwan showed how they might be combined and arranged in such a manner as to give certain and precise indications whether or not any particular substance constitutes a component part of water. Let us consider by what means the presence or the absence of all the different substances which occur in waters may be ascertained.

I. The gaseous bodies contained in water are obtained by boiling it in a retort luted to a pneumatic apparatus. The method of separating and examining these different bodies shall be described in the next section.

II. the presence of *carbonic acid*, not combined with a base, or combined in excess, may be detected by the following tests: 1. Lime-water occasions a precipitate soluble with effervescence in muriatic acid. 2. The infusion of litmus is *reddened*; but the red colour gradually disappears, and may be again restored by the addition of more of the mineral water.* 3. When boiled it loses the property of reddening the infusion of litmus.

III. The mineral acids, when present uncombined in water, give the infusion of litmus a permanent red, even

Tests.

For gases.

Carbonic acid.

Mineral acids.

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* When the carbonic acid is uncombined with a base, it reddens the infusion of litmus, though it amounts to no more than one-sixteenth of the bulk of the water which contains it. When it is combined in excess with a base, it must amount to one-sixth of the bulk of the water to produce that effect.—See Kirwan on Mineral Waters, p. 35.

Book II. though the water has been boiled. Bergman has shown that a paper stained with litmus is reddened when dipped into water containing $\frac{1}{3522}$ of sulphuric acid.

Sulphureted hydrogen.

IV. Water containing sulphureted hydrogen gas is distinguished by the following properties: 1. It exhales the peculiar odour of sulphureted hydrogen gas. 2. It reddens the infusion of litmus fugaciously. 3. It blackens paper dipped into a solution of lead, and precipitates the nitrate of silver black or brown.

Alkaline and earthy carbonates.

V. Alkalies, and *alkaline* and *earthy carbonates*, are distinguished by the following tests: 1. The infusion of turmeric, or paper stained with turmeric, is rendered *brown* by alkalies, or reddish brown if the quantity be minute. This change is produced when the soda in water amounts only to $\frac{1}{2217}$ part.* 2. Paper stained with Brazil wood, or the infusion of Brazil wood, is rendered blue: but this change is produced also by the alkaline and earthy carbonates. Bergman ascertained that water containing $\frac{1}{9945}$ part of carbonate of soda renders paper stained with Brazil wood blue.† 3. Litmus paper reddened by vinegar is restored to its original blue colour. This change is produced by the alkaline and earthy carbonates also. 4. When these changes are fugacious, we may conclude that the alkali is ammonia.

Fixed alkalies.

VI. Fixed alkalies exist in water which occasions a precipitate with muriate of magnesia after being boiled. Volatile alkali may be distinguished by the smell, or it may be obtained in the receiver by distilling a portion of the water gently, and then it may be distinguished by the above tests.

Earthy and metallic carbonates.

VII. Earthy and metallic carbonates are precipitated by boiling the water containing them; except carbonate of magnesia, which is only precipitated imperfectly.

Iron.

VIII. Iron is discovered by the following tests: 1. The addition of tincture of nutgalls gives water containing iron a purple or black colour. This test indicates the presence

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* The same change is produced by lime water; but pure lime very seldom indeed occurs in mineral waters. It is needless to observe, that the alkalies produce the same effect on turmeric, whether they be pure or in the state of carbonates. The earthy carbonates have no effect on turmeric.

† Sulphate of lime likewise renders Brazil wood blue.

of a very minute portion of iron. If the tincture has no effect upon the water after boiling, though it colours it before, the iron is in the state of a carbonate. The following observations of Westrumb on the colour which iron gives to nutgalls, as modified by other bodies, deserve attention.

A violet indicates an alkaline carbonate or earthy salt.

Dark purple indicates other alkaline salts.

Purplish red indicates sulphureted hydrogen gas.*

Whitish and then black indicates sulphate of lime.

Mr. Philips has ascertained, that while the iron is in the state of protoxide, the presence of lime rather facilitates the application of this test; but the lime prevents the test from acting, provided the iron be in the state of peroxide.† 2. The prussian alkali occasions a blue precipitate in water containing iron. If an alkali be present, the blue precipitate does not appear unless the alkali be saturated with an acid.

IX. Sulphuric acid exists in waters which form a precipitate with the following saline solutions:

1. Muriate, nitrate, or acetate of barytes.
2. .... strontian.
3. .... lime.
4. Nitrate or acetate of lead.

Of these the most powerful by far is muriate of barytes, which is capable of detecting the presence of sulphuric acid uncombined, when it does not exceed the millionth part of the water. Acetate of lead is next in point of power. The muriates are more powerful than the nitrates. The calcareous salts are least powerful. All these tests are capable of indicating a much smaller proportion of uncombined sulphuric acid than when it is combined with a base.‡ To render muriate of barytes a certain test of sulphuric acid, the following precautions must be observed: 1. The muriate must be diluted. 2. The alkalies, or alkaline carbonates, if the water contain any, must be previously saturated with muriatic acid. 3. The precipitate must be insoluble in muriatic acid. 4. If boracic acid be suspected, muriate of strontian must be tried, which is not precipi-

* Or rather manganese, according to Kirwan.

† Phil. Mag. xxiv. 349.   ‡ Kirwan on Mineral Waters, p. 65.

tated by boracic acid. 5. The hydrosulphurets precipitate barytic solutions, but their presence is easily discovered by the smell.

Muriatic acid.

X. Muriatic acid is detected by nitrate of silver, which occasions a white precipitate or a cloud in water containing an exceedingly minute portion of this acid. To render this test certain, the following precautions are necessary: 1. The alkalies or carbonates must be previously saturated with nitric acid. 2. Sulphuric acid, if any be present, must be previously removed by means of nitrate of barytes. 3. The precipitate must be insoluble in nitric acid.

Boracic acid.

XI. Boracic acid is detected by means of acetate of lead, with which it forms a precipitate insoluble in acetic acid. But to render this test certain, the alkalies and earths must be previously saturated with acetic acid, and the sulphuric and muriatic acids removed by means of acetate of strontian and acetate of silver.

Barytes.

XII. Barytes is detected by the insoluble white precipitate which it forms with diluted sulphuric acid.

Lime.

XIII. Lime is detected by means of oxalic acid, which occasions a white precipitate in water containing a very minute proportion of this earth. To render this test decisive, the following precautions are necessary: 1. The mineral acids, if any be present, must be previously saturated with an alkali. 2. Barytes, if any be present, must be previously removed by means of sulphuric acid. 3. Oxalic acid precipitates magnesia but very slowly, whereas it precipitates lime instantly.

Magnesia and alumina.

XIV. Magnesia and alumina. The presence of these earths is ascertained by the following tests: 1. Pure ammonia precipitates them both, and no other earth, provided the carbonic acid has been previously separated by a mineral alkali and boiling. 2. Lime-water precipitates only these two earths, provided the carbonic acid be previously removed, and the sulphuric acid also, by means of nitrate of barytes.

The alumina may be separated from the magnesia after both have been precipitated together, either by boiling the precipitate in pure potash, which dissolves the alumina and leaves the magnesia; or the precipitate may be dissolved in muriatic acid, precipitated by an alkaline carbonate, dried in the temperature of 100°, and then exposed to the action

of diluted muriatic acid, which dissolves the magnesia Chap. IV. without touching the alumina.

XV. Silica may be ascertained by evaporating a portion Silica. of the water to dryness, and redissolving the precipitate in muriatic acid. The silica remains behind undissolved.

Such is the method of detecting the different substances commonly found in waters. But as these different substances are almost always combined together, so as to constitute particular salts, it is not sufficient to know in general what the substances are which are found in the water we are examining; we must know also in what manner they are combined. Thus it is not sufficient to know that lime forms an ingredient in a particular water; we must know also the acid with which it is united. Mr. Kirwan first pointed out how to accomplish this difficult task by means of tests. Let us take a short view of his method.

I. To ascertain the presence of the different sulphates. Sulphates.

The sulphates which occur in water are seven; but one of these, namely, *sulphate of copper*, is so uncommon, that it may be excluded altogether. The same remark applies to sulphate of ammonia. It is almost unnecessary to observe, that no sulphate need be looked for unless both its acid and base have been previously detected in the water.

1. Sulphate of soda may be detected by the following 1. Alkaline. method: Free the water to be examined of all earthy sulphates by evaporating it to one-half, and adding lime-water as long as any precipitate appears. By this means the earths will all be precipitated except lime, and the only remaining earthy sulphate will be sulphate of lime, which will be separated by evaporating the liquid till it becomes concentrated, and then dropping into it a little alcohol, and after filtration adding a little oxalic acid.

With the water thus purified, mix solution of lime. If a precipitate appears either immediately or on the addition of a little alcohol, it is a proof that sulphate of potash or of soda is present. Which of the two may be determined by mixing some of the purified water with acetate of barytes: sulphate of barytes precipitates. Filter and evaporate to dryness. Digest the residuum in alcohol. It will dissolve the alkaline acetate. Evaporate to dryness, and the dry salt will deliquesce if it be acetate of potash, but effloresce if it be acetate of soda.

2. Sulphate of lime may be detected by evaporating the water suspected to contain it to a few ounces. A precipitate appears, which, if it be sulphate of lime, is soluble in 500 parts of water; and the solution affords a precipitate with the muriate of barytes, oxalic acid, carbonate of magnesia, and with alcohol.

2. Calcareous.

3 Alum.

3. Alum may be detected by mixing carbonate of lime with the water suspected to contain it. If a precipitate appears, it indicates the presence of alum, or at least of sulphate of alumina; provided the water contains no muriate of barytes or metallic sulphates. The first of these salts is incompatible with alum. The second may be removed by the alkaline prussiates. When a precipitate is produced in water by muriate of lime, carbonate of lime, and muriate of magnesia, we may conclude that it contains alum or sulphate of alumina.

4. Magnesian.

4. Sulphate of magnesia may be detected by means of hydrosulphuret of strontian, which occasions an immediate precipitate with this salt and with no other; provided the water be previously deprived of alum, if any be present, by means of carbonate of lime, and provided also that it contains no uncombined acid, nor even carbonic acid.

5. Of iron.

5. Sulphate of iron is precipitated from water by alcohol, and then it may be easily recognised by its properties.

Muriates.

II. To ascertain the presence of the different muriates.

The muriates found in waters amount to eight, or to nine if muriate of iron be included. The most common by far is muriate of soda.

1. Alkaline.

1. Muriate of soda and of potash may be detected by the following method: separate the sulphuric acid by alcohol and nitrate of barytes. Decompose the earthy nitrates and muriates by adding sulphuric acid. Expel the excess of muriatic and nitric acids by heat. Separate the sulphates thus formed by alcohol and barytes water. The water thus purified can contain nothing but alkaline nitrates and muriates. If it forms a precipitate with acetate of silver, we may conclude that it contains muriate of soda or of potash. To ascertain which, evaporate the liquid thus precipitated to dryness; dissolve the acetate in alcohol. Evaporate to dryness. The salt will deliquesce if it be acetate of potash, but effloresce if it be acetate of soda.

2. Barytic.

2. Muriate of barytes may be detected by sulphuric

acid, as it is the only barytic salt hitherto found in waters.

3. Muriate of lime may be detected by the following method: free the water of sulphate of lime and other sulphates, by evaporating it to a few ounces, mixing it with spirit of wine, and adding last of all nitrate of barytes, as long as any precipitate appears. Filter off the water, evaporate to dryness, treat the dry mass with alcohol, evaporate the alcohol to dryness, and dissolve the residuum in water. If this solution gives a precipitate with acetate of silver and oxalic acid, it *may* contain muriate of lime. It must contain it in that case, if, after being treated with carbonate of lime, it gives no precipitate with ammonia. If it does, separate the lime by means of oxalic acid, filter and distil with a gentle heat. If the liquid in the receiver gives a precipitate with nitrate of silver, muriate of lime existed in the water.

4. Muriate of magnesia may be detected by separating all the sulphuric acid by means of nitrate of barytes. Filter, evaporate to dryness, and treat the dry mass with alcohol. Evaporate the alcohol solution to dryness, and dissolve the residuum in water. The muriate of magnesia, if the water contained any, will be found in this solution. Let us suppose that, by the tests formerly described, the presence of muriatic acid and of magnesia in this solution has been ascertained. In that case, if carbonate of lime affords no precipitate, and if sulphuric acid and evaporation, together with the addition of a little alcohol, occasion no precipitate, the solution contains only muriate of magnesia. If these tests give precipitates, we must separate the lime which is present by sulphuric acid and spirit of wine, and distil off the acid with which it was combined. Then the magnesia is to be separated by the oxalic acid and alcohol; and the acid with which it was united is to be distilled off. If the liquid in the retort gives a precipitate with nitrate of silver, the water contains muriate of magnesia.

5. Muriate of alumina may be discovered by saturating the water, if it contain an excess of alkali, with nitric acid, and separating the sulphuric acid by means of nitrate of barytes. If the liquid thus purified gives a precipitate with carbonate of lime, it contains muriate of alumina. The

Book II. muriate of iron or of manganese, if any be present, is also decomposed, and the iron precipitated by this salt. The precipitate may be dissolved in muriatic acid, and the alumina, iron, and manganese, if they be present, may be separated by the rules laid down in the next book.

Nitrates.   III. To ascertain the presence of the different nitrates. The nitrates but seldom occur in waters; when they do, they may be detected by the following rules:

1. Alkaline.   1. Alkaline nitrates may be detected by freeing the water examined from sulphuric acid by means of acetate of barytes, and from muriatic acid by acetate of silver. Evaporate the filtered liquid, and treat the dry mass with alcohol; what the alcohol leaves can consist only of the alkaline nitrates and acetate of lime. Dissolve it in water. If carbonate of magnesia occasions a precipitate, lime is present. Separate the lime by means of carbonate of magnesia. Filter and evaporate to dryness, and treat the dried mass with alcohol. The alcohol now leaves only the alkaline nitrates, which may be easily recognised, and distinguished by their respective properties.

2. Calcareous.   2. Nitrate of lime. To detect this salt, concentrate the water, and mix it with alcohol to separate the sulphates. Filter and distil off the alcohol; then separate the muriatic acid by acetate of silver. Filter, evaporate to dryness, and dissolve the residuum in alcohol. Evaporate to dryness, and dissolve the dry mass in water. If this last solution indicate the presence of lime by the usual tests, the water contained nitrate of lime.

3. Magnesian.   3. To detect nitrate of magnesia, the water is to be freed from sulphates and muriates exactly as described in the last paragraph. The liquid thus purified is to be evaporated to dryness, and the residuum treated with alcohol. The alcohol solution is to be evaporated to dryness, and the dry mass dissolved in water. To this solution potash is to be added as long as any precipitate appears. The solution filtered, and again evaporated to dryness, is to be treated with alcohol. If it leaves a residuum consisting of nitre (the only residuum which it can leave), the water contained nitrate of magnesia.

Such are the formulas by which Mr. Kirwan conceives that the presence of the different salts may be determined in mineral waters. But I am of opinion that these formulas

are of so difficult execution, and that they labour under so many imperfections, that it is not worth our while to have recourse to them. Dr. Murray's rule will in almost all cases lead to results fully as accurate as can be obtained by the most laborious repetition of these formulas. Dr. Murray's rule is as follows. Determine by precipitants the weights of the acids and bases present in a mineral water. Suppose these united in such a manner that they shall form the most soluble salts, these salts will constitute the true saline constituents of the water under examination.

SECT. II.

METHOD OF DETERMINING THE PROPORTIONS OF THE INGREDIENTS.

THE proportion of saline ingredients, held in solution by any water, may be in some measure estimated from its specific gravity. The lighter a water is, the less saline matter does it contain; and, on the other hand, the heavier it is, the greater is the proportion of saline contents. Mr. Kirwan has pointed out a very ingenious method of estimating the saline contents of a mineral water whose specific gravity is known; so that the error does not exceed one or two parts in the hundred. The method is this: subtract the specific gravity of pure water from the specific gravity of the mineral water examined (both expressed in whole numbers,) and multiply the remainder by 1·4. The product is the saline contents in a quantity of the water denoted by the number employed to indicate the specific gravity of distilled water. Thus let the water be of the specific gravity 1·079, or in whole numbers 1079. Then the specific gravity of distilled water will be 1000. And $\overline{1079 - 1000} \times 1\cdot4 = 110\cdot6 =$ saline contents in 1000 parts of the water in question; and consequently 110·6 in 100 parts of the same water.* This formula will often be of considerable use, as it serves as a kind of standard to which we may compare our analysis. The saline contents

* Kirwan on Mineral Waters, p. 145.

indicated by it are supposed to be freed from their water of crystallization; in which state only they ought to be considered, as Mr. Kirwan has very properly observed, when we speak of the saline contents of a mineral water.

But instead of trusting to this formula a better method is to weigh out a determinate weight of the water to be examined, 1000 grains for example, to evaporate it to dryness, and weigh the residue. This weight gives us the quantity of saline matter contained in 1000 grains of the mineral water under examination.

Having ascertained the proportion of saline contents in the water examined, and having by the tests described in the last section determined the particular substances which exist in it, let us now proceed to ascertain the proportion of each of these ingredients.

I. The different aerial fluids ought to be first separated and estimated. For this purpose a retort ought to be filled two-thirds with the water, and connected with a jar full of To estimate the gaseous bodies. mercury, standing over a mercurial trough. Let the water be made to boil for a quarter of an hour. The ærial fluids will pass over into the jar. When the apparatus is cool, the quantity of air expelled from the water may be determined either by bringing the mercury within and without the jar to a level; or, if that cannot be done, by reducing the air to the proper density by the formulas given in the first chapter of the last book. The air of the retort ought to be carefully subtracted, and the jar must be divided into cubic inches and tenths.

The only gaseous bodies contained in water are common air, oxygen gas, azotic gas, carbonic acid, sulphureted hydrogen gas, and sulphurous acid. The last two never exist in water together. The presence of either of them must be ascertained previously by the application of the proper tests. If sulphureted hydrogen gas be present, it will be mixed with the air contained in the glass jar, and must be separated before that air be examined. For this purpose, the jar must be carried into a tub of warm water, and nitric acid introduced, which will absorb the sulphureted hydrogen. The residuum is then to be again put into a mercurial jar and examined.

If the water contain sulphurous acid, this previous step is not necessary. Introduce into the gaseous mixture a

quantity of peroxide of lead in the state of powder. It will gradually absorb the sulphurous acid, and the diminu- tion of bulk will indicate the bulk of that acid gas present. A little potash afterwards let up into the gaseous mixture will absorb the carbonic acid gas, and the diminution of bulk will indicate its quantity.

The air which remains after the separation of the carbonic acid gas is to be examined by the different eudiometrical methods described in the last book.

When a water contains sulphureted hydrogen gas, the bulk of this gas is to be ascertained in the following manner : fill three-fourths of a jar with the water to be examined, and invert it in a water trough, and introduce a little nitrous gas. This gas, mixing with the air in the upper part of the jar, will form nitrous acid, which will render the water turbid, by decomposing the sulphureted hydro- gen and precipitating sulphur. Continue to add nitrous gas at intervals as long as red fumes appear, then turn up the jar and blow out the air. If the hepatic smell con- tinues, repeat this process. The sulphur precipitated in- dicates the proportion of hepatic gas in the water ; one grain of sulphur indicating the presence of three cubic inches of that gas.

II. After having estimated the gaseous bodies, the next step is to ascertain the proportions of the earthy carbonates. For this purpose it is necessary to deprive the water of its sulphureted hydrogen, if it contains any. This may be done, either by exposing it to the air for a considerable time, or by treating it with litharge. A sufficient quantity of the water thus purified (if necessary) is to be boiled for a quarter of an hour, and filtered when cool. The earthy carbonates remain on the filter.

The precipitate thus obtained may be carbonate of lime, of magnesia, of iron, of alumina ; or even sulphate of lime. Let us suppose all of these substances to be present together. Treat the mixture with diluted muriatic acid, which will dissolve the whole except the alumina and sul- phate of lime. Dry this residuum in a red heat, and note the weight. Then boil it in carbonate of soda : saturate the soda with muriatic acid, and boil the mixture for half an hour. Carbonate of lime and alumina precipitate. Dry this precipitate, and treat it with acetic acid. The

lime will be dissolved, and the alumina will remain. Dry it and weigh it. Its weight subtracted from the original weight gives the proportion of sulphate of lime.

The muriatic solution contains lime, magnesia, and iron. Add ammonia as long as a reddish precipitate appears. The iron and part of the magnesia are thus separated. Dry the precipitate, and expose it to the air for some time in a heat of 200°; than treat it with acetic acid to dissolve the magnesia, which solution is to be added to the muriatic solution. The iron is to be re-dissolved in muriatic acid, precipitated by an alkaline carbonate, dried and weighed.

Add sulphuric acid to the muriatic solution as long as any precipitate appears; then heat the solution, and concentrate. Heat the sulphate of lime thus obtained to redness, and weigh it: 100 grains of it are equivalent to 74 of carbonate of lime dried. Precipitate the magnesia by means of carbonate of soda. Dry it and weigh it. But as part remains in solution, evaporate to dryness, and wash the residuum with a sufficient quantity of distilled water to dissolve the muriate of soda and sulphate of lime, if any be still present. What remains behind is carbonate of magnesia. Weigh it, and add its weight to the former. The sulphate of lime, if any, must also be separated and weighed.*

III. Let us now consider the method of ascertaining the proportion of mineral acids or alkalies, if any be present uncombined. The acids which may be present (omitting the gaseous) are the sulphuric, muriatic, and boracic.

1. The proportion of sulphuric acid is easily determined. Saturate it with barytes water, and ignite the precipitate: 100 grains of sulphate of barytes thus formed indicate 34 of real sulphuric acid.

2. Precipitate the muriatic acid by nitrate of silver. Dry the precipitate and weigh it. Every 100 grains of it indicate the presence of 25·2 grains of muriatic acid.

3. Precipitate the boracic acid by means of acetate of lead. Decompose the borate of lead by boiling it in sulphuric acid. Evaporate to dryness. Dissolve the boracic

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* A better mode of separating the magnesia is by adding carbonate of ammonia and phosphate of ammonia to the solution as long as any precipitate falls. The magnesia is obtained in the state of phosphate of magnesia and ammonia.

acid in alcohol, and evaporate the solution; the acid left behind may be weighed.

4. To estimate the proportion of alkaline carbonate pre- And alkaline carbonates. sent in a water containing it, saturate it with sulphuric acid, and note the weight of real acid necessary. Now 100 grains of real sulphuric acid saturate 120 potash, and 80 soda.

IV. Let us now consider the method of ascertaining the To estimate sulphates. proportion of the different sulphates. These are six in number; the alkaline sulphates, and those of lime, alumina, magnesia, and iron.

1. The alkaline sulphates may be estimated by precipi- 1. Alkaline. tating their acid by means of nitrate of barytes, having previously freed the water of all other sulphates : for 100 grains of ignited sulphate of barytes indicate 61·2 grains of dried sulphate of soda; and 74·8 of dry sulphate of potash.

2. Sulphate of lime is easily estimated by evaporating the 2. Calcareous. liquid containing it to a few ounces (having previously saturated the earthy carbonates with nitric acid), and precipitating the sulphate of lime by means of weak alcohol. It may be then dried and weighed.

3. The quantity of alum may be estimated by precipi- 3. Aluminous. tating the alumina by carbonate of lime or of magnesia (if no lime be present in the liquid). Twelve grains of the alumina heated to incandescence indicate 100 of crystallized alum, or 49 of the dried salt.

4. Sulphate of magnesia may be estimated, provided no 4. Magnesian. other sulphate be present, by precipitating the acid by means of a barytic salt, as 100 parts of ignited sulphate of barytes indicate 51· of sulphate of magnesia. If sulphate of lime, and no other sulphate accompany it, this last may be decomposed, and the lime precipitated by carbonate of magnesia. The weight of the lime thus obtained enables us to ascertain the quantity of sulphate of lime contained in the water. The whole sulphuric acid is then to be precipitated by barytes. This gives the quantity of sulphuric acid; and substracting the portion which belongs to the sulphate of lime, there remains that which was combined with the magnesia, from which the sulphate of magnesia may be easily estimated.

If sulphate of soda be present, no earthy nitrate or muriate can exist. Therefore, if no other earthy sulphate be present, the magnesia may be precipitated by soda, dried,

Book II. and weighed; 33 grains of which indicate 100 grains of dried sulphate of magnesia. The same process succeeds when sulphate of lime accompanies these two sulphates; only in that case the precipitate, which consists both of lime and magnesia, is to be dissolved in sulphuric acid, evaporated to dryness, and treated with twice its weight of cold water; which dissolves the sulphate of magnesia, and leaves the other salt. Let the sulphate of magnesia be evaporated to dryness, exposed to a heat of 400°, and weighed. The same process succeeds if alum be present instead of sulphate of lime.

The precipitate in that case, previously dried, is to be treated with acetic acid, which dissolves the magnesia and leaves the alumina. The magnesia may be again precipitated, dried, and weighed. If sulphate of iron be present, it may be separated by exposing the water to the air for some days, and mixing with it a portion of alumina. Both the oxide of iron and the sulphate of alumina, thus formed, precipitate in the state of an insoluble powder. The sulphate of magnesia may then be estimated by the rules above explained.

5. Of iron.   5. Sulphate of iron may be estimated by precipitating the iron by means of prussic alkali, having previously determined the weight of the precipitate produced by the prussiate in a solution of a given weight of sulphate of iron in water. If muriate of iron be also present, which is a very rare case, it may be separated by evaporating the water to dryness, treating the residuum with alcohol, which dissolves the muriate, and leaves the sulphate. Or the sulphate may be estimated with precision by the rules laid down by Mr. Kirwan.*

Estimation of muriates.   V. Let us now consider the method of estimating the quantity of the different muriates which may exist in waters.

1. Alkaline.   If muriate of potash or of soda, without any other salt, exist in water, we have only to decompose them by nitrate of silver, and dry the precipitate; for 100 of muriate of silver indicate 52 of muriate of potash, and 41 of common salt.

The same process is to be followed if the alkaline carbonates be present; only these carbonates must be previously saturated with sulphuric acid; and we must precipitate the muriatic acid by means of sulphate of silver instead of ni-

* On Mineral Waters. p. 220.

trate. The presence of sulphate of soda does not injure the success of this process.

If muriate of ammonia accompany either of the fixed alkaline sulphates without the presence of any other salt, decompose the sal ammoniac by barytes water, expel the ammonia by boiling, precipitate the barytes by diluted sulphuric acid, saturate the muriatic acid with soda. The sulphate of barytes thus precipitated indicates the quantity of muriate of ammonia; 100 grains of sulphate indicating 45·5 grains of that salt. If sulphates be present in the solution, they ought to be previously separated.

If common salt be accompanied by muriate of lime, muriate of magnesia, muriate of alumina, or muriate of iron, or by all of these together, without any other salts, the earths may be precipitated by barytes water, and redissolved in muriatic acid. They are then to be separated from each other by the rules formerly laid down; and their weight being determined, indicates the quantity of every particular earthy muriate contained in the water. For 50 grains of lime indicate 98 of dried muriate of lime; 30 grains of magnesia indicate 71·5 of the muriate of that earth; and 2·125 grains of alumina indicate 6·75 of the muriate of alumina. The barytes is to be separated from the solution by sulphuric acid, and the muriatic acid expelled by heat, or saturated with soda; the common salt may then be ascertained by evaporation, subtracting in the last case the proportion of common salt indicated by the known quantity of muriatic acid from which the earths had been separated.

When sulphates and muriates exist together, they ought to be separated, either by precipitating the sulphates by means of alcohol, or by evaporating the whole to dryness, and dissolving the earthy muriates in alcohol. The salts thus separated may be estimated by the rules already laid down.

When alkaline and earthy muriates and sulphate of lime occur together, this last salt is to be decomposed by means of muriate of barytes. The precipitate ascertains the weight of sulphate of lime contained in the water. The estimation is then to be conducted as when nothing but muriates are present; only from the muriate of lime that proportion of muriate must be deducted which is known to have been formed by the infusion of the muriate of barytes.

When muriates of soda, magnesia, and alumina, are present together with sulphates of lime and magnesia, the water to be examined ought to be divided into two equal portions. To the one portion add carbonate of magnesia till the whole of the lime and alumina be precipitated. Ascertain the quantity of lime, which gives the proportion of sulphate of lime. Precipitate the sulphuric acid by muriate of barytes. This gives the quantity contained in the sulphate of magnesia and sulphate of lime; subtracting this last portion, we have the quantity of sulphate of magnesia.

From the second portion of water precipitate all the magnesia and alumina by means of lime water. The weight of these earths enables us to ascertain the weight of muriate of magnesia and of alumina contained in the water, subtracting that part of the magnesia which existed in the state of sulphate, as indicated by the examination of the first portion of water. After this estimation precipitate the sulphuric acid by barytes water, and the lime by carbonic acid. The liquid evaporated to dryness leaves the common salt.

Estimation of nitrates.
VI. It now only remains to explain the method of ascertaining the proportion of the nitrates which may exist in waters.

1. Alkaline.
1. When nitre accompanies sulphates and muriates without any other nitrate, the sulphates are to be decomposed by acetate of barytes, and the muriates by acetate of silver. The water, after filtration, is to be evaporated to dryness, and the residuum treated with alcohol, which dissolves the acetates and leaves the nitre; the quantity of which may be easily estimated. If an alkali be present, it ought to be previously saturated with sulphuric or muriatic acid.

2. Earthy.
2. If nitre, common salt, nitrate of lime, and muriate of lime or of magnesia, be present together, the water ought to be evaporated to dryness, and the dry mass treated with alcohol, which takes up the earthy salts. From the residuum, redissolved in water, the nitre may be separated, and estimated as in the last case. The alcohol solution is to be evaporated to dryness, and the residuum redissolved in water. Let us suppose it to contain muriate of magnesia, nitrate of lime, and muriate of lime. Precipitate the muriatic acid by nitrate of silver, which gives the proportion of muriate of magnesia and of lime.

3

Separate the magnesia by means of carbonate of lime, and Book III. note its quantity. This gives us the quantity of muriate of magnesia; and subtracting the muriatic acid contained in that salt from the whole acid indicated by the precipitate of silver, we have the proportion of muriate of lime. Lastly, saturate the lime added to precipitate the magnesia with nitric acid. Then precipitate the whole of the lime by sulphuric acid; and subtracting from the whole of the sulphate thus formed that portion formed by the carbonate of lime added, and by the lime contained in the muriate, the residuum gives us the lime contained in the original nitrate; and 34·5 grains of lime form 100 of dry nitrate of lime.

BOOK III.

OF MINERALS.

ALL the solid materials of which this globe of ours is composed have received the name of *Minerals*; and that branch of chemistry which treats of them is distinguished by the title of *Mineralogy*. These substances, without doubt, must have at all times attracted the attention of mankind; because from them alone are drawn the metals, stones, and other similar substances of indispensable use. But it is only very lately that the method of ascertaining the component parts of these substances was discovered, or that it was possible to describe them so as to be intelligible to others. From the ancients no information of any consequence on these topics is to be expected. The whole science of mineralogy has been created since the year 1770, and is at present advancing towards perfection with astonishing rapidity. New minerals are every day described and analysed, collections are every where forming, and travels of discovery are succeeding each other without intermission. The fruit of these labours has been the discovery of no less than five new earths and eight new metals; besides a vast number of useful minerals which had been formerly unknown or disregarded.

Mineralogy, as far as it is a chemical science, includes under it three different topics; namely, 1. An account of the properties and constituents of minerals. 2. An account

of the various combinations which these bodies form; or of *compound minerals*, as they have been called. 3. The art of analysing minerals. These three topics will occupy our attention in their order. But as a technical language has been adopted by mineralogists in their descriptions, it will be necessary, in the first place, in order to render this book intelligible, to premise a few observations on that subject.

CHAP. I.

OF THE DESCRIPTION OF MINERALS.

NOTHING at first sight appears easier than to describe a mineral, and yet in reality it is attended with a great deal of difficulty. The mineralogical descriptions of the ancients are so loose and inaccurate, that many of the minerals to which they allude cannot be ascertained; and consequently their observations, however valuable in themselves, are often, as far as respects us, altogether lost. It is obvious, that to distinguish a mineral from every other, we must either mention some peculiar property, or a collection of properties, which exist together in no other mineral. These properties must be described in terms rigidly accurate, which convey precise ideas of the very properties intended, and of no other properties. The smallest deviation from this would lead to confusion and uncertainty. Now it is impossible to describe minerals in this manner, unless there be a peculiar term for each of their properties, and unless this term be completely understood. Mineralogy therefore must have a language of its own; that is to say, it must have a *term* to denote every mineralogical property, and each of these terms must be accurately defined. The language of mineralogy was invented by the celebrated Werner of Freyberg, and first made known to the world by the publication of his treatise on the *External Characters of Minerals.*

The object of this celebrated philosopher was to invent a method of describing minerals with such precision, that every species could readily be recognised by those who were acquainted with the terms employed. For this purpose, it

was necessary to make use of those properties only which
presented themselves to our senses on inspecting the mineral. These accordingly were chosen, and called by Werner *external characters ;* because they may be ascertained without destroying the mineral examined. The following is a short sketch of the language invented by Werner, and employed by him in the description of minerals.*

He divides the characters of minerals into two kinds, namely, *general* and *particular.*

The general characters are the following : 1. Colour ; 2. Cohesion ; 3. Uunctuosity ; 4. Coldness ; 5. Weight ; 6. Smell ; 7. Taste.

The particular characters are the following : 1. Aspect of the surface ; 2. Aspect of the fracture ; 3. Aspect of the distinct concretions ; 4. General aspect ; 5. Hardness ; 6. Tenacity ; 7. Frangibility ; 8. Flexibility ; 9. Adhesion to the tongue ; 10. The sound.

I. GENERAL CHARACTERS.

I. COLOUR. The colours of minerals are extremely various. Colour. Werner conceives eight fundamental colours, and describes all the others as compounds of various proportions of these. The fundamental colours are,

1. Snow white. The colour of new fallen snow.
2. Ash grey. The colour of well burnt wood ashes.
3. Velvet black. The colour of black velvet.
4. Berlin blue. The colour of prussian blue.
5. Emerald green. The colour of the emerald.
6. Lemon yellow. The colour of ripe lemons.
7. Carmine red.
8. Chesnut brown. The colour of the ripe chesnut.

The following table exhibits the principal subordinat colours, placed in the order in which they pass into each other :

1. *Whites.*

Snow white.

Reddish white. Snow white with a little crimson red and ash grey.

* For a more complete view of this important subject, the reader is referred to Professor Jameson's treatise on the External Characters of Minerals.

Yellowish white. Snow white with a little lemon yellow and ash grey.

Silver white.   Yellowish white with a metallic lustre.

Greyish white.   Snow white with a little ash grey.

Greenish white.   Snow white with a little emerald green and ash grey.

Milk white. Snow white with a little Berlin blue and ash grey.

Tin white.   Milk white of a metallic lustre.

2. *Greys.*

Lead grey.   Ash grey with a little blue and the metallic lustre.

Bluish grey.   Ash grey with a little blue.

Smoke grey.   Ash grey with a little brown.

Pearl grey.   Ash grey with a little crimson red and blue.

Greenish grey.   Ash grey with a little emerald green, and sometimes a trace of yellow.

Yellowish grey.   Ash grey with lemon yellow and a trace of brown.

Ash grey.

Steel grey. Ash grey with a little blue and a metallic lustre.

3. *Blacks.*

Greyish black.   Velvet black with a little ash grey.

Iron black.   Darker than the preceding with a metallic lustre.

Velvet black.

Pitch black.   Velvet black with a little brown and yellow.

Raven black.   Velvet black with a little brown, yellow, and green.

Bluish black.   Velvet black with a little blue.

4. *Blues.*

Indigo blue.   Berlin blue with grey and a little black.

Berlin blue.

Azure blue.   Berlin blue with a little red.

Violet blue.   Berlin blue with much red and a little brown.

Plum blue.   The preceding with more red and a very little black.

Lavender blue.   Violet blue with a little grey.

Smalt blue.   Berlin blue with white, a little grey, and a trace of red.

Sky blue.   Berlin blue, white, and a little emerald green.

5. *Greens.*

Verdigris green.   Emerald green with much Berlin blue and a little white.

Sea green.   The preceding with a mixture of ash grey.

Mountain green.   Verdigris green with a little yellowish grey.

Emerald green.

Apple green.   Emerald green with a little greyish white.

Grass green.   Emerald green with a little lemon yellow.

Blackish green.   Green mixed with a considerable portion of black.

Pistachio green.   Emerald green with a little yellow and some brown.

Asparagus green.   Pistachio green with a little greyish white.

Olive green.   Grass green with much brown.

Oil green.   Pistachio green with much yellow and ash grey.

Siskin green.   Emerald green with much lemon yellow and a little white.

6. *Yellows.*

Sulphur yellow.   Lemon yellow with much emerald green and white.

Brass yellow.   The preceding with the metallic lustre and a little grey.

Straw yellow.   Sulphur yellow with much greyish white.

Bronze yellow,   Brass yellow with a little steel grey and a trace of reddish brown.

Wax yellow.   Lemon yellow, reddish brown, and a little ash grey.

Honey yellow.   Sulphur yellow with chesnut brown.

Lemon yellow.

Gold yellow.   Lemon yellow with the metallic lustre.

Ochre yellow.   Lemon yellow with a considerable quantity of chesnut brown.

Wine yellow. Lemon yellow with reddish brown and grey.

Cream or Isabella yellow. Lemon yellow with greyish white and a little brown and red.

Orange yellow. Lemon yellow with a little carmine red.

7. *Reds.*

Aurora red. Carmine red with much lemon yellow.

Hyacinth red. Carmine red with lemon yellow and a little brown.

Tile red. The preceding mixed with much greyish white.

Scarlet red. Carmine red with a very little lemon yellow.

Blood red. Scarlet red mixed with brownish black.

Flesh red. Blood red mixed with greyish white.

Copper red. The preceding nearly, with the metallic lustre.

Carmine red.

Cochineal red. Carmine red mixed with bluish grey.

Crimson red. Carmine red with a considerable portion of blue.

Columbine red. The preceding with more blue and a little black.

Rose red. Cochineal red mixed with white.

Peach blossom red. Crimson red mixed with white.

Cherry red. Crimson red mixed with a considerable portion of brownish black.

Brownish red. Blood red mixed with brown.

8. *Browns.*

Reddish brown. Chesnut brown with a little red and yellow.

Clove brown. Chesnut brown with cochineal red and a little black.

Hair brown. Clove brown with ash grey.

Broccoli brown. Clove brown with ash grey and blue.

Chesnut brown.

Yellowish brown. Chesnut brown with a considerable portion of lemon yellow.

Pinchbeck brown. The preceding with the metallic lustre.

Wood brown. Yellowish brown with much ash grey. Liver brown. Chesnut brown with olive green and ash grey.

Blackish brown. Chesnut brown and black.

In respect of *intensity*, colours are either *dark, deep, light,* or *pale.* When a colour cannot be referred to any of the preceding, but is a mixture of two, this is expressed by saying, that the prevailing one *inclines* towards the other, if it has only a small tint of it; *passes* into it, if it has a greater.

When the colour of the surface of a mineral differs from its internal colour, the origin of this difference is pointed out, and the kind of colour is described. Notice is taken also whether the surface reflects the prismatic spectrum, or reflects different brilliant colours, like the *opal*, when its position is altered.

When the original colour of a mineral is changed altogether, and it has assumed another, it is then said to be *tarnished.*

When different colours appear in the same mineral, they may be disposed in *clouds, dots, streaks, rings, veins, zones,* &c.

II. Cohesion. With respect to cohesion, minerals are Cohesion. either *solid, friable,* or *fluid.*

III. The Unctuosity. Minerals are distinguished into Unctuosity. *greasy* and *meagre.* The first have a certain degree of greasiness in the feel; the second not.

IV. Coldness. ⎫
 V. Specific gravity. ⎬ These characters require no
 VI. Smell. ⎪   particular description.
VII. Taste. ⎭

II. PARTICULAR CHARACTERS.

I. Aspect of the surface. In considering the external Surface. aspect or surface of a mineral, three things claim our attention; namely, 1. The *shape* of the mineral; 2. The kind of *surface;* 3. The *lustre* of the surface.

1. *External shape.*

The external shape is of four kinds: 1. Common; 2. Particular; 3. Regular; 4. Extraneous.

(1). *Common.* The form is said to be *common* when it is too irregular to be compared to the form of any other body.

When a mineral constitutes a part of a solid rock or compound stone, it is called *massive,* when its bulk is not less than a hazel nut; when smaller than this, it is said to be *disseminated.* When it occurs loose, it is either in *angular pieces,* in *grains,* in *plates,* or in *membranes.*

(2). *Particular.* The shape of a mineral is said to be particular when it can be referred to that of some known body. Such shapes are divided into five kinds; namely, *long, round, flat, cavernous,* and *entangled.*

The *long* are divided into the following: *Dentiform, filiform, capillary, reticulated, dendritic, coralloidal, stalactitic, cylindrical, tubiform, claviform, fruticose.* The *round* are the following: *Globular, botryoidal, reniform, tuberose, fusiform.* The *flat* are *specular,* in *leaves.* The *cavernous* are *cellular, perforated, corroded, amorphous, vesicular.* The *entangled* is *ramose.* The words in these cases indicate the particular shape which the mineral resembles.*

(3). *Regular.* The form of minerals is said to be regular when they occur crystallized.

(4). *Extraneous.* Under this head are included all the petrifications.

2. *External surface.*

The surface of minerals is, *Uneven,* having small unequal elevations and depressions; *granulated,* composed of small round elevations, like shagreen; *rough,* when the elevations felt are too small to be distinctly seen; *smooth, streaked; drusy,* coated with small crystals.

3. *External lustre.*

The lustre, in point of *intensity,* is of five kinds: 1. *Splendent,* when in full day light the lustre can be seen at a great distance; 2. *Shining,* when at a distance the light reflected is weak; 3. *Glistening,* when the lustre is only observable when the mineral is at no greater distance than an arm's length; 4. *Glimmering,* when the surface held near the eye

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* For a more minute account the reader is referred to Professor Jameson's treatise on the External Characters of Minerals.

in full day light presents a number of shining points;
5. *Dull*, when the surface has no lustre.

Lustre is of two kinds, the *metallic* and the *common*; the latter is subdivided into *semimetallic*, *adamantine*, *pearly*, *resinous*, *glassy*.

II. ASPECT OF THE FRACTURE. When a mineral is broken, the new surface exposed is called the *fracture*. Three things claim attention: 1. The *lustre* of the fracture; 2. The *kind* of fracture; 3. The *shape* of the fragments.

1. *Lustre of the fracture.*

This is called the *internal* lustre, and is distinguished in the same way as the external lustre.

2. *The kind of fracture.*

By this is meant the appearance which the internal surface of a mineral presents when broken, provided it be not fractured in the direction of one of the natural points of the mineral. This appearance obviously depends upon the texture of the mineral. The fracture is either, 1. *Compact*; 2. *Fibrous*; 3. *Radiated*; or, 4. *Foliated*.

(1). *Compact.* The fracture is called compact when all the parts of the internal surface are continuous. The small inequalities which occur in this fracture are thus distinguished: 1. *Splintery*, when on a surface nearly even small wedge-shaped or scaly parts are seen adhering by their thicker end, and allowing a little light to pass. 2. *Even*, destitute of perceptible inequalities. 3. *Conchoidal*, small roundish elevations and depressions like the print of shells. 4. *Uneven*, having many small, sharp, abrupt, irregular elevations and inequalities; and from the size of these, this fracture is denominated *coarse*, *small*, or *fine*. 5. *Earthy*, when the internal surface resembles dried earth. 6. *Hackly*, having many very minute sharp hooks, more sensible to the hand than the eye. This last fracture is peculiar to the metals.

(2). *Fibrous.* The fracture is called fibrous when the internal surface shows the mineral composed of fibres or threads adhering together, and too small to be measured. These fibres are either *straight* or *curved*, and they are disposed either in *parallels*, or they *diverge* from each other, or they are *interwoven* together.

(3). *Radiated.* The fracture is called radiated when the fibres are flattish and so large that their breadth admits of measurement. The internal surface in that case exhibits *striæ* or *channels.*

(4). *Foliated.* The fracture is called *foliated* when the mineral appears composed of thin plates whose surfaces are smooth and polished like the surface of a crystal. The plates may be either *large, small,* or *very small ; perfect* or *imperfect ; straight,* or *curved* in various ways. The direction of the plates, or the *clivage,* may be either simple, double, triple, &c.

3. *The shape of the fragments.*

By this is meant the shape of the pieces into which a mineral breaks when struck with a hammer. They are either, 1. *Regular ;* or, 2. *Irregular.*

(1). By *regular* fragments are meant those which have a geometrical form. They are usually the fragments of crystallized bodies; and are either *cubic, rhomboidal, trapezoidal, tetrahedral, octahedral,* or *dodecahedral.*

(2). By *irregular* are meant the fragments which have not a geometrical form. They are *wedge-shaped ; splintery,* thin, long, and pointed; *tabular,* thin, and broad, and sharp at the corners, as common slate ; or *indeterminate,* without any particular resemblance to any other body. The *edges* of indeterminate fragments are either *very sharp, sharp, sharpish,* or *blunt.*

Distinct concretions.   III. ASPECT OF THE DISTINCT CONCRETIONS. Distinct concretions are distinct masses, of which certain minerals are composed, which may be separated from each other without breaking through the solid part of the mineral. They are separated from each other by natural seams. Three particulars respecting these concretions are to be attended to: 1. Their *shape ;* 2. Their *surface ;* 3. Their *lustre.*

1. *Shape of the distinct concretions.*

There are three kinds of shapes: 1. The *granular.* When the length, breadth, and thickness of a distinct concretion are nearly equal, it is said to be granular. Such concretions may be either *round* or *angular ; large, coarse, small, fine.* 2. The *lamellar,* when the concretions consist

of plates laid upon each other, and adhereing more or less strongly. 3. The *columnar,* when the breadth and thickness are inconsiderable compared to the length.

2. *Surface of the distinct concretions.*

The surface is *smooth, rough, streaked, uneven,* &c.

3. *The lustre of the distinct concretions.*

It is distinguished in the same way as the external lustre.

IV. GENERAL ASPECT. Under this head three particulars are comprehended; namely, 1. The *transparency;* 2. The *streak;* 3. The *soiling.*

1. *The transparency.*

By transparency is meant the proportion of light which minerals are capable of transmitting. They are *transparent* when objects can be seen distinctly through them; *semi-transparent,* when objects are seen through them indistinctly; *translucent,* when light passes, but in so small a quantity that objects cannot be seen through them; *opaque,* when no light is transmitted.

When opaque minerals become transparent in water, they are called *hydrophanous.* When objects are seen double through a transparent mineral, it is said to *refract doubly.*

2. *The streak or scratch,*

Is the mark left when a mineral is scratched by any hard body, as the point of a knife. It is either *similar,* of the same colour with the mineral; or *dissimilar,* of a different colour.

3. *The soiling,*

Is the trace which some minerals leave when rubbed on the fingers or on paper. Some minerals leave a *stain* or trace, others not. Some of the first kind may be employed to write with, others not.

V. HARDNESS. By this is meant the resistance which a body opposes when we attempt to scratch it. Minerals are either, 1. *Hard;* 2. *Semihard* : 3. *Soft.*

(1.) Minerals are called *hard* when they do not yield to the knife, and strike fire with steel. There are three degrees of it; 1. *Extremely hard,* not yielding to the file;

Book III. 2. *Very hard*, yielding a little to the file: 3. *Hard*, yielding to the file.

(2.) Minerals are *semihard* when they yield with difficulty to the knife, and do not strike fire with steel.

(3.) *Soft*, when they yield easily to the knife, but not to the nail.

Tenacity. VI. TENACITY. With respect to tenacity, minerals are, 1. *Brittle*, when on being cut with a knife the particles fly away with noise; 2. *Sectile*, when on being cut with a knife the particles do not fly off, but remain; 3. *Ductile*, when the mineral can be cut into slices.

Frangibi-lity. VII. FRANGIBILITY. By this is meant the resistance which minerals make when we attempt to break them. The degrees are five; namely, 1. *Very tough;* 2. *Tough;* 3. *Moderately tough;* 4. *Fragile;* 5. *Very fragile.*

Flexibility. VIII. FLEXIBILITY. By this is meant the property of bending without breaking. Some minerals are, (1.) *Flexible*; and of these some are, 1. *Elastic;* others, 2. *Common.* (2.) Others *inflexible.*

Adherence. IX. ADHERENCE TO THE TONGUE. Some minerals adhere, 1. Very *strongly*; 2. Others *moderately;* 3. Others *slightly;* 4. And others very *slightly.*

Sound. X. By SOUND, is meant the peculiar noise emitted by some minerals when struck or bent. Some give a *ringing* sound; others a *grating* sound; others a *creaking* sound, as tin.

The particular properties of friable and fluid minerals require no description.

With respect to ELECTRICITY, some minerals become electric when *heated*, others when *rubbed*, others cannot be rendered electric. The electricity of some minerals is *positive* or *vitreous*, of others *negative* or *resinous.*

Blowpipe. The CHEMICAL properties of minerals will be understood without any explanation. In detecting them, the *blow-pipe* is often of singular use, as it enables us in a few minutes to determine many points which by the usual processes would occupy a great deal of time. The blowpipe is merely a tube ending in a cavity as fine as a small wire, through which air is forced and made to play upon the flame of a candle, by means of which the flame is concentrated and directed against small particles of the mineral to be examined, either placed upon a bit of charcoal, or in a platinum or silver

spoon. The air is either forced into the blowpipe by the lungs of the experimenter, or by means of bellows attached to the blowpipe. By thus exposing a very small portion of a mineral to the concentrated flame, we see the effect of heat upon it, and have an opportunity of trying the action of other bodies on it at a very high temperature, as of borax, soda, microcosmic salt, &c. The properties which these experiments bring into view, enable us in many cases to ascertain the nature, and even the component parts of a mineral.

The blowpipe was first introduced into mineralogy by Von Swab. It was afterwards improved by Cronstedt, and still farther by Bergman. Saussure substituted a fine splinter of cyanite for charcoal, cemented a very minute portion of the mineral to be examined to the point of this splinter, and exposed it in that situation to the action of the blowpipe. By this contrivance he was enabled to make his experiments upon very minute particles; and this enabled him to fuse many bodies formerly considered as infusible.

CHAP. II.

OF SIMPLE MINERALS.

AVICENNA, a writer of the 11th century, divided minerals into four classes; stones, salts, inflammable bodies, and metals.* This division has been, in some measure, followed by all succeeding writers. Linnæus, indeed, the first of the moderns who published a system of mineralogy, being guided by the external characters alone, divided minerals into three classes, *petræ, mineræ, fossilia :* but Avicenna's classes appear among his orders. The same remark may be made with respect to the systems of Wallerius, Wolsterdorf, Cartheuser, and Justi, which appeared in succession after the first publication of Linnæus's *Systema Naturæ*

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* Corpora mineralia in quatuor species dividuntur; scilicet, in lapides, et in liquefactiva, sulphurea, et sales. Et horum quædam sunt raræ substantiæ et debilis compositionis, et quædam fortis substantiæ, et quædam ductibilia, et quædam non. Avicenna *de Congelatione et Conglutinatione Lapidum,* chap. iii. *Theatrum Chemicum,* t. iv, p. 997.

in 1736. At last, in 1758, the system of Cronstedt appeared. He reinstated the classes of Avicenna in their place; and his system was adopted by Bergman, Kirwan, Werner, and the most celebrated mineralogists who have written since. These classes shall be adopted in the present Work, because none which are preferable have been hitherto proposed.

    I shall therefore divide minerals into four classes:

                 1. Stones;
                 2. Salts;
                 3. Combustibles;
                 4. Ores.

The first class comprehends all the minerals which are composed chiefly of earths; the second, all the combinations of acids and alkalies which occur in the mineral kingdom; the third, those minerals which are capable of combustion, and which consist chiefly of sulphur, carbon, and oil; the fourth, the mineral bodies which are composed chiefly of metals.

CLASS I. STONES.

THIS class naturally divides itself into two orders. The first order comprehends under it all the combinations composed entirely of earthy bodies, or of earthy bodies united with only a small portion of an alkali or metallic oxide: The second order consists of combinations of earthy bodies with acids. To the first order, for want of a better term, we shall give the appellation *earthy stones;* to the second, that of *saline stones.*

ORDER I. EARTHY STONES.

CRONSTEDT divided this order into nine genera, corresponding to nine earths; one of which he thought composed the stones arranged under each genus. The names of his genera were, *calcareæ, siliceæ, granatinæ, argillaceæ, micaceæ, fluores, asbestinæ, zeolithicæ, magnesiæ.* All his earths were afterwards found to be compounds, except the first, second, fourth, and ninth. Bergman, therefore, in his *Sciagraphia,* first published in 1782, reduced the number of genera to five; which was the number of primitive earths known when he wrote. Since that period five new earths have been discovered. Accordingly, in the latest

systems of mineralogy, the genera belonging to this order are proportionally increased. Each genus is named from an earth; and they are arranged in the latest Wernerian catalogues as follows:

1. Diamond genus.
2. Zircon genus.
3. Siliceous genus.
4. Argillaceous genus.
5. Magnesian genus.
6. Calcareous genus.
7. Barytic genus.
8. Strontian genus.
9. Hallite genus.

Under each genus, those stones are placed which are composed chiefly of the earth which gives a name to the genus, or which at least are supposed to possess the characters which distinguish that earth.

A little consideration will be sufficient to discover that there is no natural foundation for these genera. Most stones are composed of two, three, or even four ingredients; and, in many cases, the proportion of two or more of these is nearly equal. Now, under what genus soever such minerals are arranged, the earth which gives it a name must form the smallest part of their composition. Accordingly, it has not been so much the chemical composition, as the external character, which has guided the mineralogist in the distribution of his species. The genera cannot be said properly to have any character at all, nor the species to be connected by any thing else than an arbitrary title. This defect, which must be apparent in the most valuable systems of mineralogy, seems to have arisen chiefly from an attempt to combine together an artificial and natural system.

I have no doubt that Werner is fully aware of this defect, and that he is gradually correcting it. His arrangement of this order of minerals, as it has been recently improved, is entitled to considerable praise; but were he to omit the present genera altogether, and to substitute in their place those groups of minerals which he at present denominates *families*, I should consider it as far better than the mixture of two systems, one founded on the chemical, the other on the external characters, to which he still adheres. Every body must be sensible that *external characters* alone ought to influence us in the arrangement of minerals, and that those bodies ought to be placed nearest each other which

possess the greatest resemblance. It is extremely probable, that whenever the external characters coincide, so also does the composition; and that when chemists obtain a contrary result, the reason probably is, that they have given the *same* name to minerals possessed of *different* characters. The knowledge of the external characters must come first, and can alone enable us to discriminate correctly the proper specimens which ought to be subjected to analysis; for I include under this title Haüy's important discoveries relative to the primitive form of crystallized minerals.

I shall therefore adopt the Wernerian arrangement of this order, discarding the old genera and substituting the families in their place. The following table exhibits the different minerals of this order, arranged according to their families.*

I. *Diamond Family*
 Diamond
II. *Zircon Family*
 Zircon
III. *Ruby Family*
 Ceylanite
 Automalite
 Spinell
 Sapphire
 Corundum
 Emery
 Chrysoberyl
IV. *Schorl Family*
 Topaz
 Shorlite
 Pyrophysalite
 Euclase
 Emerald

 Iolite
 Schorl
 Fibrolite
V. *Epidote Family*
 Epidote
 Zoisite
 Anthophyllite
 Axinite
VI. *Garnet Family*
 Leucite
 Pyrineite
 Vesuvian
 Gahnite
 Grossularia
 Melanite
 Allochroite
 Collophonite
 Garnet

* Professor Jameson in the second edition of his System of Mineralogy, published last year, has adopted the method which I have here suggested. I have carefully examined his table, and adopted every novelty in it which I considered as an improvement. I have not introduced Berzelius's very ingenious chemical system, though I think of it very highly; because I conceive that mineralogy must be founded rather upon the external characters, and in particular on the crystallization than on the composition. The composition indeed would afford an accurate criterion of arrangement, if minerals were always pure and unmixed.

Aplome
Grenatite
Pyrope
Cinnamon-stone
VII. *Quartz Family*
    Quartz
    Steinheilite
    Cat's eye
    Iron flint
    Horn-stone
    Flinty-slate
    Flint
    Float-stone
    Calcedony
    Heliotrope
    Siliceous sinter
    Hyalite
    Opal
    Menilite
    Jasper
VIII. *Pitch-stone Family*
    Obsidian
    Pitch-stone
    Pearl-stone
    Pumice
IX. *Zeolite Family*
    Wavellite
    Prehnite
    Mesotype
    Stilbite
    Iberite
    Apophyllite
    Analcime
    Chabasite
    Cross-stone
    Lomonite
    Dipyre
    Natrolite
X. *Azurstone Family*
    Azure-stone
    Azurite
    Hauyne
    Blue spar

XI. *Felspar Family*
    Gehlenite
    Andaluzite
    Saussurite
    Chiastolite
    Indianite
    Felspar
    Ekebergite
    Spodumene
    Scapolite
    Bergmannite
    Elaolite
    Sodalite
    Meionite
    Nepheline
    Icespar
XII. *Clay Family*
    Aluminite
    Alum-stone
    Porcelain earth
    Common clay
    Clay-stone
    Adhesive slate
    Polishing slate
    Tripoli
XIII. *Clay-slate Family*
    Alum-slate
    Bituminous-slate
    Drawing-slate
    Whet-slate
    Clay-slate
XIV. *Mica Family*
    Lepidolite
    Mica
    Pinite
    Chlorite
XV. *Lithomarge Family*
    Green earth
    Pimelite
    Lithomarge
    Mountain soap
    Yellow earth
    Cimolite

Collyrite   Actynolite
XVI. *Soap-stone Family*   Tremolite
    Native magnesia   Cyanite
    Meerschaum   Rhætizite
    Bole   Schiller spar
    Sphragide   Diallage
    Fuller's earth   Bronzite
    Steatite   Hyperstene
    Agalmatolite   XIX. *Chrysolite Family*
XVII. *Talc Family*   Sahlite
    Nephrite   Augite
    Serpentine   Diopside
    Picrolite   Chrysolite
    Potstone   Olivine
    Talc   XX. *Basalt Family*
    Nacrite   Basalt
    Asbestus   Wacka
XVIII. *Hornblende Family*   Clinkstone
    Hornblende   Iron clay

The minerals belonging to this order possess the following common properties: a specific- gravity varying from 4·4 to 0·7. The greater number of them are hard enough to scratch glass; and this is always the case when the specific gravity exceeds 3·5. Some of them, however, are soft. None of them have the true metallic lustre; though some possess the false metallic lustre, which disappears on scratching them. None of them are soluble in water; and very few of them are soluble in acids without some particular mode of applying them. Hitherto it has been impossible for chemists to form any of them by art.

I. DIAMOND FAMILY.

Diamond family.

To this family there belongs only a single species; namely, the diamond, which is the hardest and the most beautiful of all the mineral productions.

Sp. 1. *Diamond*. This mineral, which was well known to the ancients, is found in different parts of Asia, particularly in the kingdoms of Golconda and Visapour. It occurs also in Brazil, but has hitherto been confined to countries within the tropics.

Its most common colours are white and grey, of various

shades. It occurs also blue, red, brown, yellow, and green. The colours are commonly pale. It is always crystallized; but sometimes so imperfectly, that at the first sight it might pass for amorphous. Its primitive form is a regular octa- hedron; but it more commonly assumes a spheroidal form, and then has usually 36 curvilinear triangular faces, six of which are raised upon each of the faces of the primitive octagon. Its integrant molecule, according to Haüy, is a regular tetrahedron.---For a more particular account of the crystals of this mineral, the reader is referred to Romé de Lisle,* Haüy,† and Professor Jameson.‡

The crystals are commonly small. Their surface is smooth or streaked, except when the mineral occurs in grains, when it is rough or at least uneven. External lustre from splendent to glimmering; internal always splendent. Fracture straight foliated. Cleavage fourfold, parallel to the faces of the octahedron. Fragments octahedral or tetrahedral. Seldom occur in distinct concretions. Transparency from transparent to translucent. Causes single refraction. Hardest body in nature. Brittle. Rather easily frangible. Specific gravity 3·5185 to 3·5310.§ When rubbed it becomes positively electric, even before it has been cut by the lapidary, which is not the case with any other gem.‖

Hitherto found only in the torrid zone, in East India, and in Brazil.

II. ZIRCON FAMILY.

The minerals belonging to this family approach the nearest to the diamond in their external characters. There is only 1 species, namely, the *zircon;* which is divided into two subspecies, common zircon and hyacinth.

Species 1. *Zircon.*

Subspecies 1. *Common Zircon.*

This mineral is usually brought from Ceylon; but it has been found in Norway, and in Galloway in Scotland.

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* Crystallog. ii. 191.   † Jour. de Min. No. xxix. 343.
‡ Mineralogy, i. 2.
§ Haüy, Jour. de Min. No. xxix. 343.   ‖ Ibid. 343.

Its usual colour is grey; but it occurs also green, blue, red, yellow, and brown. It is found most commonly in roundish pieces; but it is sometimes crystallized, either in four-sided prisms or flat octahedrons. The primitive form of its crystals is an octahedron, composed of two four-sided pyramids applied base to base, whose sides are isosceles triangles.* The inclination of the sides of the same pyramid to each other is 124° 12′; the inclination of the sides of one pyramid to those of another 82° 50′. The solid angle at the apex is 73° 44′.† The crystals are usually small, their surface smooth, and their lustre shining; but the roundish pieces are sometimes rough, and their lustre glistening. The internal lustre is splendent.

The fracture foliated with a six-fold cleavage according to Mohs. Fragments sharp-edged. Translucent or semi-transparent. Causes a very great double refraction. Softer than diamond and sapphyr, much· harder than quartz. Brittle. Rather easily frangible. Specific gravity 4·557 ‡ to 4·721.§

Subsp. 2. *Hyacinth.*

This mineral is brought from Ceylon, but found likewise in France and in other parts of Europe.

Its usual colour is a hyacinth red, but it occurs also reddish brown, grey, and orange yellow. The primitive form of its crystals is the same as the preceding. It usually occurs in four-sided prisms, terminated by four planes set on the lateral edges. The crystals are commonly small, but complete. Lateral planes smooth. Lustre shining. Internal lustre splendent and vitreous. Fracture straight foliated. Cleavage as in the preceding subspecies. Fragments sharp-edged. Transparency from transparent to translucent. Scratches quartz. Rather easily frangible. Feels a little greasy when cut. Before the blow-pipe loses its colour, but not its transparency. Infusible with soda or microcosmic salt. Melts with borax into a transparent glass.

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* According to Mohs it has a six-fold cleavage, and its primitive form is a four-sided rectangular prism, terminated by four-sided pyramids set on the lateral edges. This is also the most common variety of its crystallization.   † Haüy, Jour de Min. No. xxvi. 91.

‡ Klaproth, Beitrage, i.   § Lowry, Jameson's Mineralogy, i. 17.

The constituents of these minerals, as determined by the analyses of Klaproth and Vauquelin, are as follows:

Chrysolite family.

	Zircon.			Hyacinth.		
	*	†	‡	§	‖	‖
Zirconia	69·0	65	64·5	70	64·5	66
Silica	26·5	33	32·5	25	32·0	31
Iron oxide	0·5	1	1·5	0·5	2·0	2
Loss	4·0	1	1·5	4·5	1·5	1
	100	100	100	100	100	100

If we were to consider this mineral as a silicate of zirconia, it would follow, that an atom of zirconia weighs only 4·535, which is below the weight assigned in a preceding chapter of this work. But at present we are not in possession of good data to determine the point.

III. RUBY FAMILY.

The minerals belonging to this family are divided into seven species, namely, *ceylanite*, *automalite*, *spinell*, *sapphire*, *corundum*, *emery*, and *chrysoberyl*. They are all extremely hard, and several of them highly valued on account of their beauty.

Ruby family.

Sp. 1. *Ceylanite.***

Pleonaste of Haüy.

The mineral denominated *ceylanite*, from the island of Ceylon, from which it was brought into Europe, had been observed by Romé de Lisle; †† but was first described by

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* Klaproth's Beitrage, i. 222.　　† From Norway. Ibid. iii. 271.
‡ Klaproth's Ibid. v. 130. The specimen was from Circars in India.
§ From Ceylon. Ibid. i. 231.
‖ From Expailly. Vauquelin, Jour de Min. No. xxvi. 106.
** Brochant, ii. 525. Haüy's Miner. iii. 17. Bournon. Phil. Trans, 1802, p. 318. Jameson. i. 26.
†† Crystallog. iii. 180. Note 21.

La Metherie in the Journal de Physique for January 1793.

It is most commonly found in rounded masses; but sometimes also crystallized. The primitive form of its crystals is a regular octahedron: it often occurs under this form, but more commonly the edges of the octahedron are wanting, and small faces in their place.*

Colour appears dark indigo blue, passing into bluish black; but when closely examined proves greenish black. Surface rough. External lustre small; internal shining and splendent, resinous. Fracture perfect flat conchoidal. Fragments very sharp-edged. Scratches quartz slightly. Softer than spinell. Easily frangible. Specific gravity from 3·7647 to 3·7931.† Infusible *per se*.

Sp. 2. *Automolite.*

This mineral has hitherto been found only at Fahlun. It occurs in talc slate; and, what is singular, though this rock abounds in the neighbourhood of Fahlun, the automalite is found only in Eric Matt's mine. It appears to have been discovered by Assessor Gahn, about the year 1805, and was soon afterwards examined and analysed by Ekeberg and Berzelius, who each separately obtained the same constituents. An account of it was published by Ekeberg in 1806.‡

Its colour is dark green. Always crystallized in regular octahedrons, similar to the form of the spinell. The crystals are small. Longitudinal fracture foliated; cross fracture uneven and somewhat conchoidal. Opake, but in small pieces, translucent on the edges. When pounded, it becomes light green. Scratches quartz. Specific gravity 4·261.§ Not fusible by the blow-pipe. With borax it melts into a glass, green while hot, but colourless when cold. Its constituents are,

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* Haüy, Jour. de Min. No. xxxviii. 264.   † Haüy.

‡ Afhandlingar, i. 84.

§ Ekeberg, Afhandlingar, i. 88. Sometimes small specks of galena may be observed in the crystal. Its specific gravity is then 4·3714. It is doubtless owing to some such mixture that Haüy has made the specific gravity as high as 4·6969. See Lucas, ii. 237.

	*	†
Alumina	60	42
Silica	4·75	4
Zinc oxide	24·25	28
Iron oxide	9·25	5
Sulphur and loss ..	—	17
Loss	1·75	—
Undecomposed ...	—	4
	100	100

The name automolite (*deserter*) was applied to this mineral on account of the portion of zinc which it contains. As its crystalline form is the same with that of spinell, it was believed at first that automolite was merely spinell, with particles of *blende* mixed mechanically through the crystal. I have been even told by some that they could detect the mixture by the naked eye. But as the specific gravity of automolite is greater than either that of spinell or of blende, it is obvious that it must be something more than a mechanical mixture of the two: but if it be a chemical compound of the two, it is entitled to be regarded as a distinct species. Berzelius has given to this mineral the name of *Gahnite*. It is difficult to form a correct idea of its composition. I think Vauquelin's specimen must have been impure, as neither Ekeberg nor Berzelius detected any sulphur in this mineral.

Sp. 3. *Spinell.*

Spinell and *balass ruby* of Kirwan—*Rubis spinelle octoedre* of De Lisle—*Spinellus* of Gmelin.

This stone, which comes from the island of Ceylon, and which has been found also in the granular ejected limestone of Vesuvius, and in a limestone ‡ quarry belonging to the iron foundery at Oker in Sudermanland in Sweden, is usually crystallized. The form of its integrant particles is the tetrahedron. The primitive form of its crystals is a regular octahedron, composed of two four-sided pyramids applied base to base, each of the sides of which is an equilateral triangle. In some cases two opposite sides of the

Crystals.

* Ekeberg, Gehlen's Jour. v. 443.
† Vauquelin, Gehlen's Jour. Second series, ii. 38.
‡ This lime-stone is primitive as is obvious from Hisinger's account of the structure of that part of the country. Samling till en Mineralogisk Geografi öfver Sverige, p. 150.

Book III. pyramids are broader than the other two; and sometimes the edges of the octahedron are wanting, and narrow faces in their place. For figures and descriptions of these, and other varieties of these crystals, the reader is referred to *Romé de Lisle* and the *Abbé Estner.** It occurs also in tetrahedrons, in rhomboids whose faces have angles of 120° and 60°, in rhomboidal dodecahedrons, and in four-sided prisms terminated by four-sided pyramids.†

Colour red, passing on the one side to blue, and on the other to yellow and brown. From carmine red it passes into crimson, cochineal, and cherry-red; and into plum, violet, and indigo blue; and likewise into blood red, orange yellow, and reddish brown. Surface smooth. Lustre splendent, vitreous. Fracture perfect flat conchoidal, sometimes imperfectly foliated. Fragments sharp-edged. Transparent and translucent. Scratches quartz strongly. Scratched by sapphire. Specific gravity from 3·570 ‡ to 3·705.§ Infusible before the blow-pipe: melts with borax. The ancients seem to have classed this stone among their hyacinths. ‖

The following table exhibits the composition of ceylanite and spinell, according to the most accurate experiments hitherto made:

	Ceylanite.	Spinell.		
	**	††	‡‡	§§
Alumina................	68	74·5	82·47	72·25
Magnesia..............	12	8·25	8·78	14·63
Silica.................	2	15·5	——	5·48
Oxide of iron..........	16	1·5	——	4·26
Oxide of chromium......	—	——	6·57	——
Lime.................	—	0·75	——	——
Undetermined matter....	—	——	——	1·83
Loss.................	2	——	2·18	1·55
Total...........	100	100·5	100·00	100·00

* Crystall. ii. 226.   Estner's Miner. 73.   † Bournon.
‡ Klaproth.   § Lowry, Jameson's Mineralogy, i. 31.
‖ Plinii, lib. xxxvii. c. 9.
** Collet Descotills, Ann. de Chim. xxxiii. 11.
†† Klaproth, Beitrage, ii. 10.
‡‡ Vauquelin, Jour. de Men. No. xxxviii. 89.
§§ Berzelius, Afhandlingar, i. 99.

The essential constituents of spinell appear to be 1 atom of magnesia and 6 atoms of alumina. I have placed ceylanite along with it, because, if we leave out of view the oxide of iron, which may be only accidental, its constituents seem to be the same as those of spinell. In automolite oxide of zinc appears to be substituted for magnesia. Does the alumina in these minerals perform the part of an acid?

Sp. 4. *Sapphire.*

The stones usually called precious were first distinguished on account of their colour. Those that had a red colour were called *rubies*; the yellow were *topazes*; the blue, *sapphires*; and the purple *amethysts.* It was soon observed, however, that most of the properties for which these stones were valued were proportional to their hardness; and as the finest kind came from the east, it was usual with lapidaries to distinguish them by the epithet *oriental.* Mineralogists were accustomed to consider these stones as distinct species, till Romé de Lisle observed that they agreed in the form of their crystals, their hardness, and most of their other properties; and Werner made the same remark about the same time. These observations were sufficient to constitute them one species; and accordingly they were made one species by Romé de Lisle himself, by Kirwan, and several other modern mineralogical writers. Romé de Lisle gave the species the name of *ruby*; but this has been since confined to a different mineral. This induced Haüy to invent the new word *telesia*; but the term *sapphire*, appropriated to this species by Werner and Delametherie, was adopted by mineralogists in general.

Sapphire is found in the East Indies, especially in Pegu and the island of Ceylon; and it is most commonly crystallized. The crystals are of no great size: their primitive form, as has been demonstrated by Bournon, is a rhomboid, whose angles are 86° and 94°, and which, therefore, is nearly rectangular. Sometimes it occurs in this form, though but seldom. Bournon has described no less than eight modifications of it. We may consider the primitive form as composed of two trihedral pyramids united base to base, the solid angles of which are composed of three acute angles of the faces. The eight modifications are, 1. The summit of the pyramids is replaced by a face perpendicular

to the axis, and of various sizes. 2. The edges of the base of the primitive pyramids are replaced by faces parallel to the axis, which separates the pyramids by a six-sided prism with rhombic planes. Often this modification runs into a regular six-sided prism. 3. A decrement takes place on the flat angles of the base, which converts the pyramids to six-sided, so that the crystal is often a dodecahedron, composed of two six-sided pyramids applied base to base; but it is very seldom that both pyramids are complete. This modification is often combined with the second. 4. The solid angle at the summit is replaced by three faces, which sometimes become so large as to cause the faces of the primitive rhomboid to disappear, and converts the crystal into a secondary rhomboid, whose faces have angles of 114° and 66°. 5. A more rapid decrement of the same kind produces a rhomboid still more acute, the faces of which have angles of 117° and 63°. 6. Similar decrements, still more rapid, form a third rhomboid still more acute, whose faces have angles of 119° 14′ and 60° 46′. 7. The acute angles which rest upon the base of the primitive pyramids suffer a decrement, which converts the crystal into a six-sided prism, whose faces correspond with the solid angles of the base of the primitive pyramids. 8. A six-sided pyramid, the solid angle of whose summit measures 24°. Each of the edges of the pyramid is replaced by a small face, which makes the pyramid a dodecahedron.* The crystals are complete; planes often transversely streaked. Occurs often in small rolled pieces.

Colours blue and red. From Berlin blue it passes into indigo blue, and into azure, violet, lavender, lilac, and sky-blue, and deep green : from lilac blue into peach blossom, crimson, cochineal, and carmine-red : also into rose-red, reddish-white, and yellowish-white : from lavender-blue into pearl and bluish-grey, and bluish-white. Lustre, splendent, vitreous. Fracture conchoidal. Transparency from transparent to translucent. Causes only single refraction. Harder than all minerals, except the diamond. Easily frangible. Specific gravity from 3·916 to 4·283.† Infusible before the blow-pipe. Melts with borax without effervescence.

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* Phil. Trans. 1802, p. 250.　　　　† Lowry and Haüy.

Sp. 5. *Corundum.**

Corundum of Gmelin—*Adamantine spar* of Klaproth and Kirwan—*Corindon* of Haüy—*Corivindum* of Woodward.

Though *corundum* appears to have been known to Dr. Woodward, it may be said to have been first distinguished from other minerals by Dr. Black. In 1768, Mr. Berry, a lapidary in Edinburgh, received a box of it from Dr. Anderson, of Madras. Dr. Black ascertained that these specimens differed from all the stones known to Europeans; and, in consequence of its hardness, it obtained the name of *adamantine spar*. Notwithstanding this, it could scarcely be said to have been known to European mineralogists till Mr. Greville of London, who has done so much to promote the science of mineralogy, obtained specimens of it, in 1784, from India, and distributed them among the most eminent chemists, in order to be analysed. Mr. Greville also learned that its Indian name was corundum. It is found in Indostan, not far from the river Cavery, which is south of Madras, in a rocky matrix, of considerable hardness, partaking of the nature of the stone itself.† It occurs also in China, and in Ceylon, Ava, &c. The Count de Bournon pointed out the resemblance between this mineral and the sapphire, in a dissertation published by him and Mr. Greville in the Philosophical Transactions for 1798, and suggested it as probable that corundum may be only a variety of the sapphire; and that the seeming difference in their ingredients is owing to the impurity of those specimens of corundum which have hitherto been brought to Europe. This conjecture has been since confirmed by a subsequent dissertation of Bournon, and the chemical analysis of Chenevix.‡ Werner subdivides it into two species, namely *corundum* and *adamantine spar*; but in reality they seem to be only varieties, or at most subspecies of the same species. The chief difference exists in the colours. The first is found in India, the second in China.

* See Kirwan's Min. i. Klaproth in Beob. der Berlin, viii. 295, and Beitrage, i. 47. Mr. Greville and the Count de Bournon in the Philosophical Transactions 1798, p. 403, and in Nicholson's Jour. ii. 540, and iii. 5. Mr. Haüy, Jour. de Phys. xxx. 193, and Jour. de Min. No. xxviii. 262, and Mineral. iii. 1. Brochant, i. 356. Jameson, i. 41.

† Garrow and Greville, Nicholson's Jour. ii. 540.

‡ Phil. Trans. 1802, p. 233.

The colour of corundum is various shades of green, blue, red, and brown. It occurs massive, in rolled pieces, and crystallized. Crystals the same as in sapphire. Surface rough. External lustre dull; internal shining, vitreous. Fracture perfect, foliated. Cleavage fourfold. Fragments rhomboidal. Translucent. Scratches quartz. Easily frangible. Specific gravity 3·710[*] to 4·180.[†]

Sp. 6.   *Emery.*[‡]

This mineral is brought to Britain from the isle of Naxos, where it must exist in great abundance. It occurs also in Germany, Italy, and Spain. It is always in shapeless masses, and mixed with other minerals. It has been usually considered as an iron ore, because it is always contaminated with the oxide of that metal. Colour intermediate between greyish black and bluish grey. Lustre, glistening, adamantine. Fracture small-grained uneven, sometimes splintery. Fragments rather blunt-edged. Sometimes in fine grained distinct concretions. Opaque. Scarcely yields to the file. Difficultly frangible. Specific gravity about 4. This mineral is much used in polishing hard bodies.

The following table exhibits the composition of these minerals according to the best analysis hitherto made.

[*] Klaproth.   [†] Greville, Nicholson's Jour. iii. 11.
[‡] Jameson, i. 89.

	Sapphire			Corundum						Emery	
	*	+	+	‡	‡	§	§	‖	=	**	††
Alumina............	98·5	92	90	89·5	84	86·5	86·5	91	81·75	86	53·83
Silica.............	—	5·25	7	5·5	6·5	5·25	7·	5	12·125	3	12·66
Oxide of iron	1	1	1·2	1·25	7·5	6·5	4·	1·5	—	4	24·66
Oxide of titanium .	—	—	—	—	—	—	—	—	4	—	—
Lime	—	—	—	—	—	—	—	—	—	—	1·66
Water	—	—	—	—	—	—	—	—	0·937	—	—
Loss	0·5	1·75	1·8	3·75	2	1·75	2·5	2·5	1·188	7	7·19
	100	100	100	100	100	100	100	100	100	100	100

* Klaproth, Beitrage, i. 88.   ‡ Chevenix, Phil. Trans. 1802.   The first specimen was blue, the second red.

+ Klaproth, Beitrage, i. 73 and 77. The first from China, the second from India.

§ Chenevix, Phil. Trans. 1802. The first specimen from China, the second from Malabar, the third from the Carnatic.

‖ Gregor. The specimen was from Thibet.   ** Tennant, Phil. Trans. 1802, p. 400.

†† Vauquelin, Haüy's Tableau comparative, p. 155.

This table seems to show that the composition of sapphire, corundum, and emery is essentially the same. Sapphire is nearly in a state of purity; but the other two minerals are more or less contaminated by the admixture of foreign bodies. In all probability sapphire, supposing it absolutely pure would consist entirely of alumina. The specimen examined by Klaproth contained no other foreign body but 1 per cent of iron. If we take this analysis as the type of purity and compare the others with it, we shall be able to determine how much the other specimens were contaminated by foreign bodies.

Sp. 7.   *Chrysoberyl.*[*]

Cymophane of Haüy.

Hitherto this stone has been found only in Brazil, the island of Ceylon, and in Connecticut, in North America. Werner first made it a distinct species, and gave it the name which it now bears. It is usually found in round masses about the size of a pea, but it is sometimes also crystallized. The primitive form of its crystals is a four-sided rectangular prism, whose height is to its breadth as $\sqrt{3}$ to 1, and to its thickness as $\sqrt{2}$ to 1. The most common variety hitherto observed is an eight-sided prism, terminated by six-sided summits. Two of the faces of the prisms are hexagons, two are rectangles, and four trapeziums: two faces of the summits are rectangles, and the other four trapeziums. Sometimes two of the edges of the prism are wanting, and small faces in their place.[†]

Colour asparagus green, sometimes passing on the one hand to greenish white, and on the other to yellowish grey. External lustre of the crystals, shining; internal splendent, vitreous. Fracture perfect conchoidal. Fragments sharp-edged. Semi-transparent. Scratches quartz and beryl. Brittle. Easily frangible. Specific gravity by my trial 3·733. Infusible before the blow-pipe.

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[*] Kirwan, i. 262. Brochant. i. 167. Haüy, ii. 491. Jameson, i. 44.

[†] Haüy, Jour. de Min. No. xxi. 5.

Klaproth's analysis of this mineral is as follows :

Alumina................ 71·5
Silica .... 18·0
Lime .... 6·0
Oxide of iron .... 1·5
Loss................ 3
                      ___
                      100 *

I analysed it some years ago, but having accidentally lost the result I cannot state it here. But the only constituents I found were alumina, silica, and oxide of iron. I tried for lime to no purpose. It seems to be a compound of 4 atoms alumina and 1 atom silica.

IV. SCHORL FAMILY.

This family contains, 8 species, namely, *topaz, schorlite, pyrophysalite, euclase, emerald, iolite, schorl,* and *fibrolite.* Schorl family.

Sp. 1.   *Topaz.†*

Occidental ruby, topaz, and *sapphire.*

The name *topaz* has been restricted by Mr. Haüy to the stones called by mineralogists occidental ruby, topaz, and sapphire; which, agreeing in their crystallization and most of their properties, were arranged under one species by Mr. Romé de Lisle. The word *topaz,* derived from an island in the Red Sea, ‡ where the ancients used to find topazes, was applied by them to a mineral very different from ours. One variety of our topaz they denominated *chrysolite.*

The topaz is found in Saxony, Bohemia, Siberia, Brazil, Scotland, Cornwall, and New Holland, mixed with other minerals in granite rocks.

It is most commonly crystallized. The primitive form is an octahedron composed of two four-sided pyramids whose

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* Beitrage, i. 102.

† Kirwan's Min. i. 254. Pott, Mem. Berlin, 1747, p. 46. Margraff, ibid. 1776, p. 73 and 160. Henkel, Act. Acad. Nat. Cur. iv. 316. Brochant, i. 212. Jameson, i. 48.

‡ It got its name from τοπαζω, *to seek ;* because the island was often surrounded with fog, and therefore difficult to find. See Plinii lib. xxxvii. c. 8.

base is a rectangle applied base to base. But it occurs most commonly in eight-sided prisms, the terminations of which are somewhat complicated. For a description I refer to Haüy.

Colour wine yellow. From pale wine yellow it passes into yellowish white, greenish white, mountain green, sky blue: from deep wine yellow into flesh red and crimson red. Lustre splendent, vitreous. Cross fracture perfect straight foliated; longitudinal, small imperfect conchoidal. Fragments sharp-edged, sometimes tabular and splintery. Often transparent, sometimes only translucent. It causes a double refraction. Scratches quartz, but is scratched by spinell. Very easily frangible. Specific gravity from 3·464 to 3·641.* The Siberian and Brazil topazes, when heated, become positively electrified on one side, and negatively on the other.† It is infusible by the blow-pipe. The yellow topaz of Brazil becomes red when exposed to a strong heat in a crucible; that of Saxony becomes white by the same process. This shows us that the colouring matter of these two stones is different.

Sp. 2.   Schorlite.‡

Schorlous beryl of Werner—*Leucolite* of Daubenton—
Pycnite of Haüy.

This stone, which received its name from Mr. Klaproth, is generally found in oblong masses, which when regular are six-sided prisms inserted in granite. It is found at Altenberg in Saxony, in a primitive rock, and likewise in Crystals. other places. By careful mechanical division, small four-sided prisms, whose bases are rhombs with angles of 120° and 60°, may be obtained from the larger specimens. These Bucholz considers as the primitive form of the schorlite. The crystals commonly large.

The colour is white of various shades, passing, on the one hand, through greyish white, and yellowish white, into straw yellow, and, on the other, through reddish white into peach blossom, and even crimson red. Some specimens are marked with spots of violet blue. Lustre shining

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* Werner and Lowry.   † Haüy, Jour. de Min. No. xxviii. 387.
‡ Brochant, i. 224. Haüy, iii. 236. Jameson, i. 58. Bucholz, Gehlen's Jour. ii. 15.

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resinous. Cross fracture imperfect foliated; longitudinal imperfect small conchoidal. Composed of thin prismatic distinct concretions, which are longitudinally streaked. Translucent. Moderately hard. Brittle. Very easily frangible. Specific gravity from 3·503 to 3·530.*

Sp. 3. *Pyrophysalite.*

This mineral was discovered by Assessor Gahn, at Finbo, three quarters of a Swedish mile east from Fahlun, in Dalecarlia, where it occurs embedded in gneiss. The first account of it was published by Hisinger and Berzelius in 1806.† The description as drawn up by Hisinger is nearly as follows:

Colour white, sometimes with a shade of green. Usually in irregular pieces, sometimes approaching to the shape of a rhomboid. Fracture foliated. The cleavage appears to be triple; but two of them, which are parallel to the sides of the rhomboid, are very indistinct; while the third parallel to the axis of the rhomboid is very well defined. Fragments indeterminate, sharp-edged. Translucent on the edges. Scratches glass readily, but is itself scratched by quartz. Difficultly frangible. Specific gravity 3·451. The powder phosphoresces slightly when heated. Scarcely fusible before the blow-pipe, but becomes white and opaque, and small bubbles cover its surface, which burst when the heat is kept up. With borax it melts into a transparent and colourless glass; with soda it effervesces, and forms a porous mass.

Haüy considers the three preceding minerals, not as distinct species but as mere varieties. And if we attend to their properties, and to the following table exhibiting their composition, we can have little hesitation in adopting that opinion as correct:

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* Bucholz.   † Afhandlingar, i. 111.

	Topaz.						Pyrophy-solite.	Schorlite.		
	*	*	†	‡	‡	§	‖	**	††	‡‡
Alumina	59	47·5	48	58·38	57·45	57·74	48	49·5	52·6	51
Silica	35	44·5	30	34·01	34·24	34·36	34	43·	36·8	38·43
Fluoric acid	5	7·0	18	7·79	7·75	7·77	17	4	5·8	8·84
Lime	—	—	—	—	—	—	—	—	3·3	—
Oxide of iron	Trace	0·5	2	—	—	—	1	1	—	—
Water	—	—	—	—	—	—	—	1	1·5	—
Loss	1	0·5	2	—	0·56	0·13	—	1·5	—	1·73
	100	100	100	100·18	100	100	100	100	100	100

* Klaproth, Gehlen's Journal, iii. 592. The first specimen was a Saxon, the second a Brazilian topaz, † Vauquelin, Ibid. v. 481. Vauquelin analysed four specimens, a Saxon, a Siberian, and two Brazilian topazes. But the results so nearly coincide, that I have only given one, the Siberian. ‡ Berzelius, Afhandlingar, iv. 236. The first was a Brazilian, the second a Saxon topaz.

§ Berzelius, Ibid.   ‖ Bucholz, Gehlen's Journal, ii. 38.   ** Klaproth, Ibid. 2d series, v. 213.

†† Vauquelin, Jour. de Phys. lxii. 274.   ‡‡ Berzelius, Afhandlingar, iv. 251.

From Berzelius' analysis we see that the composition of topaz and pyrophysalite is absolutely the same. Schorlite contains less alumina and rather more silica and fluoric acid. It is not easy to form a correct idea of the composition of these minerals. Berzelius considers schorlite as A F l + 3 A S; that is, a compound of 1 atom of fluate of alumina and of 3 atoms of silicate of alumina; while topaz and pyrophysalite he considers as A² F l + 3 A S, that is a

compound of 1 atom of subfluate of alumina and 3 atoms of silicate of alumina. But the numbers which we have adopted for the weight of the atoms of the constituents of topaz do not agree with this notion. Berzelius' analysis indicates 1 atom fluoric acid, $4\frac{1}{2}$ atoms silica, and $7\frac{1}{2}$ atoms alumina. Probably the acids in topaz are fluosilicic and silicic. I suspect it to be a compound of 1 atom subfluosilicate of alumina and 3 atoms subsilicate of alumina. So that its symbol will be $A^2 F l^s + 3 A^2 S$.

Sp. 4. *Euclase.**

This stone, which was brought from Peru by Dombey, and which was afterwards found in Brazil, was at first confounded with the emerald, on account of its green colour. It is always crystallized. The primitive form of its crystals is a rectangular prism, whose bases are squares; but it usually occurs in four-sided oblique prisms, two angles of which are square, the others $130° 55'$, according to the measurement of Wollaston.

The crystals are longitudinally streaked. Colour mountain-green. Lustre splendent, vitreous. Longitudinal fracture foliated. Cleavage twofold. Cross fracture conchoidal. Causes a double refraction. Scratches quartz. Very easily frangible. Specific gravity 2·907.[†] Fusible before the blow-pipe into a white enamel. This mineral was subjected to an imperfect analysis by Vauquelin,[‡] who found its constituents as follows:

Silica. 36
Alumina 23
Glucina. 15
Oxide of iron . . . 5
Loss 21
                          ——
                          100

This analysis is too imperfect to enable us to determine the constitution of euclase. Its specific gravity is sufficient to show that it is specifically different from the emerald.

* Brochant, ii. 508. Haüy, ii. 531. Jameson, i. 64.
† Lowry.   ‡ Jour. de Phys. lxii. 317.

Sp. 5. *Emerald.*

Of this species there are two subspecies, namely, *emerald* and *beryl.*

Subsp. 1. *Emerald.**

Crystals.

This mineral comes chiefly from Peru; some specimens have been brought from Egypt. Dolomieu found it in the granite of Elba. Hitherto it has been found only crystallized. The primitive form of its crystals is a regular six-sided prism; and the form of its integrant molecules is a triangular prism, whose sides are squares, and bases equilateral triangles.† The most common variety of its crystals is the regular six-sided prism, sometimes with the edges of the prism, or of the bases, or the solid angles, or both, wanting, and small faces in their place.‡

Crystals short; lateral planes smooth, terminal planes rough. Colour emerald green of all intensities. Internal lustre between splendent and shining, vitreous. Fracture small imperfect conchoidal, with a concealed foliated fracture and four-fold cleavage. Fragments sharp-edged. Transparent or translucent. Causes double refraction. Scratches quartz with difficulty. Specific gravity from 2·600 § to 2·7755.‖

Subsp. 2. *Beryl.*

This mineral is found embedded in primitive rocks and veins in many parts of the world, especially in Siberia. It is crystallized in the same forms as the emerald. The crystals are long, have their lateral planes longitudinally streaked, their terminal planes smooth.

Its most common colour is green; from mountain green, it passes into apple, asparagus, oil green, honey-yellow; also into smalt and sky-blue. The colours are usually pale. Lustre shining, vitreous. Cross fracture between uneven and small imperfect conchoidal: longitudinal fracture foliated, with a four-fold cleavage. Fragments sharp-edged.

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* Kirwan, i. 247 and 248. Dolomieu, Magazin Encyclopædique, ii. 17 and 145; and Jour. de Min. No. xviii. 19. Klaproth's Beitrage, ii. 12. Brochant, i. 217. Haüy, ii. 516. Jameson, i. 67.

† Haüy, Jour. de Min. No. xix. 72.

‡ Romé de Lisle, ii. 445, and Haüy, ibid.   § Werner.   ‖ Haüy.

When massive it consists of thin prismatic distinct concre-
tions. Transparent; sometimes only translucent, and then
it exhibits cross rents. Causes double refraction. Nearly
as hard as topaz. Easily frangible. Specific gravity 2·650
to 2·759.*

These two minerals become electric by friction, but not
by heat. The powder does not phosphoresce when thrown
on a hot iron.† At 150° Wedgewood they melt into an
opaque coloured mass. According to Dolomieu, they are
fusible *per se* by the blow-pipe. ‡

The following table exhibits the composition of this spe-
cies, according to the most accurate analyses hitherto made.

	Emerald.		Beryl.		
	§	‖	**	††	‡‡
Silica	64·5	68·50	68	66·45	68·35
Alumina...........	16	15·75	15	16·75	17·60
Glucina...........	13	12·50	14	15·50	13·13
Oxide of chromium..	3·25	0·30	—	—	—
Oxide of iron.......	——	1·00	1	0·6	0·72
Oxide of tantalum...	——	——	—	——	0·27
Lime.............	1·6	0·25	2	——	——
Water	2	——	—	——	——
Loss	——	1·70	—	0·7	——
	100·35	100	100	100	100·07

From these analyses it follows that the constituents of
emerald and beryl are precisely the same, and that the only
essential constituents are silica, alumina, and glucina. It is
therefore a double silicate. It seems to be a compound of
1 atom of bisilicate of glucina and of 2 atoms of silicate of
alumina. Chromium is the colouring matter of the emerald
and iron of the beryl.

* Werner.   † Dolomieu, Jour. de Min. No. xviii. 19.   ‡ Ibid.
§ Vauquelin, Jour. de Min. No. xxxviii. 98.
‖ Klaproth, Beitrage, iii. 226.
** Vauquelin, Jour. de Min. No. xliii. 563.
†† Klaproth, Beitrage iii. 219.
‡‡ Berzelius, Afhandlingar, iv. 192. The specimen was from Broddbo.

Sp. 6. *Iolite.**

Dichroite of Cordier ; *Cordierite* of Lucas.

This mineral was brought to France from Grenada in Spain, where it occurs in two different places apparently in floëtz trap rocks. At Arendal in Norway it has been found lately imbedded in primitive trap. As its crystalline form has not been ascertained we cannot be certain that it is entitled to be considered as a peculiar species. I have placed it here however provisionally. It may contribute to draw the attention of mineralogists towards it.

Its colour is muddy violet-blue. When viewed in the direction of the axis of the crystal its colour is violet-blue, but when looked at in a direction perpendicular to the axis, its colour is yellowish-brown.

It is frequently crystallized in equilateral six-sided prisms with rough surfaces. Lustre shining and vitreous. Fracture usually small-grained uneven, sometimes imperfect conchoidal. Fragments sharp angular. Specific gravity 2·560.† Alternates from translucent to opaque. Scratches quartz with difficulty. Easily frangible. According to the analysis of Dr. Leopold Gmelin, the constituents of iolite are as follows :

Silica	42·6
Alumina	34·4
Magnesia	5·8
Lime	1·7
Protoxide of iron	15·0
Oxide of manganese	1·7

101·2 ‡

Sp. 7. *Schorl.*§

Tourmaline of Haüy.

The word *schorl* is said to be derived from the village of Schorlaw in Saxony, where the mineral to which that name was originally given was first observed.||

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* Jameson, i. 78. Lucas, ii. 219. + Cordier.
‡ Schweigger's Jour. xiv. 316.
§ Kirwan, i. 265. Haüy, iii. 31. Brochant, i. 226. Jameson, i. 80.
|| Jameson's Mineralogy, i. 124. First edition.

No word has been used by mineralogists with less limitation than *schorl*. It was first introduced into mineralogy by Cronstedt, to denote any stone of a columnar form, considerable hardness, and a specific gravity from 3 to 3·4. This description applied to a very great number of stones; and succeeding mineralogists, though they made the word more definite in its signification, left it still so general, that under the designation of *schorl* almost 20 distinct species of minerals were included. Werner first defined the word *schorl* precisely, and restricted it to one species of stones. It occurs commonly in granite, gneiss, and other similar rocks; often massive but very frequently crystallized. Primitive form of its crystals is an obtuse rhomboid; the solid angle at the summit of which is 139°, having rhombic faces, with angles of 114° 12' and 65° 48': but it usually occurs in three, six, eight, nine, or twelve-sided prisms, terminated by four or five-sided summits, variously truncated; for a description of which the reader is referred to *Haüy* * and *Bournon*.† The faces of the crystals are often convex.

Werner divides this species into two subspecies, distinguished chiefly by their colour, and the situation in which they are found. The subdivision is in some respects convenient, as it shortens description, especially in that branch of mineralogy which Werner has distinguished by the name of *geognosy*.

Subsp. 1. *Common schorl.*

Colour velvet black. Found massive, disseminated, and crystallized. Crystals three-sided prisms, having their lateral edges truncated; sometimes terminating in a pyramid. The crystals are mostly acicular. Lustre 2, vitreous. Fracture conchoidal, between imperfect and small grained uneven. Opaque. Often composed of thin prismatic distinct concretions. Streak grey. Hardness rather inferior to quartz. Specific gravity from 3·054 to 3·092. When heated to redness, its colour becomes brownish red; and at 127° Wedgewood, it is converted into a brownish compact enamel.‡

It often becomes electric when heated, precisely like the

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* Miner. iii. 34.   † Phil. Trans. 1802, p. 313.
‡ Kirwan's Min. i. 166.

succeeding subspecies; but sometimes, from its containing particles of iron, the experiment does not succeed.*

Subsp. 2. *Tourmaline.*†

This stone was first made known in Europe by specimens brought from Ceylon; but it is now found frequently forming a part of the composition of mountains. It is sometimes in amorphous pieces, but much more frequently crystallized in three or nine-sided prisms, with four-sided summits.

Principal colours green and brown. From leek green passes into pistachio and olive green; liver brown, yellowish and reddish brown; hyacinth and crimson red; violet, azure, berlin, and indigo blue. Found usually crystallized. Crystals three, six, or nine-sided prisms, variously truncated. Lateral faces usually striated longitudinally. Internal lustre splendent, vitreous. Cross fracture has a tendency to foliated; longitudinal, perfect conchoidal. Sometimes transparent, often opaque. Hard. Rather easily frangible. Specific gravity from 3·0704‡ to 3·155.§

When heated to 200° Fahrenheit, it becomes electric; one of the summits of the crystal negatively, the other positively.|| It reddens when heated; and is fusible *per se* with intumescence into a white or grey enamel.

The *siberite* of Lermina, called *daourite* by Lametherie, a mineral found in Siberia, is considered as merely a variety of schorl. The *rubellite* also is a red schorl.

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* Haüy, iii. 56.

† Kirwan, i. 271. Bergman, ii. 118, and v. 402. Gerhard Mem. Berl. 1777, p. 14. Haüy, Mem. Par. 1784, p. 270. Wilson, Phil. Trans. xli. 308. Æpinus, Recueil sur la Tourmaline. See also La Porterie, le Sapphir, l'Oeil de Chat, et la Tourmaline de Ceylon, demasqués. Brochant, i. 288. Sir William Watson has shown that the lyncurium of the ancients, as described by Theophrastus, must have been the tourmaline. Phil. Trans. 1759, p. 394.

‡ Haüy.   § Werner. || Æpinus.

The following table exhibits the most accurate experi- ments hitherto made to determine the composition of this mineral.

	*	†	‡	‡	§	||	||	**	**
Silica	36·50	35·125	36·50	36·75	40	43·50	42	42	45
Alumina	33·75	31·500	31·00	34·50	39	42·25	40	40	30
Magnesia	6·08	5·938	1·25	0·25	12·5	—	—	—	—
Oxide of iron	8·00	6·125	23·50	21·00	2	—	—	—	—
Oxide of manganese	Trace	Trace	Trace	Trace	3·84	1·50	7	7	13
Lime	0·25	0·062	—	—	—	0·10	—	—	—
Potash	—	—	5·50	6·00	—	—	—	—	—
Soda	—	—	—	—	—	9·00	10	10	10
Water	1·50	2·000	—	—	—	1·25	—	—	—
Loss	13·91	19·250	2·25	1·50	2·66	2·40	1	1	2
	100	100	100	100	100	100	100	100	100

* Bucholz, Schweigger's Journal, iii. 34. A black schorl from St. Gothardt.

† Bucholz, ibid. Another black schorl from St. Gothardt.

‡ Klaproth, Beitrage, v. 148. The first specimen from Eibenstock, the second from Spessart.

§ Vauquelin, Haüy, iii. 33.

|| Klaproth, Beitrage, v. 90. The first red schorl from Roschna, the second from Siberia.

** Vauquelin, Gehlen's Journal, v. 489. Both specimens were red tourmaline from Siberia; the first was transparent, the second blackish.

From these analyses it would appear that there is a marked distinction between the composition of rubellite and the other varieties of schorl. Rubellite contains no iron, but a notable quantity of manganese and soda, both of which are wanting in schorl. The great loss sustained by Bucholz in his analyses, though they were made with great care, and after the analyses of Klaproth and Vauquelin render the composition of schorl doubtful. If the loss were to be ascribed to potash it is not unlikely that the symbol for schorl is $f^2 S + 2 p^2 S + 3 A l^2 S$, while the symbol for rubellite is $m\,g\,S + 2\,Sod.\,S + 12\,A\,l\,S$. But these conclusions are little better than conjectural.

Sp. 8. *Fibrolite.**

This mineral was first observed by Bournon in the matrix of the imperfect corundum. Colour white or dirty grey. Hardness rather greater than that of quartz. Specific gravity 3·214. Texture fibrous. Cross fracture compact. Internal lustre glossy. Infusible by the blow-pipe. Usually in shapeless fragments. Bournon observed one specimen crystallized in a rhomboidal prism; the angles of whose faces were 80° and 100°. It is composed, according to Chenevix, of

<div align="center">

58·25　alumina

38·00　silica

3·75　a trace of iron and loss

─────

100·00†

</div>

It is a subsilicate of alumina.

V. EPIDOTE FAMILY.

This family contains only four species; namely, *epidote*, *zoisite*, *anthophyllite*, and *axinite*. If the two first be only varieties of the same species, as seems to be the case, this family will be reduced to three species.

Sp. 1. *Epidote.‡*

Delphinite of Saussure—*Pistacite* of Werner—*Thallite* of
Lametherie—*Acanticone, arendate* of Dendrada.

This mineral, which occurs in the fissures of mountains, was first observed in Dauphiny, afterwards in Germany, Norway, Scotland, and other countries.

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* Bournon, Phil. Trans. 1802, p. 289.　　　† Ibid. p. 335.
‡ Brochant, i. 510. Haüy, iii. 102. Jameson, i. 92.

It occurs massive and crystallized. The primitive form of its crystals· is a rectangular prism, whose bases are rhombs with angles of 114° 37′ and 65° 23′.* The most usual variety is an elongated four-sided prism (often flattened), terminated by four-sided incomplete pyramids; sometimes it occurs in regular six-sided prisms.† The crystals are often very slender; longitudinally streaked. Internal lustre shining. Fracture sometimes foliated, sometimes variously radiated. Fragments sometimes wedge-shaped and splintery. In coarse granular distinct concretions. Translucent; sometimes transparent. Hard. Easily frangible. Specific gravity from 3·407 to 3·46. Powder white or yellowish green, and feels dry. It does not become electric by heat. Before the blow-pipe froths and melts into a black slag. With borax it melts into a green bead.‡

Sp. 2. *Zoisite.* §

This mineral was introduced into the system by Werner, who named it from Baron Von Zois, the discoverer. It occurs in primitive mountains, and has been found in Carinthia and Baireuth, and likewise in Aberdeenshire in Scotland. Haüy considered it as a variety of epidote.

Colour yellowish grey, sometimes smoke grey. Massive and crystallized in very oblique four-sided prisms, having their obtuse angles rounded off. Crystals longitudinally streaked. Internal lustre shining, inclining to pearly. Fracture foliated; in massive pieces, inclines to radiated. Only a single cleavage parallel to the shorter diagonal of the prism hitherto discovered. Shows a tendency to thin columnar distinct concretions. Translucent. Specific gravity 3·315.‖

The following table exhibits the experiments hitherto made to determine the composition of these minerals.

* Haüy, Jour. de Min. xxviii. 271.
† Romé de Lisle, Crystall. ii. 401, and Haüy, Jour. de Min. No. xxx. 415.
‡ Haüy and Descotils, Jour. de Min. No. xxx. 415.
§ Jameson, ii. 597.
‖ Klaproth, Gehlen's Jour. Second Series, i. 195.

	Epidote.			Zoisite.			
	*	†	‡	§	§	‖	**
Silica..............	37	37	37	45	47·5	40·25	44·0
Alumina	27	21	26·6	29	29·5	30·25	32·0
Lime	14	15	20	21	17·5	22·50	20·0
Oxide of iron	17	24	13	3	4·5	4·50	2·5
Oxide of manganese.	1·5	1·5	0·6	—	—	—	Trace
Moisture	—	—	1.8	—	0·75	2·00	—
Loss	3·5	1·5	1	2	0·25	0·50	1·5
	100	100	100	100	100	100	100

The specimens of epidote seem to have been pure, as the results in the above table accord very nearly, except in the oxide of iron, which is probably often mixed with other minerals. Berzelius considers it as $C S + 2 f S + A S$ or a compound of 1 atom silicate of lime, 2 atoms silicate of iron, and 3 atoms silicate of alumina. Zoisite is probably epidote mixed with a quantity of extraneous matter.

<div style="text-align:center">Sp. 3. <i>Anthophyllite.</i>††</div>

This mineral was first observed at Kongsberg in Norway, and described by Schumacher.

Colour light hair brown, passing into clove brown. Massive. It occurs also in thin flat six-sided prisms, longitudinally streaked, and wanting the extremity. Lustre splendent, adamantine. Fracture straight fibrous. Fragments approaching to four-sided prisms. In granular distinct concretions. Crystals transparent, massive pieces translucent on the edges. Streak white. Semihard in a high degree. Remarkably brittle. Specific gravity 3·156. Powder white with a shade of yellow. When exposed in a crucible to the temperature of 32° Wedgewood it becomes opaque and

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* Descotils, Jour. de Min. No. xxx. 420.
† Vauquelin, Haüy, iii. 104.   ‡ Laugier, Ann. de Chim. lxix. 320.
§ Klaproth, Gehlen's Jour. Second Series, i. 197.
‖ Bucholz, Ibid. p. 201.
** Klaproth, Beitrage, v. 43. The specimen was of friable zoisite.
†† Karsten and John, Gehlen's Jour. Second series. 2·496. De-la-Metherie. Jour. de Phys. lxiv. 356. Jameson ii. 42.

dark clove brown; but its other qualities remain unaltered. Infusible before the blow-pipe alone, but with borax it melts into a grass green transparent bead. With microcosmic salt it melts into an oil green bead. With fixed alkali it melts readily.

Its composition according to the analysis of John is as follows:

Silica	56
Alumina	13·3
Magnesia	14
Lime	3·33
Oxide of iron	6
Oxide of manganese	3
Water	1·43
Loss	2·94
	100·00 *

Sp. 4. *Axinite.*†

Yanolite of Lametherie—*Axinite* of Haüy—
Thummerstone of the Germans.

This stone was first described by Mr. Schreber, who found it near Balme d'Auris in Dauphiné, and gave it the name of *shorl violé.*‡ It was afterwards found near Thum in Saxony, in consequence of which Werner called it *thummerstone.*

It is sometimes massive; but more commonly crystallized. The primitive form of its crystals is a rectangular prism, whose bases are parallelograms with angles of 101° 32′ and 78° 28′.§ The most usual variety is a flat rhomboidal parallelopiped, with two of its opposite edges wanting, and a small face in place of each.‖ The faces of the parallelopiped are generally streaked longitudinally.

Common colour clove brown; it passes on the one hand to plum blue, on the other to pearl and ash-grey, and greyish black. External lustre splendent; internal shining, vitreous. Fracture fine-grained uneven. Fragments sharp-

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* Chem. Untersuchungen, i. 200.

† Kirwan, i. 273. Pelletier, Jour. de Phys. xxvi. 66. Brochant, i. 236. Haüy, iii. 22. Jameson, i. 103.   ‡ Romé de Lisle, ii. 353.

§ Haüy, Jour. de Min. No. xxviii. 264.   ‖ Romé de Lisle, ii. 353.

Book III. edged. Massive varieties occur in curved lamellar distinct concretions. From transparent to translucent. Hard; yields to the file. Very easily frangible. Specific gravity from 3·213 to 3·300.* Before the blow-pipe it froths like zeolite, and melts into a hard black enamel. With borax it exhibits the same phenomena, or even when the stone is simply heated at the end of a pincer.†

The following table exhibits the analyses hitherto made to determine the composition of this mineral:

	‡	§	‖
Silica	52·7	44	50·5
Alumina..............	25·6	18	16·
Lime..................	9·4	19	17·
Oxide of iron	9·6	14	9·5
Oxide of manganese..	—	4	5·25
Soda	—	—	0·25
Loss	2·7	1	1·5
	100	100	100

VI. GARNET FAMILY.

This family contains the following 12 species; *leucite, pyrenite, vesuvian, gahnite, grossularia, melanite, allochroite, garnet, aplome, grenatite, pyrope,* and *cinnamon stone.*

Sp. 1.   *Leucite.***

Vesuvian of Kirwan—*White Garnet* of Vesuvius—
Amphigene of Haüy.

This stone is usually found in volcanic productions, and is very abundant in the neighbourhood of Vesuvius. It is always crystallized. The primitive form of its crystals is either a cube or a rhomboidal dodecahedron, and its integrant molecules are tetrahedrons; but the va-

* Haüy.   † Vauquelin, Jour. de Min. No. xxiii. 1.
‡ Klaproth, Beitrage, ii. 126.
§ Vauquelin, Jour. de Min. No. xxiii. 1.
‖ Klaproth, Beitrage, v. 28.
** Kirwan, i. 285. Brochant, i. 188. Haüy, ii. 559. Jameson, i. 107.

rieties hitherto observed are all polyhedrons. The most common has a spheroidal figure, and is bounded by 24 equal and similar trapezoids; sometimes the faces are 12, 18, 36, 54, and triangular, pentagonal, &c. For a description and figure of several of these, I refer the reader to Mr. Haüy.* The crystals vary from the size of a pin-head to that of an inch.

Colour yellowish and greyish white; very seldom reddish white. Internal lustre shining, vitreous. Fracture imperfect flat conchoidal, sometimes inclines to foliated. Fragments sharp-edged. Translucent. Scratches glass with difficulty. Brittle. Rather easily frangible. Specific gravity from 2·455 to 2·490.† Its powder causes syrup of violets to assume a green colour.‡ Infusible by the blow-pipe. Gives a white transparent glass with borax.

The constituents of this species are as follows:

	§	‖
Silica	54	 56
Alumina..	24	 20
Potash ...	21	 20
Lime	—	 2
Loss	1	 2
	100	100

It is obvious that leucite is a compound of 1 atom of bisilicate of potash, and 3 atoms of bisilicate of alumina. Its symbol is $P S^2 + 3 A S^2$.

Sp. 2. *Pyrenite.***

This mineral is found embedded in primitive lime-stone in the Pic Enes-Lids, near Bareges in France. It was separated from garnet, and made a peculiar species by Werner.

Its colour is greyish black. It occurs massive and crystallized in rhomboidal dodecahedrons. Externally the

* Jour. de Min. No. xxvii. 185.
† Klaproth, Beitrage, ii. 41 and 55.
‡ Vauquelin, Jour. de Min. No. xxxix. 165.
§ Klaproth, Beitrage, ii. 50.   ‖ Vauquelin.
** Jameson, ii. 419.

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crystals are glistening, inclining to shining; internally glistening, and the lustre is vitreous. Fracture small grained uneven. Fragments indeterminate angular, and pretty sharp-edged. Opaque. Hard. Specific gravity 2·500. The constituents of this mineral are as follows:

Silica 43
Alumina 16
Lime 20
Oxide of iron . . . 16
Water, &c. 4
Loss 1
———
100 *

Sp. 3. *Vesuvian.*†

Hyacinthine of Delametherie—*Idocrase* of Haüy.

This mineral is found among the exuviæ of Mount Vesuvius, in a rock composed of *mica, hornblende, garnet,* and *calcareous spar*. It was formerly confounded with the hyacinth.

Colour olive-green, sometimes passing into blackish green, sometimes into liver-brown. Massive, and often crystallized in four-sided rectangular prisms, having the edges truncated. Its primitive form is a four-sided rectangular prism, little different from a cube, divisible in the direction of the diagonals of the base. Integrant molecule, a triangular prism.‡ Lateral planes of the crystals slightly streaked. Crystals short, and usually small. External lustre shining; internal glistening between vitreous and resinous. Fracture small grained, uneven. Has a tendency to small grained distinct concretions. Translucent. Scratches glass. Specific gravity from 3·0882 to 3·409.§ With borax it melts into a yellowish glass, which appears red while hot.‖

The constituents of this mineral are as follows:

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* Vauquelin, Jour. de Min. No. xliv. 571. The analysis is considered as of a common garnet, and quoted as such by Haüy, ii. 542.
† Brochant, i. 184. Haüy, ii. 574. Jameson, i. 111.
‡ Haüy, ii. 574.   § Haüy.   ‖ Vauquelin.

	*	*
Silica	35·5	 42
Alumina	22·25	.... 16·25
Lime	33·00	.... 34·
Oxide of iron	7·50	.... 5·5
Oxide of manganese ..	0·25	——
Loss	1·50	.... 2·25
	100	100

Sp. 4. *Gahnite.*†

This mineral is found in a lime quarry at Gökum, a Swedish mile south-west from the celebrated Dannemora mines in Sweden. The lime is employed in the Österby iron works. The lime is considered as primitive, and contains, besides tremolite and garnet, the mineral in question, in kidney shaped masses. It was described and analysed by Mr. C. A. Murray in 1807, under the name of a green mineral from the lime quarry of Gökum.‡ The nature of the constituents which were thus found together with some other considerations induced Swedish mineralogists in general to consider it as a variety of vesuvian. In the year 1810, Mr. Swedenstierna gave a specimen of it to the Chevalier Lobo da Silviera, at that time Portuguese Ambassador at Stockholm, pointed out the difference between it and vesuvian, and requested Lobo to subject it to a chemical analysis. Lobo published a new description and analysis of it in the third volume of the Afhandlingar (p. 276). He gave it the name of Gahnite. But Berzelius, who had assigned that name to the automolite of Ekeberg, thought proper to distinguish this new mineral by the name of Loboite. § I shall however employ here the original appellation of Lobo, as the term automolite seems pretty generally adopted by mineralogists for the Fahlun mineral.

The colour of gahnite is dark olive green with a slight shade of brown. The specimens which I have seen were all amorphous; but Murray describes it as occurring in

* Klaproth, Beitrage, ii. 32.
† Afhandlingar, ii. 173; iii. 276.   ‡ Ibid. ii. 173.
§ Ibid. iv. 147.

long confused prisms without any regular termination. These prisms are channelled longitudinally. Their fracture in the direction of the prism is foliated, and has a resinous lustre; the cross fracture is splintery, and has a less lustre.

According to Lobo the cross fracture of gahnite is small granular uneven, sometimes passing into the small conchoidal; the longitudinal fracture is foliated. The external lustre is splendent; the internal shining, and the lustre is intermediate between vitreous and resinous. Fragments indeterminate, not particularly sharp angular. Translucent when in thin fragments. Easily frangible and brittle. Specific gravity according to Murray 3·393, according to Lobo 3·54321. Before the blow-pipe on platinum it melts into a yellowish brown porous glass. On charcoal it fuses into an opaque bottle-green glass; with borax into a light sea-green transparent glass. Its constituents were found as follows :

	*	†
Silica	35·87	36
Lime	34·32	37·65
Alumina	17·87	17·5
Magnesia	2·78	2·52
Oxide of iron	6·75	5·25
Oxide of manganese	0·31	——
Volatile matter	0·25	0·36
Loss	1·85	0·72
	100·00	100·00

Sp. 5. *Grossularia.* ‡

This mineral occurs in a pale greenish claystone near the river Wilni in Siberia, and has been separated from the garnet, chiefly on account of its chemical composition.

It is always crystallized either in the garnet dodecahedron or the common figure of the leucite. Its colour is asparagus green approaching to mountain green. The faces of the crystals are smooth, which characterizes the species. Lustre shining, vitreous. Fracture small conchoidal. Strongly translucent. Hard. Rather easily frangible. Specific gravity 3·372.§ Its composition is as follows:

* Murray.   † Lobo.   ‡ Jameson, i. 115.   § Klaproth.

Silica .... 44·0
Lime .... 33·5
Alumina .... 8·5
Oxide of iron .... 12·0
Oxide of manganese .. Trace
Loss .... 2·0
——————
100·0 *

Sp. 6. *Melanite.*†

Black Garnet.

This mineral which has hitherto been found chiefly at Frescati and St. Albano, near Rome, in the Pyrenese, and at Torneo in Lapland, was long confounded with *garnet.* It was first accurately distinguished by Werner.

Its colour is velvet black, sometimes inclining to greyish black. It is usually in complete crystals. They consist of six-sided prisms accuminated by three planes, which are placed on the alternate lateral edges. Surface smooth. Lustre shining. Fracture imperfect flat conchoidal. Fragments sharp-edged. Opaque. Hard. Easily frangible. Specific gravity from 3·691‡ to 3·730.§ Its constituents are as follows:

	‖	**	††
Silica	35	35·5	34
Lime	32	32·5	33
Alumina	6·4	6·0	6·4
Oxide of iron........	25·5	24·25	25·5
Oxide of manganese ..	Trace	0·40	——
Loss	1·1	1·35	1·1
	——	——	——
	100	100	100

Sp. 7. *Allochroite.*‡‡

This mineral has been hitherto found only in Virum's

* Klaproth, Beitrage, iv. 319.
† Brochant, i. 191. Jameson, i. 116.   ‡ Karsten.
§ Klaproth, Gehlen's Jour. Second Series, v. 203.
‖ Vauquelin, Haüy, ii. 543.   ** Klaproth, Beitrage, v. 168.
†† Hissinger, Afhandlingar, ii. 153. The specimen was from Torneo.
‡‡ Jameson, i. 181.

iron mine at Drammen in Norway. It was first described and named by Professor Schumacher.

Colours greenish and yellowish-grey. Massive. Internal lustre glistening and resinous, internal glimmering. Fracture sometimes small-grained uneven, sometimes even passing into flat conchoidal. Fragments rather blunt-edged. Translucent on the edges. Gives sparks with steel, but does not scratch quartz. Rather easily frangible. Specific gravity from 3·50 to 3·58. It melts before the blow-pipe into a black, smooth, and opaque enamel. Its constituents are as follows:

	*	†
Silica....................	35	37
Lime....................	30·5	30
Alumina................	8	5
Oxide of iron..........	17	18·5
Carbonate of lime	6	—
Oxide of manganese	3·5	6·25
Loss	—	3·25
	100	100

Sp. 8. *Garnet.*‡

This mineral occurs abundantly in primitive mountains. It is usually crystallized. The primitive form of its crystals is a dodecahedron, whose sides are rhombs, with angles of 78° 31′ 44″, and 120° 28′ 16″. The inclination of the rhombs to each other is 120°. This dodecahedron may be considered as a four-sided prism, terminated by four-sided pyramids.§ It is divisible into four parallelopipeds, whose sides are rhombs; and each of these may be divided into four tetrahedrons, whose sides are isosceles triangles, equal and similar to either of the halves into which the rhomboidal faces of the dodecahedron are divided by their shorter diagonal. The integrant molecules of garnet are similar tetrahedrons ‖ Sometimes the edges of the dodecahedrons

* Vauquelin.   † Rose, Karsten's Mineral. Tabellen, p. 33.
‡ Kirwan, i. 258. Gerhard, Disquisitio Physico-chymica Granatorum, &c. Pasumot, Jour. de Phys. iii. 442. Wiegleb, Ann. de Chim. i. 231. Brochant, i. 195. Haüy, ii. 340. Jameson, i. 122.
§ Romé de Lisle, ii. 322, and Haüy, Ann. de Chim. xvii. 305.
‖ Haüy, ibid. 306.

are wanting, and small faces in their place; and sometimes garnet is crystallized in polyhedrons, having 24 trapezoidal faces. For a description and figure of these, and other varieties of garnet, the reader is referred to Romé de Lisle and Haüy.*

Werner divides this species into two subspecies; namely, the *precious* and *common garnet*. They are distinguished from each other by colour, lustre, fracture, distinct concretions, transparency, and specific gravity.

Subsp. 1. *Precious Garnet.*

This is supposed by some to be the *carbuncle* of the ancients. It is employed in jewellery.

Colour red. Hence the name of the mineral, from its supposed resemblance to the flower of the pomegranate. Passes from columbine-red to cherry and brown-red. Commonly crystallized, and the crystals are always complete: sometimes in round grains. External lustre glistening; internal shining, vitreous. Fracture perfect conchoidal, sometimes inclining to coarse-grained uneven. Fragments sharp-edged. Sometimes in lamellar distinct concretions. Transparent; sometimes only translucent. Scratches quartz. Brittle. Not particularly easily frangible. Specific gravity from 4·085 † to 4·352.‡

Subsp. 2. *Common Garnet.*

Colour, various shades of brown and green; namely, liver, yellowish and reddish-brown; olive, pistachio, blackish, and leek-green; Isabella-yellow; blood-red; greenish-black. Different colours often appear in the same mass. Massive, but never in grains or angular pieces; sometimes crystallized. Surface of the crystals diagonally streaked. External lustre shining; internal glistening, between resinous and vitreous. Fracture fine-grained uneven. Fragments not sharp-edged. In small-grained distinct concretions. Translucent; black varieties nearly opaque. Rather easily frangible. Specific gravity from 3·668 § to 3·757.‖ Melts before the blow-pipe more easily than the first subspecies.

* Haüy, Ann. de Chim. xvii. 306.   * Klaproth.   ‡ Karsten.
§ Karsten.   ‖ Werner.

The constituents of this mineral are as follows :

	Precious.		Common.
	*	†	‡
Silica	35·75 ..	36 ..	39·66
Alumina	27·25 ..	22 ..	19·66
Lime	— ..	3 ..	—
Oxide of iron	36·00 ..	41 ..	39·68
Oxide of manganese ..	0·25 ..	— ..	1·80
Water, &c.	— ..	— ..	—
Loss	0·75 ..	— ..	—
	100	102	

Sp. 9. *Aplome.*

This mineral is found in Siberia, on the banks of the river Lena. I have seen specimens also from New Holland, which bore a considerable resemblance to it. As it differs from garnet both in the primitive figure of its crystals, and in its specific gravity, I do not see how we can refuse it a particular place in the mineral system.

Its colour is similar to that of the violet varieties of axinite, and its lustre nearly the same. It is crystallized in rhomboidal dodecahedrons, having striæ parallel to the small diagonals of the rhombs, which indicates a cube for its primitive form. It is hard enough to strike fire with steel, and to scratch quartz. Fracture sometimes small conchoidal. Most commonly opaque; sometimes translucent and having an orange-colour. Specific gravity 3·4444. Its constituents, according to the analysis of Laugier are as follows :

Silica	40
Alumina	20
Lime........................	14·5
Oxide of iron................	14
Oxide of manganese	2
Mixture of silica and iron	2
Loss by calculation	2
Loss	5·5
	100 §

* Klaproth, Beitrage, ii. 26.   † Vauquelin, Haüy, ii. 542.
‡ Hisinger, Afhandlingar, iv. 385. The specimen was a Fahlum garnet, of the specific gravity 4·2.   § Ann. de Chim. lxxii. 110.

Sp. 10. *Granatite.**

Staurotide of Haüy—*Pierre de Croix* of de Lisle—
Staurolithe of Lametherie.

Granatite is found in Galicia in Spain, Britanny in France, and at St. Gothard.   It is always crystallized in a Crystals. very peculiar form; two six-sided prisms intersect each other, either at right-angles or obliquely.   Hence the name *cross-stone*, by which it was known in France and Spain.† Mr. Haüy has proved, in a very ingenious manner, that the primitive form of the granatite is a rectangular prism, whose bases are rhombs, with angles of $129\frac{1}{2}°$ and $50\frac{1}{2}°$; and that the height of the prism is to the greater diagonal of the rhomb as one to six; and that its integrant molecules are triangular prisms, similar to what would be obtained by cutting the primitive crystal in two, by a plane passing vertically through the shorter diagonal of the rhomboidal base.   From this structure he has demonstrated the law of the formation of the cruciform varieties.‡

Colour dark reddish-brown.   Surface sometimes smooth, sometimes uneven.   Internal lustre glistening; between vitreous and resinous.   Fracture between small-grained uneven, and imperfect conchoidal.   Often opaque; sometimes translucent.   Scratches quartz feebly. Brittle. Easily frangible.   Specific gravity 3·2861.   Infusible before the blowpipe.   Its constituents are as follows:

	§	§	‖	‖
Silica	33	30·6	37·5	27
Alumina	44	47·0	41·0	52·25
Lime	3·84	3·0	—	—
Magnesia	—	—	0·5	—
Oxide of iron	13	15·3	18·25	18·50
Oxide of manganese	1	—	0·5	0·25
Loss	5·16	4·1	2·25	2·
	100	100	100	100

Sp. 11. *Pyrope.***

This mineral, which is found in Bohemia, and was

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* Brochant, ii. 496. Haüy, iii. 93. Jameson, i. 133.
† Romé de Lisle, ii. 435.   ‡ Ann. de Chim. vi. 142.
§ Vauquelin, Ann. de Chim. xxx. 106.
‖ Klaproth, Beitrage. v. 80.   ** Jameson, i. 136.

Book III. formerly distinguished by the name of Bohemian garnet, has been separated from the garnet by Werner, and made a distinct species. It is never found crystallized, but only in round or angular fragments, usually small.

Colour dark blood-red, which, when held between the eye and the light, inclines strongly to yellow. Lustre splendent, vitreous. Fracture perfect conchoidal. Fragments sharp-edged. Transparent. Scratches quartz. Specific gravity 3·718 * to 3·941.†

Its constituents are as follows:

Silica	40
Alumina	28·5
Lime	3·5
Magnesia	10·0
Oxide of iron	16·5
Oxide of manganese	0·25
Loss	1·25
	100 ‡

Sp. 12. *Cinnamon Stone.*§

This mineral, which is found in the sand of the rivers in Ceylon, was first distinguished as a particular species by Werner. It received its name from the Dutch.

Colour hyacinth-red, passing on the one hand into blood-red, on the other into orange-yellow. Always in roundish pieces. External lustre glistening, internal splendent and vitreous. Fracture imperfect flat conchoidal. Fragments angular and very sharp-edged. Transparent and semitransparent. Scratches quartz with difficulty. Brittle. Rather difficultly frangible. Specific gravity 3·530.‖ Melts before the blow-pipe into a brownish-black enamel.

Its constituents are as follows:

Silica	38·80
Alumina	21·20
Lime	31·25
Oxide of iron	6·50
Loss	2·25
	100·00 **

* Klaproth.   † Werner.   ‡ Klaproth, Beitrage, ii. 21.
§ Jameson, i. 139.   ‖ Klaproth.   ** Klaproth, Beitrage, v. 138.

The essential ingredients of the minerals of this family appear to be silica, alumina, lime, magnesia, oxide of iron, and potash. Four of them seem to contain only three ingredients, the other eight contain four. I think it probable that the nature of each species may be represented by the following symbols. The letters used in these symbols are the initials of the Latin names of the ingredients, the figures denote the number of atoms present. Those figures which occupy the place of coefficients indicate the atoms of the compound, those which occupy the place of indices indicate the atoms of the ingredient to which they are attached.

$$
\begin{array}{ll}
\text{Leucite} \dots\dots\dots & P\,S + 3\,A\,S \\
\text{Pyrenite} \dots\dots\dots & C\,S^3 + A\,S^3 \\
\text{Garnet} \dots\dots\dots\dots & A\,S + f\,S \\
\text{Granatite} \dots\dots\dots & 2\,A\,S + f\,A \\
\text{Gahnite} \dots\dots\dots & A\,S + C\,S + \tfrac{1}{2}f \\
\text{Cinnamon stone} \dots & A\,S + C\,S + \tfrac{1}{2}f \\
\text{Vesuvian} \dots\dots\dots & A\,S + C\,S + \tfrac{1}{2}f \\
\text{Aplome} \dots\dots\dots & A\,S + C\,S + f \\
\text{Grossularia} \dots\dots & A\,S^2 + f\,S^2 + 2\,C\,S^2 \\
\text{Melanite} \dots\dots & A\,S + 2f\,S + 3\,C\,S \\
\text{Allochroite} \dots\dots & A\,S + 2f\,S + 3\,C\,S
\end{array}
$$

I think it probable that gahnite, cinnamon stone, and vesuvian are only varieties of the same species, and that allochroite is nothing more than a variety of melanite. However it must be acknowledged that the symbols given above do not exactly accord with the analyses. It would be too much to expect the analyses hitherto made, considering the manifold defects under which they labour, to accord exactly with the atomic theory. A new set of analyses would be necessary, performed upon the best selected specimens and with the most scrupulous attention to precision.

VII. QUARTZ FAMILY.

This family contains twelve species, several of which, on account of the numerous varieties which they present, are farther subdivided into subspecies. The names of the species are *quartz, iron flint, horn stone, flinty slate, flint, chalcedony, heliotrope, siliceous sinter, hyalite, opal, menilite, jasper.* Many of them are of importance; yet as they never occur

Book III. crystallized, the method of discriminating minerals adopted by Haüy fails when applied to them.

Sp. 1. *Quartz.**

This is one of the most abundant of all the mineral species, occurring in great quantities in almost every situation. It occurs massive, in rolled pieces, and crystallized. The primitive form of its crystals, according to Mr. Haüy, is a rhomboidal parallelopiped; the angles of whose rhombs are 94° 24′ and 85° 36′; so that it does not differ much from a cube.† The most common variety is a dodecahedron, composed of two six-sided pyramids, applied base to base, whose sides are isosceles triangles, having the angle at the vertex 40°, and each of the angles at the base 70°: the inclination of a side of one pyramid to the contiguous side of the other pyramid is 104°. There is often a six-sided prism interposed between the two pyramids, the sides of which always correspond with those of the pyramids.‡ For a description and figure of the other varieties of quartz crystals, and for a demonstration of the law which they have followed in crystallizing, we refer the reader to Romé de Lisle § and Mr. Haüy.‖

Fracture conchoidal or splintery. Its lustre varies from shining to glimmering, and its transparency from transparent to translucent on the edges; and in some cases it is opaque. It causes a double refraction. Hard. Specific gravity from 2·64 to 2·67, and in one variety 2·691. To facilitate the description of this complicated species, Werner has subdivided it into six subspecies; a subdivision attended with several advantages.

Subsp. 1. *Amethyst.*

It occurs massive and in rolled pieces, but most frequently crystallized. The crystals are six-sided pyramids, always in druses. Colour violet blue; passing on the one hand to plum blue, clove brown, brownish black; on the other, to pearl and ash grey, greyish white, greenish white, olive

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* Kirwan, i. 241. Haüy, ii. 406. Brochant, i. 239. Jameson, i. 142.
† Haüy. Mr. Phillips found them 94° 24′ and 85° 36′; Annals of Philosophy, vii. 136.   ‡ Chrystallog. ii. 71.   § Ibid.
‖ Mem. Par. 1786, p. 78; and Mineralogie, ii. 407. See also Lametherie, Jour. de Phys. xlii. 470.

green, and, in some rare cases, pistachio green. In the massive varieties several colours appear together in stripes. Lustre splendent; vitreous. Fracture perfect conchoidal; sometimes passes into imperfect conchoidal, uneven, and coarse splintery. Fragments sharp-edged. The massive varieties composed of thick prismatic distinct concretions, often shooting into crystals at their extremities. Transparency from transparent to translucent. Brittle. Easily fragible. Specific gravity 2·750. Found in veins and in the hollow cavities of agates.

Werner distinguishes the common amethyst, above described from a variety which, from its fracture, he calls *thick fibrous amethyst.* This last occurs only massive and in rolled pieces. Internal lustre shining, vitreous. Principal fracture thick fibrous; cross fracture imperfect conchoidal. Usually translucent.

Subsp. 2. *Rock Crystal.*

It occurs in rolled pieces, and very often crystallized in all the variety of form belonging to the species in general. Most common colours white and brown. From snow white passes into greyish, yellowish, and reddish white; from greyish white to pearl grey; from yellowish white to ochre yellow, wine yellow, yellowish brown, clove brown, brownish black; from yellowish brown to orange yellow and hyacinth red.

External lustre of the crystals splendent, of the rolled pieces glistening; internal lustre splendent, vitreous. Fracture perfect conchoidal, sometimes flat conchoidal; and in some varieties a concealed foliated fracture may be recognized. Fragments very sharp-edged. Occurs very rarely in granular and prismatic distinct concretions. Transparent. Easily frangible. Specific gravity from 2·605 to 2·888.

Subsp. 3. *Milk Quartz.*

Occurs only massive. Colour sometimes milk white; more commonly rose red. The rose red sometimes passes into crimson red, reddish white, pearl grey, and milk white. Internal lustre splendent, vitreous, inclining to resinous. Fracture perfect conchoidal. Fragments sharp-edged. Sometimes appears composed of thick lamellar distinct con-

cretions. Semitransparent. Constitutes beds in primitive mountains.

Subsp. 4. *Common Quartz.*

Occurs massive, in grains, and rolled pieces; in various particular shapes, and crystallized. Colour various shades of white, grey, brown, yellow, green, and red. External lustre of the crystals shining; of the rolled pieces glimmering; internal lustre shining, vitreous. Fracture coarse and fine splintery, and imperfect conchoidal. Some specimens show a parallel fibrous fracture. Fragments pretty sharp-edged. Sometimes in prismatic, and also in granular distinct concretions. Translucent. Rather easily frangible. Specific gravity 2·6404 to 2·6546.

Subsp. 5. *Prase.*

Usually massive; sometimes crystallized. Colour leek green. Lustre glistening; between resinous and vitreous. Fracture coarse splintery. Fragments sharp-edged. When massive it is composed of cuneiform, thick, prismatic, distinct concretions. Surface of the concretions rough and traversely streaked. Translucent. Hard. Rather tough. This subspecies is considered as consisting of an intimate mixture of quartz and actinolite.

Subsp. 6. *Cat's eye.*

This mineral comes from Ceylon, and is seldom seen by European mineralogists till it has been polished by the lapidary. Mr. Klaproth has described a specimen which he received in its natural state from Mr. Greville of London. Its figure was nearly square, with sharp edges, a rough surface, and a good deal of brilliancy.

Colours yellowish, greenish, and ash grey: Isabella yellow; yellowish, reddish, and hair brown; mountain and olive green; greyish black. Internal lustre shining, between resinous and vitreous. Fracture small imperfect conchoidal. Fragments more or less sharp-edged. Translucent. Sometimes presents the appearance of slender white fibres almost opaque, which gives it the appearance called *chatoyant* by jewellers. Hard. Easily frangible. Specific gravity from 2·625 to 2·660.

Subsp. 7. *Steinheilite.*

This mineral occurs in Finland and has been long known in collections under the name of blue quartz. Count Steinheil, Governor of Finland, suspecting it to differ from quartz requested Professor Gadolin to examine it, and he, it is said, found in it a considerable quantity of alumina.

Colour smalt blue with a slight admixture of red. All the specimens which I have seen were amorphous. Fracture coarse splintery, and sometimes imperfect conchoidal. Lustre shining, vitreous. Fragments indeterminate, very sharp-edged. Translucent. In thick masses only translucent on the edges. Slightly scratched by rock crystal. Very easily frangible. Sp. gr. 2·598. In short its characters correspond so closely with those of quartz that there is reason to suspect that the alumina found by Gadolin may be owing to the presence of some foreign matter in the specimen which he analysed.

These minerals consist essentially of pure silica, but they are usually contaminated with small quantities of foreign matter to which they owe their distinguishing properties. The following table exhibits the result of the analyses of them hitherto made.

	Amethyst.	Rock crystal.	Quartz.	Prase.	Cat's eye.	
	*	†	†	†	‡	‡
Silica	97·5	99·37	97·75	98·5	95	94·5
Alumina	0·25	·63	·50	·5	1·75	2·0
Lime	—	—	—	—	1·5	1·5
Oxide of iron	0·5	Trace	—	1·0	0·25	0·25
Oxide of manganese	0·25	—	—	—	—	—
Water	—	—	1·00	—	—	—
Loss	1·5	—	·75	—	1·5	1·75
	100	100	100	100	100	100

* Rose, Karsten's tabellen, p. 25.
† Bucholz, Gehlen's Journal, Second Series, vi. 147.
‡ Klaproth, Beitrage, i. 94 and 96.

Sp. 2. *Iron-flint.*[*]

This mineral occurs in veins of iron-stone, and is supposed to be an intimate mixture of quartz and iron-ochre. Commonly massive; sometimes crystallized in small six-sided prisms, acuminated at each extremity by three planes. Colour yellowish brown; sometimes between blood red and brownish red. External lustre shining; internal glistening; nearly vitreous. Fracture imperfect small conchoidal. Fragments not very sharp-edged. In small grained distinct concretions. Opaque. Hard. Rather tough. Specific gravity from 2·576 to 2·838. It is infusible before the blow-pipe without addition. Its constituents are as follows:

	[†]	[†]	[†]
Silica	76·00	93·5	92
Alumina	0·25	—	—
Oxide of iron	21·50	5	5·75
Oxide of manganese ..	—	—	1
Water	1	1	1
Loss	1·25	0·5	0·25
	100	100	100

Sp. 3. *Hornstone.*[‡]*—Chert.*

This mineral occurs sometimes massive, sometimes in round balls. Fracture splintery and conchoidal. Lustre 0. Translucent. Hard, but scratched by quartz. Specific gravity 2·699 to 2·708. Colour usually grey.

Werner subdivides this species into three subspecies, distinguished chiefly by the fracture and texture.

Subsp. 1. *Splintery Hornstone.*

This mineral is found in veins in limestone, and forms also the basis of a rock called *hornstone porphyry*.

Colour bluish grey, greenish grey, yellowish grey, smoke

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[*] Jameson, i. 178.

[†] Bucholz, Gehlen's Journal, Second Series, vi. 153. The first specimen was red, the second yellow, the third brown.

[‡] Kirwan's Min. i. 303. Baumer, Jour. de Phys. ii. 154, and Monnet, Ibid. 33. Wiegleb, Crell's Annals, 1788, p. 46 and 135. Jour. de Phys. liii. 239. Brochant, i. 25. Jameson, i. 181.

and pearl grey; flesh red, brownish red; mountain and olive green. Fracture fine splintery. Internal lustre 0. Fragments sharp-edged. Sometimes, though seldom, it occurs in distinct concretions, which are lamellar and concentric. Translucent on the edges. Hard. Brittle. Tough. Infusible without addition before the blow-pipe.

Subsp. 2. *Conchoidal Hornstone.*

This mineral occurs in beds, and also in veins. Colour greyish and yellowish white, greenish and pearl grey, flesh and cherry red, mountain green. Sometimes spotted and striped. Always massive. Internal lustre scarcely glistening. Fracture perfect conchoidal. Fragments pretty sharp-edged. Never in distinct concretions. Translucent on the edges. Hard. Easily frangible.

Subsp. 3. *Woodstone.*

This mineral is found insulated in sandy loam; it appears to be wood converted into hornstone by petrefaction. Colour ash grey, yellowish-grey, pearl-grey; flesh-red, blood-red, brownish-red; ochre yellow. Usually several colours appear together. Shape conformable to its former woody state. External surface rough. Internal lustre 0. Cross fracture imperfect conchoidal; longitudinal splintery and fibrous. Fragments not sharp-edged. Translucent on the edges. Rather softer than splintery hornstone. Easily frangible.

This mineral seems to be very nearly connected with compact felspar.

Sp. 4. *Flinty-slate.**

This mineral occurs in beds and amorphous masses, chiefly in the transition mountains. Colour various shades of grey. Structure slaty. Usually opaque. Sometimes translucent on the edges; rather softer than quartz. Hard. Brittle. Specific gravity from 2·596 to 2·629. Infusible *per se.* This species is divided into two subspecies.

Subsp. 1. *Common Flinty-Slate.*

Colour ash-grey, bluish-grey, pearl-grey, and cherry-red, approaching blood-red. Often spotted. Often tra-

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* Kirwan, i. 305. Brochant, i. 282. Jameson, i. 189.

versed by veins of quartz. Internal lustre scarcely glimmering. Fracture, when considered with respect to a considerable mass, or *in the great* as it is termed, slaty; *in the small*, between splintery and uneven. Fragments sharpedged. Sometimes occurs in lamellar distinct concretions. Translucent. Hard. Brittle. Tough.

Subsp. 2. *Lydian Stone.*

Colour greyish black passing into velvet black. Massive, and in trapezoidal rolled pieces. Often traversed by quartz veins. External surface smooth. Lustre glistening; internal lustre glimmering. Fracture even. Fragments sharp-edged; sometimes approach the cubical form. Opaque. Hard. Easily frangible.

This, or a stone similar to it, was used by the ancients as a touchstone. They drew the metal to be examined along the stone, and judged of its purity by the colour of the metallic streak. On this account they called it βασανος, " the trier." They called it also *Lydian stone*; because, as Theophrastus informs us, it was found most abundantly in the river Tmolus in Lydia.*

Sp. 5. *Flint.*†

Pyromachus—Pierre à fusil.

This mineral, which has become so necessary in modern war, is found in pieces of different sizes, and usually of a figure more or less globular, commonly among chalk, and often arranged in some kind of order.

Colour grey, of various shades; namely, ash, yellowish and smoke-grey; greyish-black; ochre-yellow; yellowish-brown, reddish-brown; sometimes it approaches blood-red. Sometimes striped. Occurs massive, in grains and plates, and in various particular shapes. Internal lustre glimmering. Fracture perfect conchoidal. Fragments very sharp-edged; sometimes tabular. Sometimes, though rarely, it occurs in lamellar distinct concretions. Translucent.

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* Hill's Theophrastus, περι λιθων, p. 190.

† Kirwan's Min. i. 301. Brochant, i. 263. Haüy, ii. 427. Jameson, i. 195. Dolomieu, Jour. de Min. No. xxxiii. 693, and Salivet, Ibid. 713. These last gentlemen give an account of the method of making gun-flints.

Rather harder than quartz. Very easily frangible. Specific gravity 2·58 to 2·63. Infusible before the blow-pipe.

The manufacture of gun-flints is chiefly confined to England and two or three departments in France. The operation is exceedingly simple : a good workman will make 1000 flints in a day. The whole art consists in striking the stone repeatedly with a kind of mallet, and bringing off at each stroke a splinter, sharp at one end and thicker at the other. These splinters are afterwards shaped at pleasure, by laying the line at which it is wished they should break, upon a sharp iron instrument, and then giving it repeatedly small blows with a mallet. During the whole operation the workman holds the stone in his left hand, or merely supports it on his knee.* The constituents of flint are as follows :

	†	‡
Silica	98·	97
Alumina	0·25	1
Lime	—	—
Oxide of iron ..	0·25	Trace
Water	1·5	—
Loss	—	2
	100	100

Sp. 6. *Calcedony.* §

This mineral is found abundantly in many countries, particularly in Iceland and the Faro islands. It is most commonly amorphous, staclactical, or in rounded masses ; but it occurs also in pseudo crystals. Surface rough. Fracture even or conchoidal. Lustre external glimmering ; internal glistening. Somewhat transparent. Hardness nearly the same as that of quartz. Specific gravity 2·479 to 2·700. Brittle. Infusible before the blow-pipe without addition.

It is subdivided into four subspecies ; viz. *common calcedony, chrysoprase, plasma,* and *carnelian,* distinguished chiefly by the colour, fracture, and lustre.

* Jour. de Min. No. xxxiii. 702.   † Klaproth, Beitrage, i. 46.
‡ Vauquelin, Jour. de Min. No. xxxiii. 702.
§ Brochant, i. 268. Kirwan, i. 298. Haüy, ii. 425. Jameson, i. 201.

Subsp. 1. *Common Calcedony.*

Colour grey, of various kinds; namely, smoke, bluish, pearl, greenish, and yellowish-grey: the bluish grey passes into milk white and smalt blue: the greenish-grey into a colour between grass and apple-green: the yellowish-grey into honey, wax, and ochre-yellow; yellowish-brown and blackish-brown: this last, when the mineral is held between the eye and the light, appears blood red. Internal lustre nearly dull. Fracture even, sometimes passing into fine splintery; also into uneven, approaching the flat conchoidal. Fragments sharp-edged. Generally in reniform, lamellar, concentric, distinct concretions. Semitransparent. Rather harder than flint. Brittle. Tough. Specific gravity from 2·583 to 2·665.

Subsp. 2. *Chrysoprase.*

This mineral, which has been hitherto found only near Kosemütz in Silesia, is always amorphous. Fracture even, sometimes inclining to the splintery. Scarcely any lustre Translucent. Scarcely so hard as calcedony. Specific gravity 2·479. Colour apple green. Rather tough. In a heat of 130° Wedgewood it whitens and becomes opaque.

Subsp. 3. *Plasma.*

Hitherto this mineral has been found only among the ruins of Rome. Colour between grass and leek green; often marked with yellow dots and white spots. Found in angular fragments; often encrusted with an earthy matter. Internal lustre glistening. Fracture perfect flat conchoidal. Fragments very sharp-edged. Translucent. Hardness equal to that of chalcedony. Brittle. Tough. Specific gravity 2·553.

Subspe. 4. *Carnelian.*

Colour blood-red; passes into flesh-red, reddish-white, milk-white, yellow, reddish-brown. External surface rough and uneven. Lustre glistening. Fracture perfect conchoidal. Fragments very sharp-edged. Very seldom in distinct concretions. Semitransparent. Specific gravity 2·551 to 2·624. The constituents of these minerals are as follows:

	Calcedony.	Chrysoprase.	Plasma.	Carnelian.
	*	†	‡	§
Silica	99 ..	96·16 ..	96·75 ..	94·00
Alumina..........	— ..	0·08 ..	0·25 ..	3·50
Lime	— ..	0·83 ..	— ..	—
Oxide of iron ...	— ..	0.08 ..	0·50 ..	0·75
Oxide of nickel ..	— ..	1· ..	— ..	—
Water	— ..	— ..	2·50 ..	—
Loss	1 ..	1·85 ..	— ..	1·75
	100	100	100	100

Both flint and calcedony consist essentially of silica. Flint appears to contain a little water; but it is difficult to understand what occasions the specific difference between rock crystal and calcedony.

Sp. 7. *Heliotrope.* ||

This mineral, which is found in various parts of Asia and Europe, nearly in the same situation as calcedony, is supposed by some to be an intimate combination of calcedony with *green earth*.

Colour between grass and leek-green, often stained or striped olive, yellow, red. Found massive, and in angular pieces. Lustre, internal, glistening, resinous. Fracture imperfect large conchoidal. Translucent on the edges. Rather softer than calcedony. Specific gravity 2·633. Easily frangible. Infusible before the blow-pipe. Its constituents are as follows:

Silica	84
Alumina	7·5
Oxide of iron ...	5
Loss	3·5
	100·0 **

* Trommsdorf, Crell's Annalen, 1800, i. 105. The specimen had a blue colour, and was from Siberia.
+ Klaproth, Beitrage, ii. 133.   ‡ Ibid. iv. 326.
§ Bindheim, Schriften der Berliner Gesellschaft, ii. 245. As quoted by Karsten in his Tabellen, p. 25.
|| Kirwan, i. 314. Brochant, i. 276. Jameson, i. 219.
** Trommsdorf, Karsten's Tabellen, p. 39.

Sp. 8. *Siliceous sinter or siliceous stalactite.**

This species includes several siliceous concretions which occur in different parts of the world, and has been divided into 3 subspecies.

Subsp. 1. *Common.*

Colours various shades of grey, as greyish-white, smoke-grey, and yellowish-grey, with light-red, and hair-brown spots and stripes. Usually stalactitical. External lustre dull, internal sometimes dull, sometimes glistening and pearly. Fracture small conchoidal, coarse grained uneven, or promiscuous fibrous. Translucent on the edges. Semihard. Brittle. Specific gravity 1·807. Hitherto it has been found only at the Geyzer springs in Iceland, where it is deposited from the water.

Subsp. 2. *Opaline.*

It occurs at the Geyzer springs along with the first subspecies. Yellowish and milk-white, with brownish, blackish, or bluish spots. Fracture imperfect conchoidal. Lustre glistening. Fragments angular and sharp-edged. Translucent on the edges. Semihard. Brittle. Easily frangible. Adheres to the tongue.

Subsp. 3. *Pearlsinter.*

Found on the surface of withered granite, in the Island of Ischia, and considered as volcanic.

Colours milk-white, yellowish-white, greyish-white. Usually stalactitical. Lustre sometimes shining, sometimes dull. Fracture small grained uneven. Fragments angular, but not sharp-edged. In concentric lamellar distict concretions. Translucent, at least on the edges. Scratches glass, but softer than quartz. Brittle. Easily frangible. Specific gravity 1·917.

The constituents of these minerals as far as they have been examined are as follows:

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* Jameson, i. 222.

	Common	Pearlsinter.
	*	†
Silica	98·0	94
Alumina	1·5	2
Lime	—	4
Oxide of iron	0·5	—
	100	100

Sp. 9. *Hyalite.*‡

This mineral occurs in wacke in reniform masses. At first sight it strikes the eye as not unlike gum. The masses are usually very much cracked. Colour yellowish or greyish white. Lustre, shining, vitreous. Fracture small flat conchoidal. Fragments sharp-edged. Translucent. Softer than quartz. Brittle. Very easily frangible. Specific gravity 2·150.§ Infusible at 150° Wedgewood, but yields to soda.§

Sp. 10. *Opal.*‖

This mineral is found in many parts of Europe, especially in Hungary, in the Crapacks near the village of Czennizka. When first dug out of the earth it is soft, but it hardens and diminishes in bulk by exposure to the air.

The opal is always amorphous. Its fracture is conchoidal. Commonly somewhat transparent. Hardness varies considerably. Specific gravity from 1·958 to 2·540. The lowness of its specific gravity, in some cases, is to be ascribed to accidental cavities which the stone contains. These are sometimes filled with drops of water. Some specimens of opal have the property of emitting various coloured rays, with a particular effulgency, when placed between the eye and the light. The opals which possess this property are distinguished by lapidaries by the epithet *oriental*, and often by mineralogists by the epithet *nobilis*. This property rendered the stone much esteemed by the ancients. Opals ac-

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* Klaproth, Beitrage, i. 112.
† Santi, as quoted by Pfaff, Crell's Annallen 1796, ii. 591.
‡ Kirwan i. 296. Brochant, i. 271. Jameson, i. 227.
§ Kopp. Gehlen's Jour. Second Series, viii. 179.
‖ Kirwan's Min. i. 289. Haüy, Jour. de Hist. Nat. ii. 9. Delius, Jour. de Phys. xliv. 45. Brochant, i. 341. Haüy, ii. 434. Jameson, i. 228.

quire it by exposure to the sun. Werner has divided this species into four subspecies.

Subsp. 1. *Precious Opal.*

This mineral is found in Upper Hungary, and said to be disseminated in clay porphyry. Occurs massive, in plates and small veins. Colours milk and yellowish-white; but between the eye and the light they pass into pale rose-red and wine-yellow. Exhibits a beautiful play of colours. Internal lustre, splendent, vitreous. Fracture perfect conchoidal. Fragments sharp-edged. Translucent. Semihard. Brittle. Very easily frangible. Specific gravity 2·114. Does not melt before the blow-pipe. When heated it becomes opaque, and sometimes is decomposed by the action of the atmosphere. Hence it seems to follow, that water enters essentially into its composition.

Subsp. 2. *Common Opal.*

This mineral occurs in many parts of the world, especially in Iceland, the Faro Isles, Ireland, and Germany. Sometimes it is in veins, sometimes disseminated, and most frequently in porphyry.

Principal colour white of various shades; namely, greyish, greenish, yellowish, and milk-white: from greenish-white it passes into apple-green; from yellowish into honey and wax-yellow: sometimes intermediate between flesh and tile-red. The white varieties, when held between the eye and the light, appear wine-yellow. Internal lustre, splendent, vitreous. Fracture perfect conchoidal. Fragments sharp-edged. Semi-transparent. Semihard. Brittle. Very easily frangible. Specific gravity from 1·958 to 2·144.

Specimens of this variety sometimes occur with rifts: these readily imbibe water, and therefore adhere to the tongue. Some opals gradually become opaque, but recover their transparency when soaked in water by imbibing that fluid. They are then called *hydrophanes*, or *oculi mundi*.

Subsp. 3. *Semi Opal.*

This mineral, which has been arranged with pitch-stone, is very common in different parts of the world, occurring in angular pieces and veins in porphyry and amygdaloid.

Common colours white and grey; namely, yellowish, greenish, and milk-white; yellowish, greenish, and ash-

grey, and greyish-black; leek, apple, and olive-green; honey and wax-yellow, yellowish-brown; chesnut and hair-brown. Sometimes several colours appear together in spots and clouds. Colours usually muddy. Occurs massive, and in various particular shapes. Lustre glistening. Fracture imperfect large flat conchoidal. Fragments sharp-edged. Harder than common opal. Very brittle. Easily frangible. Specific gravity 2·540.* Infusible before the blowpipe.

Subsp. 4. *Wood Opal.*

This mineral, which occurs near Schemnitz, and at Telkobanya in Hungary, consists of wood penetrated with opal. It occurs in pieces which have the shape of branches and other parts of trees. Colour greyish and yellowish-white; sometimes ochre-yellow; from greyish-white it passes into ash-grey and greyish-black. Internal lustre glistening. Fracture more or less perfect conchoidal, showing the ligneous texture. Fragments sharp-edged. Translucent. Harder than opal. Easily frangible. Specific gravity 2·600.

These two species are so intimately connected that it would perhaps be better to unite them. They appear to consist essentially of hydrate of silica. The following table exhibits the best analysis of them hitherto made.

	Hyalite.	Precious Opal.	Common.	Fire Opal.	Semi Opal.	
	†	‡	§	‖	**	††
Silica	92	90	93·5	92	82·75	85
Alumina ..	Trace	—	—	—	3·50	3
Lime	—	—	—	—	0·25	—
Oxide of iron	—	—	1	0·25	3·00	1·75
Carbon	—	—	—	—	—	1
Water	6·33	10	5	7·75	10·00	8
Bitumen ...	—	—	—	—	—	0·33
Loss	1·67	—	0·5	—	0·5	0·92
	100	100	100	100	100	100·00

* Klaproth.
† Bucholz, Gehlen's Journal, Second Series, viii. 177.
‡ Klaproth, Beitrage, ii. 152.   § Ibid. 161.   ‖ Ibid. iv. 159.
** Stucke.
†† Klaproth Beitrage, v. 29. The specimen was from Mahren. Colour greyish-black. Sp. gr. 2·020.

Sp. 11. *Menilite.*[*]

This mineral, which occurs in adhesive slate at Menil Montagne near Paris, was first made known to mineralogists in 1790. It is found in tuberose masses, with a smooth ribbed surface, sometimes covered with a white crust. Colour chesnut brown; externally marked with stripes of reddish brown and pearl grey alternating with each other. Internal lustre glistening. Cross fracture perfect flat conchoidal; longitudinal coarse splintery. Fragments sharp-edged. In flattened longish granular distinct concretions; the surface of which has no lustre, and is sometimes covered with a white crust. Translucent on the edges. Scratches glass. Brittle. Easily frangible. Specific gravity 2·185.[†]

Its constituents are as follows:

Silica .... 85·5
Alumina........ 1
Lime.......... 0·5
Oxide of iron. ... 0·5
Water .... 11·
Loss .... 1·5
_____
100·0 [‡]

Sp. 12. *Juspar.* [§]

This mineral is an ingredient in the composition of many mountains. It occurs usually in large amorphous masses, constituting beds and veins, sometimes in rounded or angular pieces. Either opaque, or translucent on the edges. Hard. Specific gravity from 2·0 to 2·7. Its colours are various. When heated it does not decrepitate.

Werner subdivides this species into six subspecies; some of which are again subdivided into different kinds, for the convenience of description.

Subsp. 1. *Egyptian Jasper.*

This mineral has been hitherto found only in Egypt, and in one or two places in Germany. It occurs in rolled

[*] Klaproth, Beitrage, ii. 165. Jameson, i. 248.

[†] Klaproth.   [‡] Klaproth, Beitrage, ii. 169.

[§] Kirwan's Mineral. i. 309. Borral, Hist. Natur de Corse. Henkel, Act. Acad. Nat. Curios. v. 339. Brochant, i. 332. Jameson, i. 251.

pieces, mostly spherical, with a rough surface. Werner, from its colour, divides it into two kinds.

I. *Brown Egyptian Jasper.* Found in Egypt in a breccia, of which the greater part of that country is composed. Colour chesnut-brown; sometimes yellowish-brown, cream-yellow, and yellowish-grey. The central part of this mineral has a yellowish-grey colour; the exterior part a yellowish-brown and chesnut-yellow. The brown colour forms concentric delineations, between which the mineral is spotted with black. Lustre glistening. Fracture perfect conchoidal. Fragments sharp-edged. Translucent on the edges. Easily frangible. Specific gravity from 2·564 to 2·600. Sometimes passes into flint.

II. *Red Egyptian Jasper.* Found in a bed of red clay iron-stone in the electorate of Baden. Colour between blood and scarlet-red; on the surface often ochre-yellow, also smoke and bluish-grey; colours form ring-shaped delineations. Internal lustre glistening to dull. Fracture large conchoidal. Fragments sharp-edged. Usually opaque. Hard. Specific gravity 2·632.

Subsp. 2. *Striped Jasper.*

This mineral occurs in beds, and even constitutes hills. Always massive. Colours pearl, greenish, and yellowish-grey; cream and straw-yellow; mountain and leek-green, and greenish-grey; cherry, brownish, and flesh red; plum-blue. Several colours always appear together in stripes. Hence the name of the mineral. Internal lustre dull. Fracture pretty perfect conchoidal, approaching to fine earthy. Fragments pretty sharp-edged. Translucent on the edges. Sometimes opaque. Pretty hard. Brittle. Rather easily frangible. Specific gravity 2·537.

Subsp. 3. *Porcelain Jasper.*

This mineral is supposed to have been originally a slate-clay, hardened by the combustion of subterraneous coal-mines. It occurs in whole beds in situations favourable to this opinion. Usually massive and in angular pieces; frequently rent. Colours smoke, bluish, yellowish, and pearl-grey; lilac and lavender-blue; brick-red; straw and ochre-yellow; greyish-black and ash-grey. Generally of

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only one colour, but often marked with dots and clouds. Often presents brick-red vegetable impressions, especially the blue varieties. Internal lustre glimmering; sometimes shining. Fracture imperfect large flat conchoidal. Fragments sharp-edged. Opaque. Hard. Very brittle. Easily frangible. Specific gravity 2·43.

Subsp. 4. *Common Jasper.*

This mineral, which is very common, occurs in veins in primitive mountains. Most commonly massive. Colours yellowish, liver, and blackish-brown; ochre-yellow; blood-red; rarely scarlet and cochineal-red; brownish-red; brownish-black. Sometimes several colours appear together in the same mineral. Internal lustre glistening; between vitreous and resinous. Fracture more or less perfect conchoidal, passing into even and earthy. Fragments more or less sharp-edged. Usually opaque. Sometimes translucent on the edges. Pretty hard. Brittle. Easily frangible.

Subsp. 5. *Jasper Agate.*

This mineral occurs in agate balls in amygdaloid. Always massive. Colours yellowish-white, cream and straw-yellow, reddish-white, and flesh-red. The colours are distributed in rings and stripes. Lustre dull. Fracture small flat conchoidal. Fragments scarcely sharp-edged. Usually opaque. Pretty hard. Often adheres to the tongue.

Subsp. 6. *Opal Jasper.*

This mineral occurs in nests in porphyry, in Hungary and Siberia. Massive. Colours scarlet, brick, blood, and brownish-red; Blackish-brown, approaching sometimes to liver-brown and ochre-yellow. Colours sometimes in spots and veins. Internal lustre shining, approaching splendent; between vitreous and resinous. Fracture complete flattish conchoidal. Fragments very sharp-edged. Usually opaque. Sometimes translucent on the edges. Brittle. Easily frangible. This subspecies connects jasper with opal.

VIII. PITCH-STONE FAMILY.

Pitch-stone family. This family comprehends under it four different species; namely, *obsidian*, *pitch-stone*, *pearl-stone*, and *pumice*.

Species 1. *Obsidian.*

This mineral occurs in nests in the pearl-stone of Hungary. It is common in Iceland, Siberia, the Levant islands, and in South America. Found in angular pieces and roundish grains. Principal colour velvet-black; occurs also greyish, brownish, and greenish-black; ash and smoke-grey; hair and clove-brown. Often striped and spotted. Fracture perfect conchoidal. Its internal lustre splendent, vitreous. Fragments sharp-edged. Transparent; sometimes only translucent. Easily frangible. Specific gravity 2·348 to 2.432.† Melts into an opaque grey mass.

Sp. 2. *Pitch-stone.‡*

This stone, which occurs in different parts of Germany, France, and other countries, has obtained its name from some resemblance which it has been supposed to have to pitch. It occurs in beds in porphyry; and in beds and veins in the newest floëtz trap. Massive. Colours black, green, brown, red, grey, of various shades. Fracture imperfect flat large conchoidal; sometimes approaches to splintery. Lustre from shining to glimmering, between vitreous and resinous. Translucent. Hard. Brittle. Very easily frangible; it often yields even to the nail of the finger. Specific gravity 2·314 § to 1·645.‖ Fusible. At 21° Wedgewood swells a little; softened at 31°. The green variety from Arran becomes perfectly white and porous at 70°.**

Sp. 3. *Pearl-stone.††*

This mineral, which occurs in Tokay in Hungary, in Kamschatka, and near Sandy Brae in Ireland, was first made known to mineralogists under the name of *volcanic zeolite*. Werner, when he introduced it into the system, gave it the name of *pearl-stone*. It is found in beds in porphyry, commonly vesicular, and the vesicles are round. Usual colour grey; sometimes black and red. The varieties of grey are smoke, bluish, ash, yellowish, and pearl-grey; from ash-

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* Kirwan, i. 221. Brochant, i. 288. Haüy, iv. 494. Jameson i. 270.
† Humboldt, Gehlen's Jour. v. 122.
‡ Kirwan, i. 292. Brochant, i. 353. Haüy, iv. 386. Jameson, i 276.
§ Bumenbach.   ‖ Klaproth.   ** Jameson, i. 262.
†† Jameson, i. 281. Klaproth, iii. 326.

Book III. grey it passes into greyish-black; from pearl-grey into flesh and brick-red, and reddish-brown. Lustre shining, pearly. Fracture scarcely discernible; appears to be small imperfect conchoidal. Fragments blunt-edged. Occurs in large angular-grained distinct concretions; these are composed of small round-grained concretions; and these again of very thin lamellar distinct concretions. Translucent on the edges. Not brittle. Very easily frangible. Soft. Specific gravity 2·340.*

Sp. 4. *Pumice.*†

This mineral occurs in great abundance in the Lipari Islands; it occurs also on the banks of the Rhine and in Hungary. Usually in vesicular masses. Colours light yellowish-grey and smoke-grey; sometimes ash-grey. Lustre in the principal fracture glistening, pearly; in the cross vitreous. Principal fracture parallel curved fibrous; cross fracture uneven, and imperfect conchoidal. Fragments blunt-edged and splintery. Translucent on the edges. Soft. Very brittle. Easily frangible. Swims in water.

The following table exhibits the constituents of the preceding minerals, according to the most accurate analyses hitherto made:

Constituents.	Obsidian.				Pitch-stone.	Pearl-stone.		Pumice.
	‡	§	§	‖	**	††	‡‡	§§
Silica	72·0	72	71	78	73	75·25	77	77·50
Alumina ..	12·5	14·2	13·4	10	14·5	12·00	13	17·50
Lime......	—	1·2	1·6	1	1·0	0·50	—	—
Iron oxide.	2·0	3	4·0	2	1·0	1·60	2	1·75
Mang. ox. .	—	—	—	1·6	0·1	—	—	—
Potash .. ⎱	10	3·3	5	6	—	4·50	2	3·00
Soda ... ⎰				—	1·75	—	0·7	
Water	—	—	—	—	8·50	4·50	4	—
Loss.......	3·5	6·3	5	1·4	0·15	1·65	1·3	0·25
	100	100	100	100	100	100	100	100

* Klaproth.   † Jameson, i. 284.

‡ Descotils, Gehlen's Jour. v. 122.   § Drappier, ibid.

‖ Vauquelin, ibid. p. 230.   ** Klaproth, Beitrage, iii. 265.

†† Klaproth, Beitrage, iii. 331.

‡‡ Vauquelin, Gehlen's Jour. v. 230.

§§ Klaproth, Beitrage, iii. 265.

From these analyses, it appears that all the species are composed very nearly of the same ingredients; namely, about six parts of silica, one of alumina, and a portion of fixed alkali.

<div align="center">IX. ZEOLITE FAMILY.</div>

This family contains eleven species; namely, *wavellite*, *prehnite*, *mesotype*, *natrolite*, *stilbite*, *apophyllite*, *analcime*, *chabasite*, *cross-stone*, *lomonite*, *depyre*.

<div align="center">Sp. 1. *Wavellite.**</div>

<div align="center">*Hydrargillite* of Davy.</div>

This mineral was found long ago by Dr. Wavell, in a quarry near Barnstaple in Devonshire. Dr. Babington examined it; and concluding, from its physical characters, that it differed from all minerals previously described, gave it the name of *wavellite*, from the discoverer. It has since been found in other places. Humbolt brought specimens of it from Huelgayoc in South America.

Of this mineral there are two subspecies, which have been distinguished by Mr. Gregor, who had an opportunity of examining various specimens of the mineral from the mine called Stenna Gwyn, in the parish of St. Stephen's, Cornwall.

<div align="center">Subsp. 1. *Soft Wavellite.*</div>

It consists of an assemblage of minute crystals attached in tufts to quartz, and radiating from the point of adherence. Sometimes they adhere pertinaciously; at others they are easily separated. Size of the crystals various; sometimes they have the appearance of a fine powder or down; the larger sort about the size of a hair. Seldom above a quarter of an inch in length. Seem to consist of four-sided prisms; when broken the section is rhomboidal. Colour white. Surface sometimes stained ochre yellow. Easily reduced to a powder of a brilliant whiteness. Transparent. Specific gravity 2·22. Infusible before the blowpipe.†

<div align="center">Subsp. 2. *Compact Wavellite.*</div>

It consists of an assemblage of crystals, closely com-

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* Davy, Nicholson's Jour. xi. 153. Gregor, ibid. xiii. 247. Klaproth, v. 106. Jameson, i. 334.

† Gregor.

Book III. pacted together in the form of mamillary protuberances, of the size of small peas, and intimately connected together. A stratum of these, about $\frac{1}{8}$th inch thick, is spread upon quartz in the cavities of granite. Striæ diverge from a centre. Colour the same as the preceding. Hard enough to scratch calcareous spar. Specific gravity 2·253. Does not imbibe water. Decrepitates when suddenly heated.* Does not become electrical or phosphorescent by heat or fusion.† It seems to be a hydrate of alumina. The following table exhibits the analyses of it hitherto made.

	‡	§	‖	‖	**
Alumina.......	70	58·70	71·51	68·0	81·7
Silica	—	6·12	—	4·5	—
Lime	1·4	0·37	—	—	4·0
Oxide of iron ..	—	0·19	0·5	1	—
Magnesia......	—	—	—	—	0·83
Water	26·2	30·75	28	26·5	13·5
Potash	—	—	—	—	0·5
Loss	2·4	3·87	—	—	—
	100·	100·	100·	100·	100·53

If we were to consider the analysis of Mr. Gregor as correct, and from his well known accuracy I am disposed to confide in it, wavellite is a compound of 1 atom alumina and 1 atom water.

Sp. 2. *Prehnite.*††

Though this stone had been mentioned by Sage,‡‡ Romé de Lisle,§§ and other mineralogists, Werner was the first

* Gregor.   † Davy.

‡ Davy, Nicholson's Jour. ii. 157. Davy found a minute portion of fluoric acid.

§ Gregor, ibid. xiii. 254.

‖ Klaproth, Beitrage, v. 106. First specimen from Barnstable, second from Hualgayoc.

** John, Annals of Philosophy, iv. 216. He calls the specimen earthy wavellite.

†† Kirwan, i. 274. Hassenfratz, Jour. de Phys. xxxii. 81. Sage, ibid. xxxiv. 446. Klaproth, Beob. der Berlin, 2 Band. 211; and Ann. de Chim. i. 201. Haüy, iii. 167. Brochant, i. 295. Jameson, i. 290.

‡‡ Miner. i. 232.   §§ Crystall. ii. 275.

who properly distinguished it from other minerals, and made it a distinct species. The specimen which he examined was brought from the Cape of Good Hope by Colonel Prehn; hence the name *prehnite*, by which he distinguished it. It was found near Dunbarton by Mr. Grotche;* and since that time it has been observed in other parts of Scotland.

It is both amorphous and crystallized. The primitive form is a rectangular rhomboidal prism. Sometimes they are irregular six-sided plates, and sometimes flat rhomboidal parallelopipeds.

Colour greenish-white, greenish-grey, mountain-green, apple-green, yellowish-grey, and yellowish-green. Lustre shining, pearly. Fracture sometimes foliated, with an imperfect single cleavage; sometimes radiated. Fragments wedge-shaped. The foliated varieties are composed of granular distinct concretions; the radiated in wedge-shaped distinct concretions. Translucent; sometimes transparent. Scratches glass slightly. Easily frangible. Specific gravity 2·097 to 2·6969.† Before the blow-pipe froths strongly, and melts into a brown enamel. The following table exhibits the experiments hitherto made to determine the composition of this mineral.

	‡	§	‖	**	**	††
Silica	43·8	50·0	42·5	42·875	43·00	48
Alumina	30·33	20·4	28·5	21·50	23·25	24
Lime	18·33	23·3	28·4	26·50	26·00	23
Magnesia	—	0·5	—	Trace	Trace	—
Oxide of iron	5·66	4·9	3·0	—	2·00	4
Oxide of manganese .	—	—	—	0·25	0·25	—
Potash and soda	—	—	0·75	—	—	—
Water	1·16	0·9	2·0	4·625	4·00	—
Loss	0·96	—	2·85	1·25	1·5	1
	100	100	100	100	100	100

* Ann. de Chim. i. 213. † Haüy.

‡ Klaproth, Ann. de Chim. i. 208. § Hassenfratz, ibid.

‖ Laugier, Ann. de Chim. lxxv. 78.

** Gehlen, Schweigger's Journal, iii. 182.

†† Vauquelin, Haüy, iv. 373.

These analyses indicate combinations of silicate of alumina, silicate of lime, and perhaps also silicate of iron with some water. But they vary too much to allow us to determine the number of atoms of each silicate, which enter into the composition of prehnite.

Sp. 3. *Zeolite.**

This mineral was first noticed by Cronstedt, who described it in the Stockholm Transactions for 1756, and gave it the name which it now bears; but it is to Werner and Haüy that we are indebted for the exact discrimation of its different varieties. I propose, in this place, to confine the word zeolite to the mineral species which Haüy has distinguished by the name of *mesotype.*

It is found massive, globular, and crystallized. The primitive form of its crystals, according to Haüy, is a rectangular prism, whose bases are squares. The most common variety is a long four-sided prism, terminated by low four-sided pyramids.†

Colour yellowish, greyish, reddish, and snow-white. External lustre shining, pearly; internal glistening, pearly. Fracture narrow and broad radiated. Fragments sometimes wedge-shaped. In large longish distinct concretions. Translucent, sometimes semitransparent. Occasions double refraction. Scratches calcareous spar. Brittle. Easily frangible. Absorbs water. Specific gravity 2·0833. When heated it becomes electric like the tourmaline.‡ Before the blow-pipe it froths,§ emits a phosphorescent light, and melts into a white semitransparent enamel, too soft to cut glass, and soluble in acids. In acids it dissolves slowly and partially without effervescence; and at last, unless the quantity of liquid be too great, it is converted into a jelly.

The substance called by Werner *mealy zeolite* is merely a variety of this species. Colour yellowish or reddish-white. Occurs massive and coralloidal, and sometimes covers the surface of the other subspecies. Internal lustre dull.

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* Kirwan, i. 278. Guettard, iv. 637. Bucquet, Mem. Sav. Etrang. ix. 576. Pelletier, Jour. de Phys. xx. 420. Haüy, iii. 151. Brochant, i. 298. Jameson, i. 297.

† Haüy, Jour. de Min. No. xiv. 86.

‡ Haüy, Jour. de Min. No. xxviii. 276.

§ Hence the name *zeolite;* from ζεω and λιθος.

Fracture coarse earthy; sometimes delicately fibrous. Fragments blunt-edged. Opaque. Very soft. Easily frangible. Light. When the finger is drawn across it, a sound is given not unlike that from burnt bricks.

The mineral called *needle stone*, hitherto found only in Iceland and Britanny, is likewise a variety of zeolite. Common colour yellowish-white. Occurs massive and crystallized in rectangular four-sided acicular prisms, flatly acuminated by four planes set on the lateral faces. Crystals sometimes scopiform aggregated, sometimes intersect each other. They are longitudinally streaked. External lustre shining, bordering on splendent; internal glistening, vitreous. Principal fracture imperfect narrow straight radiated; cross fracture uneven and glassy. Composed of very thin columnar distinct concretions, again aggregated into large angular concretions. Amorphous specimens translucent, crystals transparent. Hard. Brittle.

The following table exhibits the experiments hitherto made to determine the composition of zeolite.

	*	†	‡	§
Silica.............	49	50·24	60·0	54·40
Alumina........	27	29·30	15·6	19·70
Lime.............	—	9·46	8·0	1·61
Oxide of iron...	—	—	1·8	—
Soda.............	17	—	—	15·09
Water..........	9·5	10·	11·6	9·83
Loss	—	1	3·0	—
	102·5	100·00	100·	100·63

Sp. 4. *Natrolite.*‖

This mineral, which was first described and analysed by Klaproth, received its name from that chemist, on account of the large proportion of soda which it contains. Hitherto it has been found only in the mountains of Suabia, where it borders on Switzerland, and at Burntisland in Scotland.

* Smithson, Phil. Trans. 1811, p. 171.
† Vauquelin, Jour. de Min. No. xliv. p. 576, a needle zeolite from Ferro.
‡ Hisinger, Afhandlingar, iii. 313. A mealy zeolite from Fahlun.
§ Gehlen, Schweigger's Journal, viii. 355.
‖ Jameson, i. 332.

Mr. Smithson has shown that it is only a variety of the preceding species.

Colours yellowish-white, cream-yellow, and light yellowish-brown. These colours form stripes, which are curved in the direction of the external surface. Massive and reniform. Crystals, the same as those of zeolite. Surface drusy, being covered with minute crystals, seemingly rhomboidal. Internal lustre glimmering. Fracture delicate fibrous. Occurs in granular distinct concretions. Harder than staurolite. Translucent on the edges. Easily frangible. Before the blow-pipe it melts easily into a transparent glass full of cavities. Specific gravity 2·229.

Its constituents are as follows : *

Silica	48·00
Alumina	24·25
Oxide of iron	1·75
Soda	16·50
Water	9·
Loss	0·5
	100

If we compare this analysis with Mr. Smithson's analysis of zeolite it will be evident that the two constitute only one species.

Sp. 5.   *Stilbite.*†

This species, which is the foliated zeolite of Werner, occurs massive, globular, and crystallized. The primitive form of its crystals is a rectangular prism, whose bases are rectangles. It crystallizes sometimes in dodecahedrons, consisting of a four-sided prism with hexagonal faces, terminated by four-sided summits, whose faces are oblique parallelograms ; sometimes in six-sided prisms, two of whose solid angles are wanting, and a small triangular face in their place.‡

Colour yellowish or greyish-white; and sometimes, though seldom, snow and reddish-white. Internal lustre shining, pearly. Fracture perfect foliated ; folia somewhat curved; cleavage single. In granular, and sometimes, though

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* Klaproth, Beitrage, v. 44.   † Jameson, i. 307.
‡ Haüy, Jour. de Min. No. xiv. 86.

rarely, in lamellar distinct concretions. Crystals transparent; massive portions translucent. Hardness inferior to that of zeolite. Brittle. Specific gravity 2·500.* Powder, when exposed to the air, cakes and adheres as if it had absorbed water. It causes syrup of violets to assume a green colour. When heated in a porcelain crucible, it swells up and assumes the colour and semitransparency of baked porcelain. By this process it loses 0·185 of its weight. Before the blow-pipe it froths like borax, and then melts into an opaque white coloured enamel.† Does not gelatinize in acids. Not electric by heat.

The fibrous zeolite of Werner is merely a variety of this species. It is massive, in balls, and likewise in capillary crystals. Colours snow white, yellowish white, greenish white, reddish white; ochre yellow; greenish grey; flesh red. Internal lustre glimmering, pearly. Fracture fine fibrous; sometimes splintery. Fragments wedge-shaped. In granular distinct concretions. Translucent. Semihard. Easily frangible.

The following table exhibits the composition of this species according to the most accurate experiments hitherto made:

	‡	§	‖
Silica	55·615	58	52
Alumina	16·681	16·1	17·5
Lime	8·170	9·2	9
Soda	1·536		
Water	19·300	16·4	18·5
Loss	——	0·3	3·0
	101·302	100·0	100

Sp. 6. *Apophylite.***
Ichthyophthalmite.

This mineral is said to occur in Uton, in Sudermania. Colour yellowish, reddish, greyish, and greenish white.

* Haüy, Jour. de Min. No. xxviii. 276.
† Vauquelin, Ibid. No. xxxix. 161.
‡ Gehlen, Schweigger's Journal, viii. 355.
§ Hisinger, Afhandlingar, iv. 357.
‖ Vauquelin, Jour. de Min. No. xxxix. 164.
** Jameson, i. 312.

Book III. Occurs massive and crystallized in rhomboids which deviate very little from cubes, in rectangular four-sided tables, having their edges truncated, and in thick six-sided tables. External lustre of the crystals splendent, and they are distinguished by a characteristic lustre; internal glistening, pearly. Principal fracture foliated, with a single cleavage parallel to the lateral faces of the table; its lustre splendent. Cross fracture fine grained uneven; its lustre glistening. Semi-transparent, sometimes translucent. Semihard. Very easily frangible. Specific gravity 2·491. Before the blowpipe froths and melts into an opaque bead.*

The following table exhibits the constituents of this mineral:

	†	‡
Silica	52	51
Lime	24·5	28
Potash	8·1	4
Water	15·0	17
Loss	0·4	—
	100·0	100

Sp. 7. *Analcime.* §
Cubizite of Werner.

This stone, which was discovered by Mr. Dolomieu, is found crystallized in the cavities of basalt. It was first made a distinct species by Mr. Haüy. Mineralogists had formerly confounded it with zeolite.

Crystals. The primitive form of its crystals is a cube. It is sometimes found crystallized in cubes, whose solid angles are wanting, and three small triangular faces in place of each; sometimes in polyhedrons with twenty-four faces. External lustre splendent, between pearly and vitreous: internal shining. Fracture very imperfect foliated. Cleavage triple, parallel to the sides of the cube. Fragments approaching to cubic. Has a tendency to granular distinct concretions. Translucent. Hard; scratches glass slightly. Specific gravity 2·244. Colour white; sometimes red. When

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* Fourcroy and Vauquelin.
† Rose, Gehlen's Journal, v. 44.
‡ Fourcroy and Vauquelin, Ann. de Mus. d'Hist. Nat. i. 472.
§ Haüy, iii. 180. Brochant, i. 309. Jameson, i. 317.

rubbed, it acquires only a small degree of electricity, and with difficulty.* Before the blow-pipe it melts without frothing into a white semi-transparent glass.†

Its constituents are as follows:

	‡		‡
Silica	58	....	50
Alumina	18	....	20
Lime	2	....	4·5
Soda	10	....	4·5
Water	8·5	....	21·0
Loss	3·5	....	——
	——		——
	100		100

Sp. 8.   *Chabasite.*§

This mineral, which was first separated from the preceding species by Bosc d'Antic and Haüy, is found at Oberstein in Germany. It occurs usually in crystals. The primitive form is a rhomboid differing very little from a cube, having the angle at its summit $93\frac{1}{2}°$. Sometimes it occurs in that form; at other times six of its edges are truncated, and the truncatures unite, three and three, at the two opposite angles, while the other six angles are truncated : sometimes in double six-sided pyramids applied base to base, having the six angles at the base and the three acute edges of each pyramid truncated. Colour white; sometimes transparent. Specific gravity 2·7176. Scratches glass. Melts before the blow-pipe into a white spongy mass.

It constituents are as follows :

Silica	43·33
Alumina	22·66
Lime	3·34
Soda with potash	9·34
Water	21·00
Loss	0·33
	——
	100·00‖

* Hence the name *analcime* given it by Haüy, from αναλκις, *weak.*
† Haüy, Jour. de Min. No. xiv. 86, and xxviii. 278.
‡ Vauquelin, Haüy's tableau compar. p. 199.
§ Haüy, iii. 176.—Brochant, i. 309.—Jameson, i. 321.
‖ Vauquelin, Ann. de Mus. d'Hist. Nat. ix. 333.

Sp. 9. *Cross-stone.**

Andreolite of Lametherie—*Hyacinthe blanche cruciforme,*
var. 9. of Romé de Lisle—*Harmotome* of Haüy.

This stone has been found at Andreasberg in the Hartz,
and at Strontian in Argyleshire, in veins. At Oberstein it
occurs crystallized in agate balls. The form of its crystals
has induced mineralogists to give it the name of *cross-stone.*
Its crystals are two four-sided flattened prisms, terminated
by four-sided pyramids, intersecting each other at right
angles: the plane of intersection passing longitudinally
through the prisms. Sometimes these prisms occur solitary.
Primitive form an octahedron with isosceles triangular
faces. The faces of the crystals striated longitudinally.

Colour greyish white. Lustre shining, between pearly
and vitreous. Cross fracture uneven, sometimes small con-
choidal; longitudinal fracture foliated. Translucent.
Scratches glass easily. Easily frangible. Specific gravity
2·333 to 2·361. When heated slowly, it loses 0·15 or 0·16
parts of its weight, and falls into powder. It effervesces
with borax and microcosmic salt, and is reduced to a
greenish opaque mass. With soda it melts into a frothy
white enamel. When its powder is thrown on a hot coal,
it emits a greenish yellow light.†

Its constituents are as follows:

	‡		§
Silica	49	....	47·5
Alumina	16	....	19·5
Barytes	18	....	16
Water	15	....	13·5
Loss	2	....	3·5
	100		100

Sp. 10. *Lomonite.*||

This mineral was named by Werner from Gillet Lau-
mont, who found it in 1785 in the mine of Huelgoët.

* Kirwan, i. 282. Haüy, iii. 191. Brochant, i. 311. Jameson, i.
324. See also Gillot, Jour. de Phys. 1793, p. 1 and 2.
† Haüy, Jour. de Min. No. xxviii. 280.
‡ Klaproth, Beitrage, ii. 83.
§ Tassaert, Haüy's Tableau Comparatif, p. 201.
|| Jameson, ii. 540. Haüy, iv. 410.

Colour snow white. Massive. Sometimes crystallized. Primitive form a rectangular octahedron. Fracture foliated; surface of the folia streaked, which gives a peculiar lustre to the surface of the mineral. Lustre shining, pearly. Composed of longish granular distinct concretions. Scarcely translucent. Very soft. Sectile. Easily frangible. Rather light.

The mineral, while kept from the external air, preserves a certain degree of cohesion; but when exposed it soon splits in the direction of the folia, and falls into small pieces.

Sp. 11. *Dipyre.**

Schmelzstein of Werner.

This mineral has been found at Mauleon in the Pyrenees, imbedded either in fascicular masses or in small prisms in a rock of steatite. Colour reddish or greyish white. Longitudinal fracture foliated, and the folia are parallel to the plains of the regular hexahedron. Lustre shining, glassy. Hard. Easily frangible. Specific gravity 2·630. Melts and froths before the blow-pipe. Phosphoresces slightly on hot coals.

The constituents of this mineral are as follows:

$$
\begin{array}{lr}
\text{Silica} & 60 \\
\text{Alumina} & 24 \\
\text{Lime} & 10 \\
\text{Water} & 2 \\
\text{Loss} & 4 \\
\hline
& 100 \dagger
\end{array}
$$

X. Azure-stone Family.

Azure-stone family.

This family contains four species; namely, *lazulite, azurite, hauyne, blue spar.*

Sp. 1. *Lazulite.‡*

Lapis Lazuli of Mineralogists.

This stone, which is found chiefly in the northern parts

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* Brochant, ii. 508. Haüy, iii. 242. Jameson, i. 330.

† Vauquelin, Haüy, iii. 243.

‡ Kirwan, i. 283. Haüy, iii. 145. Brochant, i. 313. Jameson, i. 337.

of Asia, was long known to mineralogists by the name of *lapis lazuli.*

Colour azure blue. Some varieties pass into berlin blue, and others into smalt blue. Found massive, disseminated, and in rolled pieces. Lustre glistening. Fracture fine-grained uneven. Translucent on the edges. Scratches glass. Brittle. Easily frangible. Specific gravity 2·76 to 2·945.*

It retains its colour at 100° Wedgewood; in a higher heat it intumesces, and melts into a yellowish black mass. With acids it effervesces a little; and if previously calcined, forms with them a jelly. Margraff published an analysis of lazulite in the Berlin Memoirs for 1758. His analysis has since been confirmed by Klaproth. Lermina has announced that this mineral has been found crystallized in garnet dodecahedrons.†

Its constituents, according to the analysis of Klaproth, are as follows:

Silica .... 46·0
Lime .... 28·0
Alumina . ... 14·5
Oxide of iron .... 3·0
Sulphate of lime .... 6·5
Water .... 2·0
               ————
               100·0 ‡

There is reason to suspect from this analysis that the mineral is not a chemical compound, or at least that it is mixed with foreign matter.

Sp. 2. *Azurite.*§

Lazulite of Werner.

This mineral was first made known to mineralogists by Klaproth,‖ who gave a short description of it as found at Vorau in Austria, and proved that it differed from every other known mineral. A substance, to which the same name was given, was found afterwards in Stiria near Waldbach, and in the neighbourhood of Winerisch Neustadt;

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* Brisson.   † Ann. de Chim. i. 144.
‡ Beitrage, i. 196. The lime was in the state of carbonate.
§ Jameson's Min. i. 341.   ‖ Beitrage, i. 197.

and described and analysed in 1806 by Bernhardi and Trommsdorff.*   A mineral was discovered about the same time by Baron Von Moll, to which the name of *mollite* was first given. It was afterwards called *siderite;* and Mohs showed that it was the same with the azurite. In 1807 Leonhard † published a description of the *lazulite* and *siderite*, which he considers as two distinct species. According to him, Bernhardi, Trommsdorff, and Mohs had seen only the lazulite and not the siderite. Leonhard's description of the lazulite differs considerably from that of Bernhardi. In 1807, Klaproth ‡ published a description and analysis of a mineral from Krieglach in Stiria, which he called *lazulite*, but which obviously differed in its properties both from the *lazulite* and *siderite* of preceding writers. The name *azurite* is here confined to the mineral originally pointed out by Klaproth as from Vorau.

It occurs imbedded in mica slate, and according to Leonhard in the rifts of clay-slate. Colour intermediate between berlin and smalt blue. Disseminated and in crystals, which are imperfect, but appear to be very oblique four-sided prisms.§   The sides of the prisms are sometimes smooth, sometimes faintly streaked longitudinally. Lustre shining, vitreous. Longitudinal fracture imperfect foliated, cross fracture small grained uneven. Fragments indeterminate, rather sharp edged. Opaque or nearly so. Semihard. Brittle. Easily frangible. Its constituents are as follows :

Alumina	66
Magnesia	18
Silica	10
Lime	2
Oxide of iron	2·5
Loss	1·5

100·0 ‖

Sp. 3. *Hauyne.*

This mineral has been hitherto found only in four

* Gehlen's Jour. Second Series, i. 204.   † Ibid. iii. 101.
‡ Beitrage, iv. 279.
§ Bernhardi describes the crystals as octahedrons ; but Leonhard says he never perceived any such figure in the azurite of Saltzburg.
‖ Trommsdorf, Gehlen's Jour. Second Series, i. 208.

Book III. places, all of which are considered as volcanic ; namely, the neighbourhood of Rome, Naples, Andernach, and Auvergne. It was first observed near Rome by Gismondi, who gave it the name of *latialite*. Neergaard afterwards described it and gave it the name of *hauyne*, in honour of the Abbe Haüy to whom mineralogy lies under so many obligations. It was afterwards described and analysed by Leopold Gmelin.*

Colour prussian blue, passing into beryl blue, through sky blue. Imbedded in lava in angular grains. Gmelin found one specimen crystallized in an imperfect octahedron. Internal lustre shining and vitreous. Fracture imperfect conchoidal. Fragments sharp edged. Semitransparent and translucent. Scratches glass and even quartz, but very feebly. Easily frangible. Powder whitish. Specific gravity according to Gismondi 3·333, according to Neergaard 3·100, according to Gmelin 2·833. Before the blowpipe it melts with difficulty into an opaque bead, full of air bubbles. With borax it melts into a transparent topaz coloured bead. In muriatic acid it becomes opaque and loses its colour. When thrown into that acid in the state of powder it emits the odour of sulphureted hydrogen and gelatinizes. Its constituents are as follows :

	†	‡
Silica	35·48	30·0
Alumina	18·87	15·0
Lime	11·79	13·5
Sulphuric acid	12·60	12
Oxide of iron	1·16	1
Potash	15·45	11
Sulphureted hydrogen and loss	3·45	Trace
Loss	—	17·5
	100	100

Sp. 4. *Blue spar*.§

This mineral occurs in a mountain in Stiria, where it performs the part of felspar; the rock being composed chiefly of quartz and mica. Its colour is azure blue, passing

* Annals of Philosophy, iv. 193.
† Gmelin, Annals of Philosophy, iv. 198.
‡ Vauquelin, Haüy's tableau comparatif.
§ Jameson, i. 346.

into bluish white. Internal lustre glistening, resinous. Frac-
ture splintery, passing into concealed foliated. Fragments in-
determinate, not sharp-edged. Translucent on the edges.
Streak snow white. Semihard. Specific gravity 3·046.
Before the blow-pipe it becomes isabella-yellow, and splits,
but does not melt. With phosphate of soda or borax it
gradually melts into a transparent glass bead. Its con-
stituents are

Alumina	71
Silica	14
Magnesia	5
Lime	3
Iron oxide	0·75
Potash	0·25
Water	5
Loss	1
	100*

XI. Felspar Family.

This family contains fifteen species; namely, *gehlenite,*
andaluzite, saussurite, chiastolite, indianite, felspar, ekeber-
gite, spodumene, scapolite, bergmannite, elaolite, sodalite,
meionite, nepheline, and ice-spar.

Sp. 1. *Gehlenite.*

This mineral has been hitherto found only in the Tirol.
It occurs in calcareous spar on the south side of a mountain
at Bezza, two hours' journey from Pera. It was brought to
Munich by the mineral dealer, Frischholz, during the
course of 1815, and was described and analysed soon after
by Professor Fuchs.

It occurs usually crystallized in four-sided rectangular
prisms whose bases are squares; they are generally so low
as to approach the appearance of cubes. They are en-
tangled in each other, and the intervals between them are
filled up with calcareous spar. They have a triple clea-
vage, two of which can be readily distinguished, but the
third with difficulty.

Fracture sometimes uneven, sometimes fine splintery.
Lustre weakly glimmering, or almost dull; intermediate

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* Klaproth, Beitrage, iv. 279.

Book III. between vitreous and resinous. Semihard in a high degree, scratching glass; but not striking fire with steel. Translucent on the edges or opaque. Feel of the crystals resinous, of the powder meagre. Easily frangible. Brittle. Sp. gravity 2·98. Principal colour intermediate between olive and leek green. Sometimes bluish grey or bluish black, or oil green or liver brown. Before the blow-pipe it melts with difficulty into a yellowish green semitransparent bead. When the flame is long continued it becomes black. Its constituents are

Silica	29·64
Alumina	24·80
Lime	35·30
Oxide of iron	6·56
Water	3·30
	99·60 *

Sp. 2. *Andaluzite.*†

This mineral was discovered by Bournon in a primitive granitic mountain in Forez, and described by him in the Journal de Physique of 1789. At first it was considered as a variety of corundum or felspar. It has been found in Aberdeenshire in Scotland, and near Dublin.

Colour flesh red, sometimes approaching to rose red. Massive, and crystallized in rectangular four-sided prisms. Fracture imperfect foliated. Translucent. Scratches quartz, and even sometimes spinell. Easily frangible. Specific gravity 3·165. Infusible by the blow-pipe without addition. Its constituents are as follows:

Alumina	52
Silica	32
Potash	8
Oxide of iron	2
Loss	6
	100 ‡

Sp. 3. *Saussurite.*§

This mineral was originally described by Saussure in his

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* Fuchs, Schweigger's Jour. xv. 377.
† Kirwan, i. 377. Haüy, iv. 362. Jameson, i. 348.
‡ Vauquelin, Brogniart's Miner. i. 36.   § Jameson, i. 351.

travels under the name of *jade.* It was confounded with felspar till Th. de Saussure drew the attention of mineralogists to it.* Still more lately it was described and analysed by Klaproth.† It occurs most commonly with diallage forming a very beautiful rock, called *diallage rock.* In this state it occurs in the peninsula of the Lizzard in Cornwall, near Christiania in Norway, and in Corsica constituting the well known rock called *Verde di Corsica.* It is common also about the lake of Geneva.

Colours white, grey, and green. It occurs massive and disseminated. Internal lustre dull or feebly glimmering. Fracture splintery; sometimes imperfect foliated with a double rectangular cleavage. Fragments very sharp edged. Faintly translucent on the edges. Very tough. Hard enough to scratch quartz. Feel meagre. Sp. gravity from 3·200 to 3·319. Its constituents are as follows:

Silica	44·00	49·00
Alumina	30·00	24·00
Lime	4·00	10·50
Magnesia	——	3·75
Soda	6·00	5·50
Potash	0·25	——
Oxide of iron	12·50	6·50
Oxide of manganese	0·05	——
Loss	3·20	0·75
	100·00 ‡	100·00 §

Sp. 4. *Chiastolite.* ||

This singular mineral was first observed in Britanny, and near St. Jacques de Compostella in Spain. It is always crystallized in four-sided prisms nearly rectangular. When we view the end of the prism, we perceive in the centre of it a blackish prism inclosed in the larger one, which is of a greyish, yellowish, or reddish white colour. From each angle of the central prism, a blackish line passes to the corresponding angle of the outer prism; and in each of these external angles there is commonly a small prismatic space, filled with the same matter as that of which

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* Jour. de Min. No. cxi. p. 205.   † Beitrage, iv. 276.
‡ Th. de Saussure, Jour. de Min. No. cxi. p. 217.
§ Klaproth, Beitrage, iv. 278. || Jameson, i. 353.

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the central prism is composed. This matter is a blackish coloured clay slate, the same as the rock in which the hollow spar is found imbedded.

Fracture foliated. Cleavage double, the folia being parallel to the lateral planes of the prism. Translucent; but opaque, when the crystals are in the state of decomposition. Scratches glass when in a fresh state. Specific gravity 2·9444. When rubbed upon sealing wax, it usually communicates negative electricity.* Before the blow-pipe it is converted into a whitish scoria. The clay slate yields a black glass.

Sp. 5. *Indianite.*†

This mineral has hitherto been observed only in the Carnatic where it is associated with hornblende, and contains imbedded crystals of corundum. It was first distinguished as a peculiar species by Count Bournon.

Colours white and grey. Massive. Lustre shining. Fracture foliated. In granular distinct concretions. Translucent. Scratches glass, but is scratched by felspar. Sp. gravity 2·742. Its constituents, according to the analysis of Chenevix, are as follows :

Silica . . . . 42·5
Alumina . . . . 37·5
Lime . . . . 15·0
Oxide of iron . . . . 3·0
Oxide of manganese . . . . Trace
Loss . . . . 2·0
                                   ————
                                   100·0

Sp. 6. *Felspar.*‡

This is one of the most widely distributed and most abundant of minerals, forming a constituent of granite, gneiss, and many other primitive and transition rocks. It is very frequently crystallized, and the primitive form of its crystals is an irregular parallelopiped, for a description of which I refer to Haüy. Occurs usually in rhomboidal prisms, or in six or ten-sided prisms, terminated by irregular summits. It gives out a peculiar odour when rubbed. Becomes electric by friction, but with great difficulty.

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* Haüy, iii. 268. Jameson, ii. 545.   † Jameson, i. 352.
‡ Kirwan, i. 316. Haüy, ii. 590. Brochant, i. 361. Jameson, i. 358.

Fusible *per se* into a more or less transparent glass. When crystallized it decrepitates before the blow-pipe. It has been divided into four subspecies.

Subsp. 1. *Adularia.*

This subspecies was first observed by Mr. Pini on the summit of Mount St. Gothard, in Switzerland, called Adula; hence its name. It has been found also in other places. The variety called *moon-stone* comes from Ceylon.

Colour greenish white, often inclining to asparagus green. Sometimes has milk-white spots, with a silvery lustre. Found massive, in rolled pieces, and crystallized in oblique four-sided prisms, bevelled on both ends; in six-sided prisms; and in rectangular four-sided prisms, with oblique terminal faces. Crystals streaked longitudinally. External lustre splendent, pearly; lustre of the principal fracture splendent; of the cross fracture shining, between vitreous and pearly. Principal fracture perfect specular splendent, with a double rectangular cleavage; cross fracture small imperfect conchoidal. Fragments rhomboidal. Tends to thick straight lamellar distinct concretions. Transparent and translucent. Hard, gives sparks with steel. Brittle. Easily frangible. Specific gravity 2·559.

Subsp. 2. *Labrador Felspar.*

This subspecies was first observed on the coast of Labrador by Mr. Wolfe, and since that time it has been discovered in the northern parts of the old continent.

Colour smoke grey, which passes into dark ash and yellowish grey; in certain positions it reflects a great variety of colours, as blue, green, yellow, red, brown. Occurs commonly massive and in rolled pieces. Fracture perfect foliated, folia crossing at right angles. Lustre of the principal fracture splendent; of the cross fracture glistening; between pearly and vitreous. Usually in granular distinct concretions; sometimes in thick straight lamellar distinct concretions. Translucent. Specific gravity 2·67 to 2·69.

Subsp. 3. *Common Felspar.*

Colours white, red, grey, and green. The varieties of grey are smoke and bluish grey: of white, greyish, milk, yellowish, greenish, and reddish white: of red, flesh, blood,

and brick red; of green, asparagus, leek, mountain, and verdigris green. Occurs massive, in rolled pieces, and in grains; also crystallized in six and four-sided prisms. External lustre shining; lustre of the principal fracture shining; of the cross fracture glimmering, vitreous. Fracture more or less perfect foliated; cleavage double, the folia intersecting at right angles; cross fracture fine-grained uneven, passing into splintery. Occurs in granular distinct concretions. Translucent. Scratches glass. Brittle. Easily frangible. Specific gravity from 2·4378 to 2·594.*

This subspecies frequently occurs in a *disintegrated* state, and then approaches porcelain clay; except that the crystalline form may sometimes be recognised. Its colour is yellowish or reddish white, sometimes verging on grey. Internal lustre between glistening and dull. Fracture sometimes imperfect foliated, passing into earthy; sometimes between uneven and earthy. Usually opaque. Soft. Easily frangible.

<div align="center">Subsp. 4.   <i>Compact Felspar.</i></div>

Petrosilex of the older French mineralogists. This mineral occurs abundantly in many countries, being a constituent of green-stone. Colours grey, white, blue, green, and red. The varieties of grey are greenish, smoke, and ash-grey; of green, apple, pistachio, mountain-green; of blue, sky and smalt-blue; of red, flesh and blood-red. Occurs massive, in rolled pieces, and in crystals, in antique-green porphyry. Internal lustre glimmering. Fracture appears splintery, but on examination proves to be very small foliated. Sometimes in fine granular distinct concretions. Translucent. Hard. Easily frangible. Melts before the blow-pipe without addition.

The following table exhibits the composition of this species:

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* Haüy.

	Adularia.		Glassy felspar.	Common.		Compact.	
	*	†	‡	§	‖	**	††
Silica	64	68·5	68·0	62·83	72·75	68	71·7
Alumina...........	20	20·5	15	17·02	13	19	13·6
Lime	2	7	—	3·00	9·5	1	0·4
Oxide of iron	—	1·5	5	1·00	1	4	1·4
Oxide of manganese	—	—	—	—	—	—	0·1
Potash	14	—	14·5	13·00	—	5·5	3·19
Water	—	—	—	—	0·25	2·5	3·5
Loss	—	2·5	2	3·15	3·50	—	6·64
	100	100	100	100	100	100	100

Sp. 7. *Ekebergite.*

This mineral was first described by Ekeberg, in 1807, under the name of natrolite.‡‡ It occurs in the iron-mine of Hesselkulla in Nerike, a province of Sweden, in amorphous masses usually associated with quartz. Its colour is greenish-grey. Lustre sometimes shining, sometimes glimmering and resinous. Sometimes the fracture is foliated with a twofold cleavage. Sometimes small conchoidal and splintery. In some directions it has a radiated appearance, owing to the position of the folia. Translucent on the edges. Strikes fire with steel and scratches glass. Rather tough. Specific gravity 2·746. Before the blow-pipe it melts into a semitransparent glass. With borax it fuses into a transparent olive-green glass bead. Its constituents, according to the analysis of Ekeberg, are as follows:

* Vauquelin, Haüy, ii. 592.
† Chenevix, Phil. Trans. 1802, p. 337.
‡ Klaproth, Beitrage, v. 18.   § Vauquelin, Haüy, ii. 593.
‖ Hedenberg, Afhandlingar, i. 118.
** Godon St. Menin, Gehlen's Jour. Second Series, iii. 511.
†† Mackenzie, Wernerian Memoirs, i. 618.
‡‡ Afhandlingar, ii. 144.

Silica 46
Alumina ..... 28·75
Lime .... 13·50
Oxide of iron.. 0·75
Soda .... 5·25
Water .... 2·25
Loss .... 3·50
                ———
                100·00

Sp. 8. *Spodomene.**
Triphane of Haüy.

This mineral, which has been found in the mine of Uton in Sweden, and in Norway, was first described by Dandrada. Colour greenish-white, sometimes apple-green. Massive. Lustre of the principal fracture shining; of the cross fracture glistening, pearly. Principal fracture foliated: cleavage double, the folia intersecting obliquely; cross fracture fine-grained uneven. According to Haüy, it yields by mechanical division a rhomboidal prism, with angles of 100° and 80°. Fragments sometimes in oblique rhombs. The massive varieties exhibit granular distinct concretions. Translucent. Scratches glass, and strikes fire with steel. Very easily frangible. Specific gravity 3·1923 to 3·218.† When heated in a crucible it splits into small plates; many of a golden-yellow colour, like some varieties of mica; others are dark-grey: in a few days they all lose their lustre, and become dark-grey.‡ Melts before the blow-pipe into a greyish globule.

The constituents of this mineral are as follows :

	§	‖	**	††
Silica.........	56·5	64·4	63·40	67·5
Alumina......	24·0	24·4	29·40	27·0
Lime.........	5·0	3·0	0·75	0·63
Oxide of iron..	5·0	2·2	3·00	3·0
Potash	—	5·0	—	—
Water.........	—	—	0·53	0·53
Loss	9·5	1·0	2·92	1·34
	——	——	——	——
	100	100	100	100

* Haüy, iv. 407. Brochant, ii. 528. Jameson, i. 383.
† Haüy and Dandrada.   ‡ Vauquelin, Haüy, iv. 408.
§ Vauquelin, Haüy, iv. 409.
‖ Vauquelin, Haüy's Tabldeau Comparatif, p. 168.
** Hisinger, Af handlingar, iii. 293.   †† Berzelius, ibid. p. 294.

Sp. 9. *Scapolite.*[*]

This species is divided into two subspecies, *radiated sca-polite* or *common scapolite*, and *foliated scapolite* or *Wer-nerite.*

Subsp. 1. *Radiated Scapolite.*

This mineral was first found near Arendal in Norway, in mines of freestone; it occurs likewise in Sweden. Colour greyish, yellowish, and greenish-white. Massive; but more commonly crystallized in long, thin, oblique, four-sided prisms, often acicular. Primitive form, a rectangular prism. Crystals slightly streaked longitudinally; aggregated into thick fasciculi, which are again united together. External lustre glistening; internal shining, between resinous and pearly. Longitudinal fracture imperfect foliated; cross fracture fine-grained uneven. Translucent. Scratches glass. Brittle. Easily frangible. Specific gravity from 2·7404 to 3·708. Before the blow-pipe, froths and melts into a white enamel.[†]

Subsp. 2. *Foliated Scapolite, or Wernerite.*

Arctizite of Werner.

This mineral was discovered and described by Dandrada, who named it after Werner. Hitherto it has been found chiefly in Sweden and Norway. Colour greenish-grey; surface of the crystals between sky-blue and celadon-green. Massive, and crystallized in low equiangular eight-sided prisms, terminated in flat four-sided pyramids. Internal lustre glistening, pearly. Fracture foliated. From the appearance of the folia, Werner gives the fracture the name of *torn*-foliated. Translucent. Scratches glass, and strikes fire with steel; but is scratched by felspar. Specific gravity 3·6063. The powder phosphoresces when heated. Before the blow-pipe, froths and melts into an imperfectly white and opaque enamel.

The constituents of these subspecies are as follows:

---

* Jameson, i. 385.   † Dandrada.

	Radiated scapolite.			Wernerite.	
	*	†	‡	§	§
Silica..............	45	61·50	48	51·5	40
Alumina............	33	25·75	30	33	34
Lime..............	17·6	3	14	10·45	16·5
Magnesia	—	0·75	—	—	—
Oxide of iron	1	1·50	1	3·5	8
Oxide of manganese...	—	1·50	—	Trace	1·5
Potash	0·5	—	—	—	—
Soda..............	1·5	—	—	—	—
Water	—	5·0	2	—	—
Loss	1·4	1·0	5	1·55	—
	100	100	100	100	100

Sp. 10.   *Bergmannite.*||

This mineral was first described by Schumacher. It occurs in a bed at Friedichswärn in Norway.

Colours greenish and greyish-white, and muddy flesh-red. Massive. Lustre glistening and intermediate between pearly and resinous. Fracture fibrous, which passes into fine-grained uneven. Fragments angular and not very sharp-edged. Slightly translucent on the edges. Scratches felspar. Melts before the blow-pipe without intumescing into a white semitransparent enamel.

Sp. 11.   *Elaolite.***
Fettstein of Werner.

It is found in Norway, in the rock called *zircon-syenite*. Its colours are duck-blue, inclining to green, and flesh-red, with a shade of grey or brown. Massive. Lustre shining and resinous. Fracture in the red variety flat and imperfect conchoidal, in the blue imperfect foliated, with a double cleavage. Fragments angular and not very sharp-edged. Translucent. Scratches glass. Rather easily frangible. Specific gravity 2·613. When pounded and thrown into

* Laugier, Ann. du Mus. d'Hist. Nat. x. 472.

† Hisinger, Afhandlingar, ii. 202.

‡ Abilgard, Jour. de Phys. lii. 33.

§ John, Gehlen's Jour. Second Series, iv. 183. The first specimen was white, the second green.

|| Jameson, i. 393.   ** Jameson, i. 394.

acids it gelatinizes. Before the blow-pipe melts into a milk-white enamel. Its constituents are as follows:

Silica............	46·50
Alumina........	30·25
Lime	0·75
Potash.........	18
Oxide of iron...	1
Water	2
Loss...........	1·5

$$100·00*$$

Sp. 12. *Sodalite.*[†]

This mineral was found by Giesecke at Kanerdluersuk, a narrow tongue of land in latitude 61°, West Greenland, where it occurs in a bed in mica-slate. I first described and analysed it, and constituted it a distinct species.

Colour between celandine and mountain-green. Massive and crystallized in garnet dodecahedrons. Externally it is smooth and shining; internally the longitudinal fracture is vitreous, the cross fracture resinous. Longitudinal fracture foliated with a twofold cleavage: cross fracture small conchoidal. Fragments angular and sharp-edged. Translucent. As hard as felspar. Brittle and easily frangible. Specific gravity 2·378. Its constituents are as follows:

	[‡]	[§]	[||]
Silica	31·52	36·00	44·87
Alumina.	27·48	32·00	23·75
Lime	2·70	—	—
Oxide of iron	1·00	0·25	0·12
Soda...........	25·50	25·00	27·50
Muriatic acid ...	3·00	6·75	—
Volatile matter ..	2·10	—	—
Loss...........	1·70	—	3·76
	100	100	100

Sp. 13. *Meionite.*[**]

This mineral is found on Somma, among the substances ejected by Mount Vesuvius. It was first described by Romé de Lisle, and constituted into a peculiar species by Haüy.

* Klaproth, Beitrage, v. 178.
† Edin. Trans. vi. 390. Jameson, i. 396.   ‡ By my analysis.
§ Ekeberg. || Borkowski.   ** Jameson i. 398.

The meionite occurs most usually in crystals, though sometimes it is observed in irregular grains. The primitive form of its crystals is a rectangular prism whose bases are squares. It occurs most commonly in an eight-sided prism terminated by four-sided pyramids. Sometimes the prism is twelve-sided by the truncation of some of its edges. Colour greyish-white. Lustre shining, vitreous. Fracture flat conchoidal. Translucent. Scratches glass, but not felspar. Melts before the blow-pipe into a white spongy glass.

Sp. 14.   *Nepheline*, or *Sommite*.[*]

Nepheline of Haüy.   *Hexagonal white schorl* of Ferber.
White hyacinth of Somma.

This stone was called *sommite* by Lametherie, from the mountain Somma, where it was first found. It is usually mixed with volcanic productions. It crystallizes in six-sided prisms, sometimes terminated by pyramids, and its primitive form is a regular six-sided prism. Colour greyish-white. External lustre shining, vitreous. Longitudinal fracture foliated; cross fracture conchoidal. Translucent. Easily frangible. Cuts glass. Specific gravity 3·2741. infusible by the blow-pipe. According to the analysis of Vauquelin, it is composed of

> Alumina 49
> Silica 46
> Lime. 2
> Oxide of iron . . . 1
> Loss. 2
> _____
> 100[†]

Sp. 15.   *Icespar.*[‡]

This mineral occurs also at Monte Somma near Naples, where it is mixed with the two last species, and with mica and hornblende.

Colour greyish-white, inclining sometimes to yellowish-white, sometimes to greenish-white. Often massive. Sometimes crystallized in thin longish six-sided tables, in which the shorter lateral planes meet under an obtuse angle, and the terminal planes are bevelled. Crystals small. Lateral planes

* Brochant, ii. 522. Haüy, iii. 186. Jameson, 401.
† Jour. de Min. No. xxviii. 279.   ‡ Jameson, i. 403.

of the prism longitudinally streaked. Lustre shining and vitreous. Fracture imperfect foliated. Fragments sharp-edged. Composed of large granular distinct concretions. Strongly translucent; crystals transparent. Hard in a low degree. Easily frangible. Rather heavy.

XII. CLAY FAMILY.

This family contains eight species; namely, *alumstone*, *porcelain earth*, *common clay*, *claystone*, *adhesive slate*, *polishing slate*, *tripoli*, *floatsone*.

Clay family.

Sp. 1. *Alumstone.* *

This mineral occurs at Tolfa, near Rome. where it is said to constitute a hill. From it the famous Roman alum is made.

Colour greyish-white, sometimes light yellowish-grey. Massive. Lustre dull, and sometimes (scarcely) glimmering. Fracture uneven, approaching to fine earthy. Fragments blunt-edged. Rather hard. Does not adhere to the tongue. Specific gravity 2·587.

The constituents of this mineral are as follows:

	†	‡	§
Silica.	24·00	56·5	62·25
Alumina	43·92	19·0	17·50
Lime	—	—	—
Magnesia.	—	—	—
Potash	3·08	4·0	1·00
Oxide of iron	—	—	—
Sulphuric acid	25·00	16·5	12·50
Water	4·00	3·0	5·00
Sulphate of lime	—	—	—
Sulphate of barytes	—	—	—
Charcoal	—	—	—
Loss.	—	1·0	1·75
	100	100	100

* Brochant, i. 381. Jameson, i. 407. Klaproth, Gehlen's Jour. vi. 35. Gay-Lussac, Ann. de Chim. lv. 266.

† Vauquelin, Gehlen's Jour. vi. 44.

‡ Klaproth, ibid. From these analyses, it appears that the alum-stone of Tolfa contains in itself all the constituents of alum. Hence, probably, the superiority which the alum obtained from it originally possessed; especially as the mineral does not appear to contain any foreign substance which can injure the purity of the alum. For a short sketch of the process followed at Tolfa, the reader is referred to Klaproth, Gehlen's Jour. vi. 37. § From Hungary. Klaproth, Beitrage, iv. 253.

Sp. 2. *Porcelain Earth.*

Kaolin of the Chinese.

This mineral, from the situation which it occupies, is considered as analogous to felspar, differing chiefly in the state of aggregation. Felspar indeed seems sometimes to be converted into it by exposure to the weather.

Colour reddish white, sometimes inclining to yellowish and greyish white. Massive and disseminated. Particles fine dusty. Colours strongly. Slightly cohering. Feels fine, but meagre. Scarcely adheres to the tongue. Specific gravity 2·216. Does not fuse *per se.*

Its constituents are,

$$
\begin{aligned}
&\text{Silica} \ldots \ldots \ldots \ 52\\
&\text{Alumina} \ \ldots \ldots \ 47\\
&\text{Oxide of iron} \ . \ \ 0\text{·}33\\
&\text{Loss} \ \ldots \ldots \ldots \ 0\text{·}67\\
&\overline{}\\
&100\text{·}00 \dagger
\end{aligned}
$$

Sp. 3. *Common Clay.* ‡

Clay is a mixture of alumina and silica in various proportions. The alumina is in the state of an impalpable powder; but the silica is almost always in small grains, large enough to be distinguished by the eye. Clay, therefore, exhibits the character of alumina, and not of silica, even when this last ingredient predominates. The particles of silica are already combined with each other; and they have so strong an affinity for each other, that few bodies can separate them; whereas the alumina, not being combined, readily displays the characters which distinguish it from other bodies. Besides alumina and silica, clay often contains carbonate of lime, of magnesia, barytes, oxide of iron, &c. And as clay is merely a mechanical mixture, the proportion of its ingredients is exceedingly various.

Werner, for the conveniency of description, has subdivided common clay into four subspecies, namely, *loam, potters' clay, variegated clay,* and *slate clay.*

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* Kirwan, i. 178. Brochant, i. 320. Haüy, ii. 616. Jameson, i. 409.　　　† Rose, Karsten's Tabellen, p. 37.

‡ Kirwan, i. 176. Jameson, i. 413.

Subsp. 1. *Loam.*

This may be considered as a very impure potter's clay, mixed with mica and iron ochre. Colour yellowish grey, often spotted yellow and brown. Occurs in masses. Lustre dull; sometimes glimmering, from scales of mica. Fracture *in the great*, uneven; *in the small* fine earthy. Fragments very blunt-edged. Colours a little. Between loose and cohering. Adheres pretty strongly to the tongue. Feels slightly greasy. Not heavy.

Subsp. 2. *Potter's Clay.*

This mineral, which occurs in great abundance in different countries, is used for the various purposes of pottery. Hence the name by which it is distinguished. It occurs in large rock masses and in beds. Colours yellowish and greyish white; greenish, bluish, and smoke grey. Fracture *in the great*, coarse-grained uneven; *in the small*, pretty fine earthy. Fragments blunt-edged. Opaque. Colours a little. Very soft, passing into loose. Adheres strongly to the tongue. Feels a little greasy. Sp. gr. 2·085.

There is a variety of potter's clay which Werner distinguishes by the name of *slaty*. Colour dark ash grey. Principal fracture imperfect conchoidal; cross fracture earthy. Fragments tabular. Rather light, and feels more greasy than common potter's clay; in other particulars it agrees with it.

Subsp. 3. *Variegated Clay.*

This mineral is found in Upper Lusatia. Colours white, red, and yellow, which appear in stripes and spots. Massive. Fracture earthy; sometimes tending to slaty. Lustre in the first case dull, in the second glimmering. Lustre of the streak shining. Very soft, passing into friable. Feels a little greasy. Adheres a little to the tongue. Sectile. Light.*

Subspecies 4. *Slate Clay.*

This mineral occurs frequently along with coal, and in the floëtz trap formation. Colour smoke, yellowish, and ash grey; greyish black. Massive. Lustre dull; some-

* Jameson, i. 308.

times glimmering, from particles of mica intermixed. Fracture slaty; sometimes approaches earthy. Fragments tabular. Opaque. Soft. Sectile. Easily frangible. Specific gravity, according to Kirwan, from 2·6 to 2·68. Adheres slightly to the tongue. Softens and breaks to pieces in water.

Sp. 4.   *Clay-stone.**

This mineral occurs in considerable quantities on the top of several of the Pentland hills, in the neighbourhood of Edinburgh, and likewise in other parts of Scotland, and in Germany.

Colours greenish, bluish, ash, smoke, and pearl grey; brownish red. Sometimes spotted or striped. Massive. Lustre dull. Fracture usually fine earthy; sometimes passing into fine grained uneven, into slaty, and into splintery. Fragments seldom tabular, not sharp-edged. Opaque. Soft. Easily frangible. Does not adhere to the tongue. Feels rather meagre.

Sp. 5.   *Adhesive Slate.*†

Klebschiefer of Werner.

This mineral occurs at Menil Montagne, near Paris, and has been by most mineralogists confounded with the next species. It is found in beds. Colour light yellowish grey, inclining to greenish. Internal lustre dull. Fracture *in the large,* slaty; *in the small,* fine earthy. Fragments slaty. Opaque. Lustre of streak shining. Sectile. Very soft. Easily frangible. Exfoliates easily. Adheres strongly to the tongue. Specific gravity as ascertained by Klaproth, 2·080. Absorbs water with avidity, air bubbles separating with a crackling noise.

Sp. 6.   *Polishing Slate.*‡

This mineral occurs near pseudo volcanoes, and is supposed by Werner to be composed of the ashes of pit-coal, washed down and regularly deposited. Hitherto it has been found only in Bohemia. Colour yellowish grey, approaching cream yellow and yellowish white. Always

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* Jameson, i. 540.

† Klaproth, ii. 170. Jameson, i. 421. Brochant, i. 376. Haüy, iv. 449.   ‡ Jameson, i. 423.

striped, and the colours alternate in layers. Massive. Lustre dull. Principal fracture slaty; cross fracture earthy. Fragments usually tabular. Very soft. Adheres to the tongue. Feels fine, but meagre. Rather light. Specific gravity, before it imbibes water, only from 0·590 to 0·606. After it has imbibed water, its specific gravity becomes from 1·909 to 1·911.*

Sp. 7. *Tripoli.* †

This mineral occurs in veins and beds along with coal, and in floëtz trap rocks. Colour yellowish grey, which passes into ash grey. Massive. Internal lustre dull. Fracture pretty coarse earthy. Fragments blunt-edged. Very soft. Feels meagre and rough. Does not adhere to the tongue. Specific gravity from 2·080 to 2·529. Used for polishing.

Sp. 8. *Float-stone.* ‡

This mineral has hitherto been found only at St. Omer, near Paris. Colour light yellowish grey, which inclines to yellowish and greyish white. Occurs tuberose, and is porous. Lustre dull. Fracture earthy. Fragments blunt-edged. Very soft. Rather brittle. Feels rough, and emits a creaking sound. Very light.

The following table exhibits the constituents of these different species, as far as they have been hitherto ascertained.

* Haberle, Gehlen's Jour. Second Series, ii. 29.
† Kirwan, i. 202. Brochant, i. 379. Jameson, i. 426.
‡ Jameson, i. 429.

	Pure Clay			Porcelain Earth		Potter's Clay		Adhesive Slate			Polishing Slate
	*	†	‡	§	‖	**	††	‡‡	§§	‖‖	***
Silica	0·45	2	1	62	55	52	43·5	66·5	62·50	58	79
Alumina	32·5	45	31	19	27	47	33·2	7	0·50	5	1
Lime	0·35	2	0·5	12	2	—	3·5	1·25	0·25	1·5	1
Magnesia	—	—	—	—	—	—	—	1·5	8	6·5	—
Potash	—	—	—	—	—	—	—	—	—	—	—
Oxide of iron	0·45	—	0·5	—	0·5	0·33	1	2·5	4	9	4
Sulphuric acid	19·35	—	21·5	—	—	—	—	—	—	—	—
Water	47	24	45	—	—	—	18	19	22	19	14
Sulphate of lime	—	27	—	—	14	—	—	—	—	—	—
Sulphate of bar	—	—	—	7	—	—	—	—	—	—	—
Charcoal	—	—	0·5	—	—	—	—	2·25	0·75	—	—
Loss	—	—	—	—	1·5	0·67	0·8	—	2	1	1
	100·1	100	100	100	100	100	100	100	100	100	100

* Simon, Gehlen's Jour. i. 671.　　† Fourcroy, Ann. de Mus. Nat. i. 43.　　‡ Bucholz, Gehlen's Jour. iv. 446. The result of Bucholz and Simon has been confirmed by Gehlen (Jour. i. 673), and Chenevix (Ann. de Chim. liv. 200). The specimen examined by Fourcroy must have contained an unusual proportion of sulphate of lime.

§ Hassenfratz, Ann. de Chim. xiv. 144.　　‖ Vauquelin, Bull. Phil. No. xxvi.　　** Rose, Jameson's Min. i. 298.

†† Vauquelin, Bull. Phil. No. xxvi.　　‡‡ Klaproth, Beitrage, ii. 171.　　§§ A more accurate analysis by Klaproth, Beitrage, iv. 314.　　‖‖ Bucholz, Gehlen's Jour. Second Series, ii. 37.　　*** Bucholz, Ibid. 28.

XIII. CLAY-SLATE FAMILY.

Clay-slate family.

This family contains five species, namely, *alum-slate, bituminous-slate, drawing-slate, whet-slate, clay-slate.*

Sp. 1. *Alum-slate.**

This mineral occurs in beds and strata in the newest clay-slate, and in transition mountains. Werner divides it into two subspecies, *the common* and the *glossy,* distinguished chiefly by their lustre.

Subsp. 1. *Common Alum-slate.*

This mineral occurs massive, and sometimes in balls. Colour between greyish and bluish black, falling strongly into grey. Internal lustre glimmering. Fracture perfect straight slaty. Fragments tabular. Retains its colour in the streak; becomes a little shining. Soft. Not particularly brittle. Easily frangible. When exposed to the air, effloresces and acquires an aluminous taste.

Subsp. 2. *Glossy Alum-slate.*

Massive. Colour between bluish and iron black. In the rents exhibits colours resembling tempered steel and the peacock's tail. Lustre of the principal fracture shining, and semi-metallic; of the cross fracture glimmering. Fracture partly straight, partly wave slaty. Fragments tabular, often running into wedge-shaped. In other respects resembles the former subspecies.

Sp. 2. *Bituminous Shale.*†

This mineral, which occurs along with coal, seems to be a mixture of clay and bitumen. Massive. Colour brownish black. Internal lustre glimmering. Fracture perfect straight slaty. Fragments tabular. Colour of streak not altered, but lustre shining. Very soft. Rather sectile. Feels greasy. Easily frangible. When laid on burning coals, it emits a pale flame and burns white.

Sp. 3. *Drawing-slate, or Black Chalk.*‡

This mineral occurs in the primitive mountains, and is usually accompanied by alum-slate. It is employed in drawing; hence the name.

Colour greyish black, sometimes approaching to bluish black. Massive. Lustre of the principal fracture glimmering; of the cross fracture dull. Principal fracture

* Jameson, i. 431.
† Kirwan, i. 183. Brochant, i. 389. Jameson, i. 434.
‡ Kirwan, i. 112. Brochant, i. 391. Jameson, i. 436.

slaty; cross fracture fine earthy. Fragments usually tabular. Opaque. Stains paper black. Colour of streak unchanged; its lustre glistening. Soft. Sectile. Easily frangible. Feels meagre, but fine. Specific gravity 2·144 to 2·77. Burns red. Does not fall to pieces in water.

Sp. 4.   *Whet-slate.**

Novaculite of Kirwan.

This mineral is found in Germany, and on the Levant, from which it is brought under the name of *Turkey hone stone.*

Common colour greenish grey; but it occurs also mountain, asparagus, olive, and oil green. Massive. Internal lustre glimmering or dull. Fracture *in the large*, slaty; *in the small*, splintery. Fragments tabular. Translucent on the edges. Semihard. Feels rather greasy. Specific gravity 2·677.

Sp. 5.   *Clay-slate.*†

Argillaceous schistus—Argillite of Kirwan.

This mineral is very widely distributed, constituting a part both of primitive and transition mountains. Colours yellowish, bluish, greenish, smoke, ash, and pearl grey; blackish green; greyish black; brownish red; sometimes spotted. Massive. Internal lustre varying from shining to glimmering, resinous, approaching to pearly. Fracture more or less slaty; in some varieties approaching foliated, in others compact. Fragments tabular, and likewise splintery. Streak usually greyish white. Opaque. Soft. Sectile. Sometimes feels a little greasy. Easily frangible. Specific gravity from 2·67 to 2·88.

The following table exhibits the composition of such of the preceding species as have been analysed:

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* Kirwan, i. 238.   Brochant, i. 393.   Jameson, i 439.

† Kirwan, i. 234.   Brochant, i. 395.   Jameson, i. 441.

	Drawing-slate.	Clay-slate.	Chap. II.
	*	†	
Silica	64·06	.... 48·6	
Alumina	11·00	.... 23·5	
Magnesia	——	.... 1·6	
Peroxide of iron	2·75	.... 11·3	
Oxide of manganese	——	.... 0·5	
Potash.......................	——	.... 4·7	
Carbon......................	11·00	.... 0·3	
Sulphur	——	.... 0·1	
Water and volatile matter ..	7·20	.... 7·6	
Loss	3·99	.... 1·8	
	100	100	

XIV. MICA FAMILY.

This family contains four species; namely, *lepidolite*, *mica*, *pinite*, and *chlorite*.

Sp. 1. *Lepidolite.*‡

This stone appears to have been first observed by the Abbé Poda, and to have been first described by De Born. §
It occurs embedded in granite and other primitive rocks in various parts of the world, as in Argylshire in Scotland.

Colour peach blossom red, verging on lilac blue; passes into pearl and yellowish grey. Massive and crystallized in equiangular six-sided prisms. Internal lustre glistening. Fracture *in the small* foliated, *in the great* splintery. Fragments blunt-edged. Translucent. Sectile. Soft; but the crystals scratch glass. Not easily pulverized.‖ Specific gravity from 2·816 to 2·8549.** Powder white with a tint of red.‖ Before the blow-pipe froths and melts easily into a white semitransparent enamel full of cells. Dissolves in borax with effervescence, but communicates no colour.‖ Effervesces slightly with soda, and melts into a mass spotted

* Wiegleb, Crell's Annalen, 1797, ii. 487.
† Daubuisson, Jameson, i. 442.
‡ Kirwan, i. 208. Klaproth, Beitrage, i. 279, and ii. 191. Brochant, i. 399. Haüy, iv. 375. Jameson, i. 448. Lelievre, Jour. de Min. No. li. 221. § Crell's Annals, 1791, ii. 196.
‖ Lelievre, Jour. de Min. No. li. 219. ** Klaproth and Haüy.

with red; with microcosmic salt into a pearl-coloured glo-
bule.*

This mineral was first called *lilalite*, from the resem-
blance of its colour to that of the lily. Klaproth, who as-
certained its composition, gave it the name of *lepidolite*, or
scale-stone, from its structure.

The constituents of lepidolite are as follows:

	†	‡	§
Silica.............	54·50	54	61·6
Alumina...........	38·25	20	20·61
Lime..............	—	—	1·60
Oxide of iron	0·75	1	trace
Oxide of manganese ...	—	3	0·5
Potash	4	18	9·16
Fluate of lime......	—	4	—
Water	—	—	1·86
Loss	2·5	—	4·67
	100	100	100

Sp. 2.   *Mica.*‖

This stone forms an essential part of many mountains,
and has been long known under the names of *glacies mariæ*
and *Muscovy glass*. It consists of a great number of thin
laminæ adhering to each other, sometimes of a very large
size. Specimens have been found in Siberia nearly $2\frac{1}{2}$ yards
square.**

It is sometimes crystallized: its primitive form is a rect-
angular prism, whose bases are rhombs, with angles of
120° and 60°: its integrant molecule has the same form.
Sometimes it occurs in rectangular prisms, whose bases also
are rectangles, and sometimes in short six-sided prisms;
but it is much more frequently in plates or scales of no de-
terminate figure or size.††

* Klaproth, Ann. de Chim. xxii. 37.   † Klaproth, Beitrage, ii. 195.
‡ Vauquelin, Jour. de Min. No. xli. p. 235.
§ Hisinger, Afhandlingar, iii. 294.
‖ Kirwan, i. 210.   Gmelin, Nov. Com. Petropol. xii. 549.   Haüy, iii.
208.   Brochant, i. 402.   Jameson, i. 451.
** Hist. General de Voyages, t. xviii. 272, quoted by Haüy, Jour. de
Min. No. xxviii. 299.
†† Haüy, Jour. de Min. No. xxviii. 296.

Colours yellowish, ash, and greenish grey; blackish green; silver white; pinchbeck brown; brownish black. Lustre of the crystals splendent. Internal lustre shining; usually pearly or resinous; sometimes semimetallic. Fracture perfect foliated, with a single cleavage; sometimes radiated. Fragments usually tabular. The foliated varieties occur in granular distinct concretions, the radiated in wedge-shaped distinct concretions. Transparent when in thin plates. Soft. Sectile. Very tough. The lamellæ flexible, and somewhat elastic. Often absorbs water. Specific gravity from 2·6546 to 2·9342. Feels smooth, but not greasy. Powder feels greasy. Mica is fusible by the blowpipe into a white, grey, green, or black enamel; and this last is attracted by the magnet.* Spanish wax rubbed by it becomes negatively electric.†

The constituents of mica are as follows:

Silica......	47	 48	.... 42·5
Alumina.............	20	.... 34·25	.... 11·5
Magnesia............	—	.... 0·5	 9
Oxide of iron.........	15·5	.... 4·5	 22
Oxide of manganese...	1·75	.... —	 2
Potash	14·5	.... 8·75	 10
Water................	——	.... 1·25	 1
Loss	1·25	.... 2·75	 2
	100·00	100·00	100‡

Sp. 3. *Pinite.*§

Micarell of Kirwan.

This mineral was first observed in the mine called Pini, at Schneeberg in Saxony; hence its name. Since that time it has been found in other places.

Colour blackish grey; but often covered with iron ochre on the surface. Almost always crystallized in six-sided prisms, having their lateral edges and angles truncated. Surface of the crystals smooth. Internal lustre glistening, resinous; longitudinal fracture small grained uneven; cross.

* Haüy, Jour. de Min. No. xxviii. p. 295. Bergman, however, found pure mica infusible *per se*.   † Ibid.

‡ Klaproth, Beitrage, v. 64. The first specimen common mica, the second broad leave mica, the third black mica from Siberia.

§ Kirwan, i. 212. Brochant, i. 456. Jameson, i. 456.

fracture imperfect foliated. Fragments sometimes blunt-edged. Translucent on the edges. Soft. Sectile. Easily frangible. Specific gravity 2·980.* At 153° Wedgewood, melts into a black compact glass with a reddish surface.†
Infusible before the blow-pipe.

Its constituents are as follows:

Silica	29·5	46·0
Alumina......	63	42·0
Oxide of iron ..	6·75	2·5
Water........	——	7·0
Loss	0·75	2·5
	100‡	100·0§

Sp. 4.   *Chlorite.*‖

This mineral occurs abundantly in primitive rocks and the older veins. Werner has divided it into four subspecies.

Subsp. 1. *Chlorite Earth.*

This mineral is found in different parts of Germany and Switzerland, chiefly in clay-slate. Colour between mountain and blackish green. Composed of small scales. Lustre glimmering, pearly. Streak mountain green and shining. Adheres strongly to the skin. Feels rather greasy. Specific gravity 2·612. It bears a strong resemblance to green earth.

Subsp. 2. *Common Chlorite.*

Found in different parts of Saxony. Colour blackish green. Massive. Internal lustre glimmering. Fracture foliated, passing into earthy. Fragments blunt-edged. Colour of the streak lighter green. Soft. Opaque. Sectile. Feels rather greasy. Easily frangible. Specific gravity 2·832.

Subsp. 3. *Chlorite Slate.*

Occurs in beds subordinate to clay-slate. Colour blackish green. Massive. Internal lustre glistening, resinous. Fracture curve slaty; those varieties that have the greatest lustre pass into scaly foliated. Double cleavage. Fragments slaty.

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* Kirwan.   † Kirwan, Mineral. i. 212.
‡ Klaproth, Berg. Jour. 1790, ii 229.
§ Drappier, Jour. de Min. No. c. p. 311.
‖ Kirwan, i. 137.   Brochant, i. 408.   Jameson, i. 458.

3

Opaque. Streak mountain green. Sectile. Feels rather greasy. Specific gravity 2·822.

Subsp. 4. *Foliated Chlorite.*

Hitherto found chiefly at St Gothard in Switzerland, and in the island of Jura.* Colour between mountain and blackish green. Massive; but usually crystallized in six-sided tables, cylinders terminated by two cones, and in double cones with the bases joined. Surface streaked. External lustre glistening; internal shining, pearly. Fracture foliated. Cleavage simple. Fragments tabular. Translucent on the edges or opaque. Soft. Sectile. Folia usually flexible. Feels rather greasy. Easily frangible. Streak light-coloured. Specific gravity 2·823.

The following table exhibits the constituents of the preceding subspecies, as far as they have been hitherto ascertained.

	Chlorite earth. †	Common chlorite. ‡	§	Foliated chlorite. ‖
Silica	50	26	41·15	35
Alumina	26	18·5	6·13	18
Lime	1·5	—	1·5	—
Magnesia	—	8	39·47	29·9
Oxide of iron	5	43	10·15	9·7
Potash	17·5	—	—	—
Mur. of potash	—	2	—	—
Water	—	—	1·50	2·7
Loss	—	2·5	0·10	4·7
	100	100	100	100

XV. LITHOMARGE FAMILY.

This family contains seven species, namely, *green earth,* *pimelite, lithomarge, rock soap, yellow earth, cimolite,* and *collyrite.*

Sp. 1. *Green Earth.***

This mineral occurs in balls and crusts in amygdaloid.

* Jameson's Mineralogy of the Scottish Isles.
† Vauquelin, Haüy, iii. 266. Under the potash is included a little muriatic acid. ‡ Vauquelin, Ibid. p. 264.
§ Hœpner, Crell's Annals, 1790, i. 56. ‖ Lampadius, Handbuch.
** Kirwan, i. 196. Brochant, i. 445. Jameson, i. 466.

Colour seladon green; sometimes passing into other varieties. Massive and in globular pieces. Internal lustre dull. Fracture even. Fragments blunt-edged. Lustre of streak glistening. Very soft. Sectile. Easily frangible. Specific gravity 2·598. Used by painters, as the colour is not altered by acids.

Its constituents are as follows:

	Green earth.	
	*	†
Silica	53	51·5
Magnesia.	2	1·5
Oxide of iron	28	20·5
Potash	10	18
Water	6	8
Loss	1	0·5
	100	100

Sp. 2. Pimelite.‡

This mineral which accompanies chrysophrase was first constituted into a distinct species by Karsten, who divides it into two subspecies, § the friable and the indurated. His description of these is as follows:

Subsp. 1. Friable Pimelite.

Colour siskin green. Massive. Dull. Fracture earthy. Fragments blunt-edged. Very soft, passing into friable. Feels somewhat heavy. Its constituents are

Silica	35·00
Water	38·13
Alumina.	5·00
Magnesia.	1·25
Lime	0·42
Oxide of nickel.......	15·62
Oxide of iron.	4·58
	100 ‖

Subsp. 2. Indurated pimelite.

Colour apple green. Partly earthy, partly in crusts.

* Green earth of Verona. Klaproth, Beitrage, iv. 239.
† From Cyprus. Klaproth, ibid. p. 242.
‡ Jameson, i. 468.   § Tabellen, p. 88.
‖ Klaproth's Beitrage, ii. 139.

Internal lustre feebly glimmering. Fracture even. Fragments rather sharp-edged. Soft. Feels very greasy. Infusible before the blow-pipe, but loses part of its weight.

Sp. 3. *Lithomarge.**

This mineral is found in veins, cavities, and beds, in various kinds of rocks, and is far from uncommon. Werner divides it into two subspecies.

Subsp. 1. *Friable Lithomarge.*

Colours snow, yellowish, and reddish-white. Massive. Lustre scarce glimmering. Generally coherent, sometimes loose; composed of fine scaly particles. Feels greasy. Adheres to the tongue. Phosphoresces in the dark. Soils slightly. Its constituents are as follows:

$$
\begin{array}{ll}
\text{Silica} \dots\dots\dots & 32 \cdot 0 \\
\text{Alumina} \dots\dots & 26 \cdot 5 \\
\text{Oxide of iron} \; . & 21 \cdot 0 \\
\text{Common salt} \dots & 1 \cdot 5 \\
\text{Water} \dots\dots\dots & 17 \cdot 0 \\
\text{Loss} \dots\dots\dots & 2 \cdot 0 \\
\hline
& 100 \cdot 0 \dagger
\end{array}
$$

Subsp. 2. *Indurated Lithomarge.*

Colours snow, yellowish, and reddish-white; pearl-grey; plum and lavender-blue; flesh-red, and ochre-yellow. The white and red varieties have only one colour; the others spotted and clouded. Massive. Internal lustre dull. Fracture large conchoidal. Lustre of streak shining. Very soft. Sectile. Easily frangible. Adheres strongly to the tongue. Feels greasy. Light.

Sp. 4. *Rock-soap.‡*

This mineral has been hitherto found chiefly at Olkuzk in Poland, in Cornwall, the Isle of Sky, and always imbedded in rocks belonging to the floëtz trap formation.

* Kirwan, i. 187. Brochant, i. 447. Jameson, i. 470.

† Klaproth, Beitrage, iv. 349.

‡ Brochant, i. 453. Jameson, i. 474. Bucholz, Gehlen's Jour. iii. 597.

Colour pitch or brownish-black. Massive. Lustre dull. Fracture fine earthy. Fragments blunt-edged. Opaque. Does not soil. Writes well. Lustre of streak shining, resinous. Very soft. Sectile. Easily frangible. Adheres strongly to the tongue. Rather light.

Sp. 5. *Yellow Earth.**

This mineral occurs in Upper Lusatia, along with iron-stone in the floëtz clay formation. Colour ochre-yellow. Massive. Lustre of the principal fracture glimmering; of the cross fracture dull; of the streak shining. Principal fracture more or less perfect slaty; cross fracture earthy. Fragments partly indeterminate and blunt-edged, partly tabular. Soils. Writes. Very soft. Adheres strongly to the tongue. Feels a little greasy. Light. Used as a pigment.

Sp. 6. *Cimolite.†*

Found by Hawkins in the Isle of Argentiers in the Archipelago, where it is used for whitening stuffs. It was mentioned by Pliny under the name of *cimolia*. Colour pearl-grey: when exposed to the air becomes reddish. Texture earthy. Fracture uneven. Opaque. Does not stain. Adheres strongly to the tongue. Soft. Difficultly broken. Specific gravity 2·000. Becomes white before the blow-pipe. Its constituents are as follows:

Silica	63
Alumina	23
Oxide of iron	1·25
Water	12
Loss	0.75
	100·00 ‡

Sp. 7. *Collyrite. §*

This mineral occurs in the Stephen's pit at Schemnitz, in Hungary, where it forms a vein four or five inches wide in sandstone.

It is snow-white, often with a shade of grey, red, or

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* Kirwan, i. 294. Brochant, i. 455. Jameson, i. 475.
† Brochant, i. 329. Klaproth, i. 477.
‡ Klaproth Beitrage, i. 299.   § Jameson, i. 478.

yellow. Massive. Lustre dull, except the reddish-white variety, which is feebly glimmering. Fracture fine, earthy, and even. Fragments indeterminate, and sharp-edged. Translucent on the edges. Streak shining and resinous. Soils slightly. Very soft. Brittle, and very easily frangible. Adheres strongly to the tongue. Light. Its constituents are as follows:

Silica 14
Alumina . 45
Water ... 42
———
101 *

XVI. SOAPSTONE FAMILY.

This family contains seven species, namely, *native mag-* Soapstone *nesia, meerschaum, bole, sphragide, fuller's-earth, steatite,* family. *agalmatolite.*

Sp. 1. *Native Magnesia.*†

This mineral, which has been found in small veins in serpentine at Hoboken, in New Jersey, was discovered and described by Dr. Bruce, Professor of Mineralogy, in New York.‡ It is a hydrate of magnesia.

Colour snow-white, passing into greenish-white. Massive. Lustre pearly. Fracture foliated or radiated. Semitransparent in the mass: the single folia are transparent. Soft, and somewhat elastic. Adheres slightly to the tongue. Specific gravity, 2·13. Soluble in acids. Its constituents are as follows:

Magnesia 70
Water .. 30
———
100

Supposing it a compound of 1 atom magnesia, and 1 atom water, its composition would be

Magnesia 68·94
Water .. 31·06
————
100·00

* Klaproth, Beitrage, i. 257. † Jameson, i. 480.
‡ Bruce's Journal, i. 26.

Sp. 2. *Meerschaum.*[*]

Kiffekill—Sea-froth.

This mineral is dug up near Konie in Natolia, and is employed in forming the bowls of Turkish tobacco-pipes. The sale of it supports a monastery of dervises established near the place where it is dug. It is found in a large fissure, six feet wide, in grey calcareous earth. The workmen assert that it grows again in the fissure,[†] and puffs itself up like froth.[‡] This mineral, when fresh dug, is of the consistence of wax. When thrown on the fire it sweats, emits a fetid vapour, becomes hard and perfectly white.

Colour yellowish-white; rarely snow-white. Massive. Internal lustre dull; of the streak shining. Fracture fine earthy, passing into flat conchoidal. Fragments pretty sharp-edged. Opaque. Soft. Sectile. Not very easily frangible. Feels a little greasy. Specific gravity 1·600.[§] Its constituents are as follows:

Silica	50·5	41
Magnesia	17·25	18·25
Lime	0·5	0·5
Carbonic acid	5	—
Water	25	39
Loss	1·75	1·25
	100·00	100·00 [‖]

Sp. 3. *Bole.*[**]

This mineral occurs chiefly in the Isle of Lemnos, at Sienna in Italy, and in Silesia.

Massive. Fracture perfect conchoidal. Internal lustre glimmering; of streak shining. Translucent and opaque. Soft. Sectile. Specific gravity from 1·4 to 2. Acquires a polish by friction. Adheres to the tongue. Feels greasy. Colour cream-yellow, passing into brown and flesh-red; sometimes spotted brown and black. When dry and put

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[*] Kirwan's, Min. i. 144. Brochant, i. 462. Jameson, i. 483.

[†] Reignegg, Phil. Mag. iii. 165.

[‡] Hence the name *kiff-kill*, or rather *keff-kelli*, " clay-froth, or " light clay."   § Klaproth.

[‖] Klaproth, Beitrage, ii. 174.

[**] Kirwan, i. 191. Brochant, i. 459. Jameson, i. 486.

into water, it breaks with a crackling noise. Its con-
stituents are as follows:

Silica	47
Alumina	19
Oxide of iron	5·4
Carbonate of lime	5·4
Carbonate of magnesia	6·2
Water	17·0
	100·0 *

Sp. 4. *Lemnian Earth.*†
Sphragid of Karsten.

This mineral has been hitherto found only in the Island of Lemnos, where it is held in great veneration. Specimens of it were brought to Klaproth, by Hawkins, who analysed it, and described its properties.

Colours yellowish-grey, and yellowish white; often marbled on the surface with rust like spots. Dull. Fracture fine, earthy. Perfectly meagre to the feel. Adheres slightly to the tongue. When immersed in water it falls to pieces, and numerous air bubbles are evolved. Its constituents are as follows:

Silica	66·00
Alumina	14·50
Magnesia	0·25
Lime	0·25
Soda	3·50
Oxide of iron	6·00
Water	8·50
Loss	1·00
	100·00 ‡

Sp. 5. *Fuller's Earth.* §

This mineral occurs in greatest perfection in the south of England; it is found also in Upper Saxony and in Sweden.

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* Bergman, Opusc. iv. 157. The specimen was from Lemnos.
† Jameson, i. 489.   ‡ Klaproth, Beitrage, iv. 333.
§ Kirwan, i. 184. Brochant, i. 464. Jameson, i. 491.

Colour greenish white, greenish grey, olive and oil green. Sometimes spotted. Massive. Internal lustre dull; of the streak shining. Fracture uneven; sometimes large conchoidal, sometimes splintery. Fragments indeterminate, blunt edged; also slaty. Usually opaque. Very soft. Sectile. Scarcely adheres to the tongue. Feels greasy. Sp. gr. 1·72. Falls to pieces in water. Melts into a brown spongy scoria. Its constituents are as follows:

Silica	53·0	48·5
Alumina	10·0	15·5
Lime	0·5	—
Magnesia	1·25	1·5
Oxide of iron	9·75	7·0
Common salt	0·1	—
Water	24	25·5
Loss	1·4	2·0
	100·00	100·0*

Sp. 6. *Steatite.†*

Though this mineral was noticed by the ancients, little attention was paid to it by mineralogists, till Mr. Pott published his experiments on it in the Berlin Memoirs for 1747.

It is usually amorphous, but sometimes it is crystallized in six-sided prisms. Colour greyish, greenish, yellowish, and reddish white. Sometimes spotted. Lateral planes of the crystals transversely streaked. Internal lustre dull or glimmering; of the streak shining. Fracture coarse splintery; sometimes uneven, conchoidal, and even tending to coarse fibrous. Fragments blunt-edged. Translucent on the edges. Soft. Sectile. Easily frangible. Does not adhere to the tongue. Feels greasy. Specific gravity 2·614. Before the blow-pipe loses its colour and hardens, but does not melt. Its constituents are as follows:

* Klaproth, Beitrage, iv. 334. The first specimen was from Ryegate in Surrey, the second from Nimptch in Silesia.

† Kirwan, i. 151. Pott, Mem. Berlin, 1747, p. 57. Wiegleb. Jour. de Phys. xxix. 60. Lavoisier, Mem. Par. 1778, p. 433. Brochant, i. 474. Jameson, i. 495.

Silica	59·5	45·0	61·25	64
Magnesia	30·5	24·75	26·25	22
Alumina	—	9·25	1	3
Lime	—	—	0·75	—
Oxide of iron	2·5	1	1	5
Potash	—	0·75	—	—
Water	5·5	18·0	6	6
Loss	2	1·25	3·75	—
	100·0	100·00*	100·00	100†

Sp. 7. *Agalmatolite, Bildstein,* or *Figure-stone.* ‡

This mineral, which was originally classed with steatite, is brought from China, and is always cut into various figures; hence the name. The attention of mineralogists was first drawn to it by the analysis of Klaproth.

Colour greenish grey, yellowish grey, yellowish brown; some varieties appear to be of a flesh red colour, and some are spotted. Massive. Internal lustre scarce glimmering. Fracture perfect splintery. Has a tendency to the slaty. Fragments sometimes indeterminate angular, pretty sharp-edged; sometimes slaty. Translucent. Soft, and very soft. Sectile. Feels rather greasy. Specific gravity from 2·785 to 2·815. § Its constituents are as follows:

	‖	‖	**	††	††	‡‡	‡‡
Silica	54	62	56	54·5	55	55	51·5
Alumina	36	24	29	34	33	30	32·5
Lime	—	1	2	—	—	1·75	3·0
Oxide of iron	0·75	0·5	1	0·75	0·5	1	1·75
Oxide of Manganese	—	—	—	—	—	Trace	1·2
Potash	—	—	7	6·25	7	6·25	6
Water	5·5	10	5	4	3	5·5	5·13
Loss	3·75	2.5	—	0·5	1·5	0·5	—
	100·00	100	100	100·0	100	100·0	101·08

* Klaproth, Beitrage, ii. 179. The first specimen from Baireuth, the second from Cornwall analysed in Beitrage, v. 24.

† Vauquelin, Ann. de Chim. 49, 83. The first specimen was the variety called Craie de Briançon.

‡ Jameson, i. 500. Klaproth, Beitrage, ii. 184. Vauquelin, Ann. de Chim. xlix. 77. § Klaproth.

‖ Klaproth, Beitrage, ii. 187.

** Vauquelin, Ann. de Chim. xlix. 83.

†† Klaproth, Beitrage, v. 21. The first from China, the second from Nagyag. ‡‡ John, Annals of Philosophy, iv. 214.

XVII. TALC-FAMILY.

This family contains six species, namely, *nephrite, serpentine, potstone, talc, nacrite,* and *asbestus.*

Sp. 1. *Nephrite.**

Jade.

This stone was formerly called *lapis niphriticus,* and was much celebrated for its medical virtues. It is found in Egypt, China, America, and in the Siberian and Hungarian mountains. It is sometimes adhering to rocks, and sometimes in detached round pieces. Werner divides it into two subspecies, *common nephrite* and *axe-stone.*

Subsp. 1. *Common.*

Colour leek green; sometimes greenish white. Massive and in rolled pieces. Lustre usually dull; sometimes glimmering and silver white, from particles of talc and asbestus. Fracture coarse splintery; splinters greenish white. Fragments not remarkably sharp-edged. Translucent. Hard. Rather tough. Feels a little greasy. Somewhat brittle. Specific gravity from 2·966 to 3·071.† Takes a good polish, but has a muddy aspect; cut into handles for knives, &c.

Subsp. 2. *Axe-stone.*

Colour between mountain and leek green. Massive. Internal lustre glimmering. Fracture in the great, slaty; in the small, splintery. Fragments tabular. Translucent. Hard. Not very brittle. Rather tough. Made into hatchets, &c. by the natives of New Zealand. The constituents of nephrite are as follows :

Silica	50·5
Magnesia	31·0
Alumina	10·0
Oxide of iron	5·5
Oxide of chromium	0·05
Water	2·75
Loss	0·20
	100·00 ‡

* Kirwan, i. 171. Bartolin, De Lapide Nephritico. Lehmann, Nov. Comm. Petropol. x. 381. Hæpfner, Hist. Nat. de la Suisse, i. 251. Brochant, i. 467. Jameson, i. 503.

† Saussure, Gehlen's Jour. Second Series, ii. 453.

Kastner, Gehlen's Jour. Second Series, ii. 459.

Sp. 2. *Serpentine.**

This stone is found in amorphous masses, forming strata, and even entire rocks. It occurs in great abundance in many countries, particularly at Zobiltz in Upper Saxony, and at Portsoy in Scotland, where it is known by the name of *Portsoy marble*. Werner divides it into two subspecies, the *common* and the *precious*.

Subsp. 1. *Common Serpentine*.

Colours various shades of green, yellow, and red. Several colours usually occur together in stripes, dots, and clouds. Massive. Internal lustre dull. Fracture sometimes splintery, sometimes large flat conchoidal; and also small-grained uneven, passing into even. Translucent on the edges. Soft, scratched by calcareous spar. Passing into sectile. Rather tough. Feels a little greasy. Specific gravity from 2·574 to 2·709. Does not melt before the blow-pipe.

Subsp. 2. *Precious Serpentine*.

Colour dark leek green, passing into blackish green. Massive. Internal lustre glistening; sometimes glimmering, resinous. Fracture conchoidal: sometimes splintery. Fragments in the conchoidal variety very sharp-edged: in the splintery less so. Translucent. Feels rather greasy. Soft. Specific gravity 2·173. Its constituents are as follows. The two first analyses are of common, the two last of precious serpentine.

Silica 28	.. 32·00	.. 42·5	.. 43·07
Magnesia .... 34·5	.. 37·24	.. 38·6	.. 40·37
Lime .... 0·5	.. 10·60	.. —	.. 0·5
Alumina 23	.. 0·5	.. —	.. 0·25
Oxide of iron . 4·5	.. 0·6	.. 1·5	.. 1·17
Volatile matter 10·5	.. 14·16	.. 15·2	.. 12·45
Loss .... —	.. 4·90	.. 2·2	.. 2·19
101 †	100·00‡	100·0 §	100·00‖

* Kirwan, i. 156. Margraff, Mem. Berlin, 1759, p. 3. Bayen, Jour. de Phys. xiii. 46. Mayer, Crell's Annals, 1789, ii. 416. Brochant, i. 481. Jameson, i. 507.

† Chenevix, Ann. de Chim. xxviii. 199. Doubtful if the specimen was really serpentine. ‡ Hisinger Afhandlingar, iii. 303.

§ John, Magazin Naturf; Freund, 4 Jahrg. 2 Quart, p. 114.

‖ Hisinger, Afhandlingar, iv. 341.

Sp. 3. *Pot-stone.**

This mineral is found in beds at Como, in the country of the Grisons. It is said also to have been discovered in other places.

Colour greenish grey. Massive. Internal lustre glistening, pearly. Fracture sometimes curve-foliated, sometimes imperfect slaty. Fragments tabular. The foliated shows imperfect granular distinct concretions. Translucent on the edges. Very soft. Sectile. Feels greasy. Rather tough. Very refractory, and therefore used for lining furnaces. May be easily turned into culinary utensils; hence the name.

Sp. 4. *Talc.†*

This stone has some resemblance to mica, but is easily distinguished from it. It occurs sometimes loose, and sometimes in an indurated form. It is divided into two subspecies.

Subsp. 1. *Common Talc; Venetian Talc.*

Occurs imbedded in serpentine. Colour apple green; greenish and silver white; asparagus green. Massive and in very fine delicate tabular crystals. Lustre splendent; internally pearly or semimetallic. Fracture straight and curved foliated. Fragments wedge-shaped; seldom splintery. Cleavage single. Translucent, in thin leaves transparent. Sometimes in granular distinct concretions. Leaves flexible, but not elastic. Very soft. Sectile. Feels very greasy. Specific gravity from 2·7 to 2·8. Infusible before the blow-pipe without addition. By this property it is distinguished from chlorite.

Subsp. 2. *Indurated Talc.*

Occurs, like the preceding, in primitive mountains. Colour greenish grey. Massive. Lustre shining pearly. Fracture between imperfect foliated and curve-slaty. Fragments slaty. Translucent, at least on the edges. Soft. Sectile. Easily frangible. Feels rather greasy. Has a strong resemblance to pot-stone. Specific gravity 2·982. The constituents of this mineral are as follows :

* Kirwan, i. 155. Brochant, i. 405. Jameson, i. 514.

† Kirwan, i. 150. Pott, Mem. Berl. 1746, p. 65. Haüy, iii. 252. Brochant, i. 486. Jameson, i. 517.

Silica	62	62
Magnesia	27	30·5
Alumina	1·5	—
Potash	—	2·75
Oxide of iron	3·5	2·5
Water.............	6	0·5
Loss	—	1·75
	100·0 *	100·00 †

Sp. 5. *Nacrite*.‡ *Talcite* of Kirwan.

This mineral occurs in cavities of primitive rocks. It was constituted a particular species by Brogniart.

Colours cream yellow, greenish white, and greenish grey. It consists of scaly parts which are more or less compacted. Strongly glimmering and pearly inclining to resinous. Friable. Feels rather greasy. Soils. Gives out a clayey smell when breathed upon. Light. Its constituents, according to the analysis of John, are as follows:

Silica	60·20
Alumina	30·83
Oxide of iron	3·55
Water	5·00
Lime	Trace
Loss	0·42
	100·00 §

Sp. 6. *Asbestus*.‖

This mineral was well known to the ancients. They even made a kind of cloth from one of the varieties, which was famous among them for its incombustibility. It is found in primitive mountains, especially in serpentine, which it traverses in veins. Werner divides it into four subspecies.

Subsp 1. *Elastic Asbestus*, or *Rock-Cork*.

Colours yellowish grey; yellowish and greyish white;

* Vauquelin, Ann. de Chim. xlix. 77.
† Klaproth, Beitrage, v. 63. The specimen was from St. Gothard.
‡ Jameson, i. 523.   § Ann. de Chim. lxvii. 264.
‖ Kirwan, i. 159. Bergman, iv. 160. Plot, Phil. Trans. xv. 1051. Nebel, Jour. de Phys. ii. 62. Ibid. iii. 367. Haüy, iii. 245. Brochant, i. 492. Jameson, i. 524.

pale ash grey; yellowish brown and cream yellow. Some-times shows ochre yellow spots. Massive and in plates. Lustre dull; of streak shining. Fracture very fine pro-miscuous fibrous, which on a slight inspection appears fine-grained uneven. Opaque, or translucent on the edges. Very soft; receives an impression from the nail. Sectile Flexible and elastic. Very tough. Cracks when handled. Feels meagre. Specific gravity from 0·993 to 0·680.* Melts with great difficulty before the blow-pipe.

Subsp. 2. *Amianthus.*

Colours greenish white; greenish grey; olive green; sometimes blood red. Massive, and in plates, and in ca-pillary crystals. Internal lustre glistening; sometimes splendent, pearly. Fracture very delicate parallel fibrous. Fragments thin splintery. Translucent on the edges. Very soft. Sectile. Flexible and somewhat elastic. Splits easily. Tough. Specific gravity from 0·9888 to 2·3134. Melts with difficulty before the blow-pipe.

Subsp. 3. *Common Asbestus.*

Colours dark leek and mountain green; greenish grey. Massive and in capillary crystals. Internal lustre glisten-ing, pearly. Fracture parallel radiated, and parallel curved fibrous. Fragments splintery. Translucent on the edges. Soft. Tough. Not flexible. Feels rather greasy. Specific gravity 2·547 to 2·995. Melts with difficulty into a greyish black scoria.

Subsp. 4. *Ligniform Asbestus* or *Rock-Wood.*

Colour wood brown. Massive and in plates. Internal lustre glimmering. Fracture *in the great* curve-foliated; *in the small* promiscuous fibrous. Fragments slaty. Soft. Sectile. Tough. Somewhat flexible and elastic. Feels meagre. Specific gravity 2·051.

The following table exhibits the constituents of the pre-ceding subspecies, as far as they have been analysed:

* Bergman.

	Rock-cork.		Amianthus.				Common Asbestus.
	*	*	†	†	†	‡	§
Silica	62	56·2	64	64	72	59	63·9
Alumina....	2·8	2	2·7	3·3	3·3	3	1·1
Lime	10	12·7	13·9	6·9	10·5	9·5	12·8
Magnesia ...	22	26·1	17·2	18·6	12·9	25	16·0
Oxide of iron	3·2	3	2·2	1·2	1·3	2·25	6·0
Barytes	—	—	—	6	—	—	—
Loss	—	—	—	—	—	1·25	0·2
	100	100	100	100	100	100	100

XVIII. HORNBLENDE FAMILY.

This family contains seven different species; namely, Hornblende, *hornblende*, *actinolite*, *tremolite*, *cyanite*, *rhætizite*, *diallage*, family. and *hyperstene*.

Sp. 1. *Hornblende.*‖

Amphibole of Haüy.

This mineral enters into the composition of many mountains. It is often amorphous, but frequently also crystallized. The primitive form of its crystals is a rhomboidal prism, the faces of which are inclined at angles of 124° 34′ and 55° 26′, and whose bases have angles of 122° 56′ and 57° 4′. The most common variety is a six-sided prism, terminated by trihedral or tetrahedral summits. This species is divided into three subspecies.

Subsp. 1. *Common Hornblende.*

This mineral forms one of the constituents of the rocks

* Bergman, iv. 169 and 170. The lime and magnesia were in the state of carbonates.

† Bergman, ibid. p. 161, 164, and 168. The magnesia and lime were in the state of carbonates. First specimen from Svartvik in Dalecarlia; second from Tarentaise; third from Corias in Asturias.

‡ Chenevix, Ann. de Chim. xxviii. 201.

§ Bergman, iv. 170. From Grænge in Dalecarlia.

‖ Kirwan, i. 213. Haüy, iii. 58. Brochant, i. 415. Jameson, ii. 1.

Book III. called syenite and green stone. Colour greenish black,
sometimes approaching to grey and velvet black; some-
times to greenish grey. Massive, and sometimes crystal-
lized in prisms which intersect each other, so that it is dif-
ficult to determine their figure. Internal lustre shining
pearly. Fracture usually foliated, sometimes radiated.
Surface of the fracture streaked longitudinally. Cleavage
of the foliated varieties double. Fragments usually indeter-
minate; sometimes approach the rhomboidal. In granular
distinct concretions. Black varieties opaque, green trans-
lucent on the edges. Streak mountain green. Semihard.
Tough. Specific gravity 3·287. When moistened,
exhales a bitter smell. Before the blow-pipe melts into a
black glass.

Subsp. 2. *Hornblende-Slate.*

Occurs in beds in clay-state, and is very common.
Colour between greenish and raven black. Massive. Inter-
nal lustre shining, pearly. Fracture *in the great*, slaty; *in
the small*, promiscuous radiated. Fragments sometimes
tabular. Streak greenish grey. Semihard. Not particu-
larly easily frangible.

Subsp. 3. *Basaltic Hornblende.*

Found imbedded in basalt and wacka. Colour velvet
black. Always in single crystals. The form of the crys-
tals is that described under the general character of the
species; for the amphibole of Haüy refers particularly to
this subspecies. Surface smooth. Lustre of the principal
fracture splendent; of the cross fracture glistening vitre-
ous. Principal fracture perfect straight foliated, with a
double obliquely intersecting cleavage. Cross fracture
fine-grained uneven. Opaque. Semihard. Pretty brittle.
Rather easily frangible. Specific gravity 3·250.* Melts
into a black glass, but is more refractory than common
hornblende. The constituents of this mineral are as fol-
lows:

* Haüy.

Silica	37 ..	42	.. 42	.. 47
Alumina , ...	27 ..	7·69	.. 12	.. 26
Lime	5 ..	9·8	.. 11	.. 8
Magnesia	3 ..	10·9	.. 2·25 ..	2
Potash	— ..	—	..Trace	.. —
Oxide of iron	25 ..	22·69	.. 30	.. 15
Oxide of manganese	— ..	1·15	.. 0·25	.. —
Water	— ..	—	.. 0·75	.. 0·5
Loss	3 ..	5·77	.. 1·75	.. 1·5
	100*	100†	100‡	100§

Sp. 2.   *Actinolite.*‖

Strahlstein of Werner.

This mineral occurs chiefly in beds in primitive moun-
tains.   It is subdivided into four subspecies.

Subsp. 1.   *Asbestous Actinolite.*

Colours greenish-grey, mountain-green, smalt-blue, olive-
green, yellowish and liver-brown.   Massive and in capillary
crystals, which are sometimes a little flexible and elastic.
Internal lustre shining, pearly.   Fracture between fibrous
and narrow radiated.   Fragments wedge-shaped.   In
coarse wedge-shaped distinct concretions.   Opaque.   Soft.
Rather sectile.   Tough.   Specific gravity 2·584 to 2·916.**
Melts before the blow-pipe into a black or grey scoria.

Subsp. 2.   *Common Actinolite.*

Usual colour leek-green ; sometimes pistachio and olive-
green ; blackish-green.   Massive, and crystallized in very
oblique six-sided prisms.   Primitive form of its crystals,
according to Haüy, is a four-sided prism whose bases are
rhombs, and which he presumes to be the same with the
primitive form of hornblende.   Crystals often longitudi-
nally streaked : large and often acicular.   External lustre
splendent ; internal shining, between resinous and vitreous.
Fracture commonly radiated, and usually scopiform and

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* Hermann, Beob. der Berlin, v. 317. Common hornblende.
† Laugier, Ann de Mus. d'Hist. Nat. v. 79. Common hornblende.
‡ Klaproth, Beitrage, v. 150. Common hornblende.
§ Klaproth, ibid. Basaltic hornblende.
‖ Brochant, i. 504. Haüy, iii. 73. Jameson, ii. 12.
** By my trial.

diverging; sometimes foliated with an indistinct twofold cleavage. Fragments sometimes wedge-shaped and splintery. In wedge-shaped and granular distinct concretions. Massive varieties translucent; crystals transparent. Semihard. Pretty brittle. Tough. Specific gravity 3·000 to 3·310.

Subsp. 3. *Glassy Actinolite.*

Principal colour mountain-green, passing to greenish-grey and to emerald-green. Massive, and in thin six-sided acicular crystals. Lustre shining, vitreous. Fracture promiscuous fibrous, and narrow scopiformly diverging radiated. Fragments splintery and wedge-shaped. In prismatic distinct concretions, inclosing smaller ones. Translucent. Brittle. Easily frangible. Has cross rents. Semihard. Specific gravity from 2·95 to 3·903.

Subsp. 4. *Granular Actinolite.*

Colour grass-green. Massive. Internal lustre shining and vitreous. Principal fracture imperfect foliated with a twofold cleavage: cross fracture splintery. In granular distinct concretions. Faintly translucent. Semihard. Brittle. Easily frangible. The constituents of these subspecies, as far as they have been analysed, are as follows :

Silica	33·4	47	64	50
Alumina	28·2	—	2·7	0·75
Lime	1·046	11·3	9·3	9·75
Magnesia	0·6	7·3	20	19·25
Oxide of iron	17·15	20	4	11
Oxide of manganese	7·2	10	—	0·5
Tungstic acid	3·84	—	—	—
Oxide of chromium	—	—	—	3
Copper	1	—	—	—
Soda	3·8	—	—	—
Potash	—	—	—	0·5
Moisture	1·7	—	—	5
Loss	2·064	4·4	—	0·25
	100·000 *	100 †	100 ‡	100·0 §

* By my analysis, Annals of Philosophy, iv. 209. Asbestous actinolite from Cornwall.

† Vauquelin, Haüy, iv. 335. The variety of asbestous actinolite called *byssolite*. ‡ Bergman, Opusc. iv. 172.

§ Laugier, Ann. du Musc. d'Hist. Nat. v. 79. Glassy actinolite.

Sp. 3.   *Tremolite.**

Grammatite of Haüy.

This mineral occurs chiefly in primitive mountains, and usually in lime-stone. It was first observed at Tremola in Switzerland; hence the name. It is subdivided into three subspecies.

Subsp. 1.   *Asbestous Tremolite.*

Colour yellowish-white; also greyish, reddish, and greenish-white. Massive and in capillary crystals. Internal lustre glistening, pearly. Fracture fine fibrous, either straight or scopiform diverging. Fragments splintery and wedge-shaped. In wedge-shaped prismatic concretions. Translucent on the edges. Very soft. Very easily frangible. Sectile. Specific gravity 2·683.

Subsp. 2.   *Common Tremolite.*

Colours greyish, greenish, yellowish, and reddish-white; pale asparagus-green; dark smoke-grey. Sometimes massive, sometimes crystallized. Primitive form of the crystals, according to Haüy, is a rhomboidal prism, whose sides are inclined to each other at angles of 126° 52′ 12″ and 53° 7′ 48″. It usually occurs in four-sided prisms, terminated by dihedral summits; and not unfrequently the two acute edges, or all the four, are truncated. Crystals middle-sized and small. Internal lustre shining, pearly. Fracture sometimes broad radiated, sometimes foliated; both streaked; the latter appears to have a two-fold longitudinally intersecting cleavage. Cross fracture uneven. Fragments usually indeterminate; sometimes somewhat cubical. The massive variety is in granular distinct concretions. Translucent; crystals semitransparent. Semihard. Rather easily frangible. Specific gravity 2·9257.

Subsp. 3.   *Glassy Tremolite.*

Colours yellowish, reddish, greyish, and greenish-white. Massive and crystallized. Internal lustre shining; passing to glistening, pearly. Fracture very narrow radiated. Has parallel oblique cross rents, like the shorlite. Fragments

* Brochant, i. 514. Haüy, iii. 227. Jameson, ii. 21.

2 B 2

Book III. usually splintery. Composed of thin prismatic distinct concretions, which are collected into thick ones. Translucent. Very easily frangible. Brittle. Specific gravity 2·863. Melts before the blow-pipe into a white cellular scoria.

The constituents of these subspecies, as far as they have been analysed, are as follows:

Silica	59·244	65	35·5	28·4	41	50
Magnesia......	22·133	10·33	16·5	18	15·25	25
Lime..........	15·200	18	26·5	30·6	15	18
Oxide of iron...	1·311	0·16	—	—	—	—
Oxide of manganese	1·000	—	—	—	—	—
Alumina........	0·888	—	—	—	—	—
Carbonic acid and water..	0·020	6·5	23	23	23	5
Loss..........	0·204	0·01	—	—	5·75	2
	100·000*	100†	101·5‡	100‡	100‡	100‡

Sp. 4.   Cyanite.§

Sappare of Saussure.   *Disthene* of Haüy.

This stone was first described by Mr. Saussure the son, who gave it the name of *sappare*.|| It is commonly found in talc and mica slate. The primitive form of its crystals is a four-sided oblique prism, whose sides are inclined at an angle of 103°. The base forms with one side of the prism an angle of 103°; with another, an angle of 77°. It is sometimes crystallized in six-sided prisms.**

Colour various shades of blue; as smalt, berlin, sky; also milk-white, bluish-grey, and pearl-grey. Some specimens entirely blue, others only spotted with it. Massive and crystallized. Internal lustre shining, pearly. Fracture very broad, diverging, promiscuous radiated; passes some-

* Hisinger Afhandlingar, iv. 378.   Common tremolite.
† Klaproth, Crell's Annals, 1790, i. 54.   Glassy tremolite.
‡ Laugier, Gehlen's Jour. Second Series, ii. 46.   Glassy tremolite from St. Gothard.
§ Kirwan, i. 209.   Sage, Jour. de Phys. xxxv. 39.   Haüy, iii. 220. Brochant, i. 501.   Jameson, ii. 31. || Jour. de Phys. xxxiv. 213.
** Haüy. Jour. de Min. No. xxviii. 282.

times into curve foliated. Fracture of the crystals foliated with a threefold cleavage. Fragments slaty, splintery, wedge-shaped, and sometimes imperfect rhomboidal. In wedge-shaped distinct concretions. Translucent and transparent. Refracts singly. Slightly flexible. Semihard. Approaching sectile. Feels somewhat greasy. Specific gravity from 3·517 to 3·680. Infusible before the blow-pipe.

The constituents of this mineral are as follows:

Silica	30	38·8	43
Alumina	55	55·5	55·5
Magnesia	2	—	—
Lime	2	0·5	—
Potash	—	—	Trace
Oxide of iron	6	2·75	0·5
Water	—	0·75	—
Loss	5	1·70	1·0
	100 *	100 †	100 ‡

Sp. 5. Rhœtizite.§

This mineral occurs at Pfizsch, in the Tyrol, and has been lately constituted into a particular species by Werner. It seems formerly to have been considered as a variety of cyanite.

Its colours are cream-yellow and brick-red. Massive. Glistening and lustre pearly. Fracture radiated, long, and narrow, and either parallel, scopiform, or promiscuous. Feebly translucent on the edges. Soft. Streak-white. Difficultly frangible. Specific gravity 3·100.

Sp. 6. Diallage.‖

Under this name I include the *schillerspar*, *diallage*, and *bronzite* of Professor Jameson, because Haüy has shown that the primitive form of these three minerals is the same. I shall describe them as three subspecies.

Subsp. 1. Schillerstone.

Colour various shades of green; it occurs also brown,

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* Saussure, junior, Jour. de Phys. 1793. ii. 13.
† Laugier, Gehlen's Jour. iv. 535.   ‡ Klaproth, Beitrage, v. 10.
§ Jameson, ii. 424.   ‖ Jameson, ii. 36.

yellow, and white. Occurs in plates, sometimes indeterminate, sometimes round or hexangular. Principal fracture splendent and metallic; that of the cross fracture splintery, sometimes passing into fibrous. Opaque; but translucent when in thin plates. Streak greenish-grey and dull. Sectile. Scratched by common hornblende. Very slightly common flexible. Feels meagre.

Subsp. 2. *Diallage,* or *smaragdite.*

Colours grass-green, apple-green, and hair-brown. Massive and disseminated. Lustre shining and semimetallic. Fracture foliated with a double nearly rectangular cleavage. Fragments indeterminate angular. Translucent on the edges. Semihard. Brittle. Difficultly frangibly. Specific gravity 3·140.

Subsp. 3. *Bronzite.*

Colour intermediate between yellowish-brown and pinchbeck-brown. Massive and disseminated. Lustre shining and semimetallic. Fracture foliated, fracture surface streaked. Fragments blunt-edged. In granular distinct concretions. Opaque in mass; but transparent in thin folia. Streak white. Semihard. Brittle. Easily frangible. Specific gravity 3·200. The constituents of these three subspecies are as follows:

	Schiller-stone.	Diallage.	Bronzite.
Silica	52	50	60
Alumina	23·33	11	—
Lime	7	13	—
Magnesia	6	6	27·5
Oxide of iron	17·5	5·5	10·5
Ox. of chrom.	—	7·5	—
Ox. of copper	—	1·5	—
Water	—	—	0·5
Loss	—	5·5	1·5
	105·83 *	100·0 †	100·0 ‡

* Heyer, Brochant's Mineral. i. 422.
† Vauquelin, Ann. de Chim. xxx. 106.
‡ Klaproth, Beitrage, v. 34.

Sp. 7. *Hyperstene.**

This mineral has been hitherto observed only on the coast of Labrador, from which it was brought by the Missionaries, and was long distinguished by the name of *Labrador hornblende.* Haüy constituted it into a peculiar species under the name of *hyperstene ;* and I suspect, though I am not quite certain, that Werner has lately given it a distinct place in his system under the name of *paulite.*

Colours greyish-black, greenish-black and brownish-black. Internally it reflects a colour intermediate between copper-red, pinchbeck-brown, and iron-grey. Hitherto it has been found only in rolled pieces. Internal lustre shining and semimetallic. Fracture foliated with a twofold cleavage, in which the folia meet under angles of 80° and 100°. Fragments oblique rhomboidal. In granular distinct concretions. Opaque. Streak greenish-white. Scratches common hornblende. Specific gravity 3·390. Infusible before the blow-pipe. Its constituents are as follows :

<div align="center">

Silica .... 54·25
Magnesia .... 14·00
Alumina .... 2·25
Lime .... 1·50
Oxide of iron .... 24·50
Ox. of manganese. Trace
Water .... 1·00
Loss .... 2·50
                    ————
                    100·00 †

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XIX. CHRYSOLITE FAMILY.

This family contains three species, namely, *augite,* *chrysolite,* and *olivine.*

Chrysolite family.

Sp. 1. *Augite.*

Under this species I include the *sahlite,* *augite,* and *diopside* of mineralogists, because Haüy has shown that they have all the same primitive form. But it will be worth while to describe each of them separately as subspecies.

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* Jameson, ii. 44.
† Klaproth, Gehlen's Journal, Second Series, v. 212.

Subsp. 1. *Augite.**

Pyroxene of Haüy—*Volcanite* of Delametherie—*Octahedral Basaltine* of Kirwan.

This mineral is found in basalt. It is sometimes in grains, but most commonly in crystals. The primitive form of its crystals is an oblique-angled prism, whose bases are rhombs with angles of 92° 18′ and 87° 42′.† It is generally crystallized in six or eight-sided prisms, terminated by dihedral summits.‡ Crystals mostly small, but complete.

Colour blackish-green, sometimes passing into leek-green, and rarely to liver-brown. Internal lustre shining resinous. Fracture uneven, passing into imperfect small conchoidal. The crystals pass into perfect foliated with a double cleavage. Fragments sharp-edged. Translucent. Scratches glass. Easily frangible. Specific gravity from 3·2265 § to 3·4771. ‖ Before the blow-pipe it is with difficulty converted into a black enamel.

Subsp. 2. *Sahlite.***

Malacolite of Abilgaard and Haüy.

This mineral was first observed in the silver mine of Sahla in Vestmanland; hence the name. Afterwards it was found in Norway.

Colour light greenish-grey. Massive. Internal lustre shining. Principal fracture foliated; cleavage threefold. Fragments frequently rhomboidal. Composed of very coarse granular distinct concretions. Translucent on the edges. Semihard. Brittle. Easily frangible. Specific gravity from 3·2368 to 3·2307.†† Melts before the blow-pipe into a transparent glass.

Subsp. 3. *Diopsite.*‡‡

Mussite and *Alalite* of Bonvoisin.

This mineral occurs in the Piedmontese Alps, and was

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* Kirwan, i. 219. Brochant, i. 179. Haüy, iii. 80. Jameson, ii. 49. The mineral called *coceolite* by Dandrada is a granular variety of augite.   † Haüy, Jour. de Min. xxviii. 269.

‡ De Lisle, ii. 398.   § Haüy.   ‖ Werner.

** Haüy, iv. 379. Brochant, ii. 518. Jameson, ii. 46. Bournon, Jour. de Min. No. lxxiv. p. 108.   †† Haüy and Dandrada.

‡‡ Haüy and Tonnelier, Nicholson's Jour. xxii. 14.

discovered by Bonvoisin, and described by him in the Chap. II.
Journal de Physique for May 1806. Specimens of it were
sent to Paris, where it was examined by Haüy; and from
its peculiar characters constituted by him into a new species,
under the name of *diopside*, from the appearance of its
primitive crystals. He afterwards found that the crystals
agree with those of augite.

It occurs sometimes amorphous, but most commonly
crystallized. The principal varieties of the crystals are:
—1. The primitive form:—2. A didodecahedral crystal
consisting of a twelve-sided prism, terminated at each ex-
tremity by six-faces, situated two and two, one above the
other. Sometimes it is compact, and sometimes in cilin-
droidal prisms. The crystals of the variety called *mussite*
are small, elongated, and commonly opaque. Those of
the variety called *alalite* are larger, translucid, and of a
greenish-white colour. Colour green, greenish-grey, green-
ish-white, and yellowish-white. Lustre shining and vitre-
ous. Fracture foliated. Translucent. It scarcely scratches
glass, but it scratches fluate of lime. Specific gravity
3·2374. Before the blow-pipe it fuses into a glass of the
same greenish colour as the mineral itself.

The constituents of these minerals are as follows:

	Augite.				Cocco-lite.	Sahlite.		Drop-side.
	*	†	‡	‡‡	§	‖	**	††
Silica............	48	55·0	52	52	50	53	54·18	57
Lime	24	12·5	14	13·2	24	20	22·72	16·5
Magnesia........	8·75	13·75	12·75	10	10	19	17·81	18·25
Alumina	5	5·5	5·75	3·33	1·5	3	—	—
Oxide of iron	12	11·0	12·25	14·66	7	—	2·18	} 6
Oxide of mang. ...	1	Trace	0·25	2	3	4	1·45	
Potash	Trace	—	Trace	—	—	—	—	—
Water	—	1	0·25	—	—	—	1·20	—
Loss	1·25	1·25	2·75	4·81	4·5	1	0·46	2·25
	100	100	100	100	100	100	100	100

* Klaproth, Gehlen's Jour. Second Series, v. 199. Black augite
from Frascati.

† Klaproth, Beitrage, v. 165. The first black, and of the specific
gravity 3·333, the second green, and of the specific gravity 3·280.

‡ Vauquelin, Jour de Min. No. lxxxix. p. 172.

§ Vauquelin, Haüy, iv. 357. ‖ Ibid. p. 382.

** Hisinger, Afhandlingar, iii. 300.

†† Laugier, Ann. du. Mus. d'Hist. Nat. ii. 157.

Sp. 2. *Chrysolite.* *

Peridot of the French—*Topaz* of the ancients.

The name *chrysolite* was applied, without discrimination, to a great variety of stones, till Werner defined it accurately, and confined it to that stone which the French chemists distinguish by the appellation of *peridot*. This stone, found principally in Upper Egypt, is the *topaz* of the ancients; their chrysolite is now called *topaz*.†

The chrysolite is found in angular fragments, in grains, and crystallized. The primitive form of its crystals is a right-angled parallelopiped, whose length, breadth, and thickness, are as 5, $\sqrt{8}$, $\sqrt{5}$.‡ The edges of the prism are usually truncated. The lateral planes are longitudinally streaked.

Colour pistachio-green, sometimes approaching olive-green, grass-green, or even broccoli-brown. External lustre of the crystals splendent; internal splendent, and vitreous. Fracture perfect conchoidal. Fragments sharp-edged. Transparent. Causes double refraction. Hard. Scratches felspar. Brittle. Easily frangible. Specific gravity from 3·410 to 3·440. Infusible at 150° Wedgewood, but loses its transparency, and becomes blackish-grey.§ With borax it melts without effervescence into a transparent glass of a light-green colour. Infusible with microcosmic salt,‖ and fixed alkali.**

Sp. 3. *Olivine.*††

This species has been united with the preceding by Haüy, on account of the sameness of the primitive form of the crystals. It occurs chiefly in basalt, and is very common, usually in roundish pieces or grains, though sometimes crystallized in rectangular four-sided prisms.

Colour intermediate between asparagus and olive-green. Internal lustre shining; resinous. Fracture imperfect small conchoidal. Fragments sharp-edged. Often in small-

* Kirwan, i. 262. Cartheuser, Min. 94. Dolomieu, Jour. de Min. No. xxix. 365. La Metherie, Nouv. Jour de Phys. i. 397. Brochant, i. 170. Haüy, iii. 198. Jameson, ii. 66.

† Plinii Lib xxxvii. c. 8.

‡ Haüy, Jour. de Min. No. xxviii. 281. § Kirwan's Min. i. 263.

‖ Vauquelin, Ann. de Chim. xxi. 97. ** Kirwan, i. 263.

†† Kirwan, i. 263. Lelievre, Jour. de Phys. xxx. 397. Brochant, i. 175. Jameson, ii. 71. Haüy, iii. 205.

grained distinct concretions. Semitransparent. Very easily
frangible. Hard. Specific gravity 3·225* to 3265.†
Nitric acid dissolves its iron,‡ and deprives it of its colour.
Infusible before the blow-pipe. Melts with borax into a
dark-green bead. The constituents of these two species
are as follows:

	Chrysolite.		Olivine.	
	§	‖	**	††
Silica......	39·0	38·0	50·0	52·00
Magnesia ..	43·5	50·5	38·50	37·75
Lime......	—	—	0·25	0·12
Iron oxide..	19·0	9·5	12·00	10·75
Loss	—	2	—	—
	101·5	100·0	100·75	100·62

XX. BASALT FAMILY.

This family contains four species, namely, *basalt, wacka,*
clink-stone, and *iron clay.*

Sp. 1. *Basalt.*‡‡

This mineral is confined to the floëtz trap formation, but
occurs abundantly in almost every country, and in none is
it more common than in Scotland. Colours greyish-black;
ash-grey, inclining to brown; sometimes nearly raven-
black. Massive. Internal lustre commonly dull; some-
times glimmering, from foreign particles. Fracture usually
coarse-grained, uneven; sometimes imperfect large con-
choidal and fine splintery. Fragments not sharp-edged.
Mostly in columnar distinct concretions of various sizes,
sometimes in globular distinct concretions; sometimes
tabular. Usually opaque; sometimes translucent on the
edges. Streak light ash-grey. Semihard. Brittle. Tough.
Specific gravity from 2·864 to 3·00. Melts before the
blow-pipe into an opaque black glass.

* Werner.   † Klaproth.   ‡ Kirwan, i. 264.
§ Klaproth, Beitrage, i. p. 110.
‖ Vauquelin, Ann. de Chim. xxi. 97.
** From Unkel. Klaproth, Ibid. p. 118.
†† From Karlesberge. Klaproth, Ibid. p. 128.
‡‡ Kirwan, i. 231. Brochant, i. 430. Jameson, ii. 79.

Sp. 2.   *Wacka.**

This species, like the preceding, is confined to the floëtz trap formation, and occurs in beds and veins. It constitutes the basis of amygdaloid.

Colour greenish-grey of various degrees of intensity. Massive and vesicular. Lustre dull. Fracture even; sometimes imperfect flat conchoidal, sometimes uneven and earthy. Fragments blunt-edged. Never in distinct concretions. Opaque. Lustre of streak shining. Sectile. Soft. Easily frangible. Specific gravity 2·535 to 2·893. Melts like basalt.

Sp. 3.   *Clink-stone.†*

This mineral, like the preceding, belongs to the floëtz trap formation, and is common in Germany, Scotland, &c.

Colour dark greenish-grey, sometimes passing into yellowish and ash-grey. Massive. Lustre of the cross facture dull; of the principal fracture glimmering. Cross fracture splintery; passing into conchoidal and even; principal fracture slaty. Fragments mostly sharp-edged, sometimes tabular. In irregular columnar and tabular distinct concretions. Translucent on the edges. Semihard. Brittle. Easily frangible. Specific gravity 2·575.‡ When struck with a hammer sounds like a piece of metal. Melts easily, and gives a glass nearly colourless.

Sp. 4.   *Iron Clay.§*

This mineral likewise belongs to the floëtz trap formation, and seems till lately to have been confounded with wacka. It was named by Werner from the great proportion of peroxide of iron which it contains.

Colour brownish red; sometimes approaching reddish-brown and blood-red. Almost always contains vesicles. Internal lustre dull. Fracture fine earthy; sometimes inclining to conchoidal. Soft. Easily frangible. Moderately heavy.

The following table exhibits the constituents of the pre-

* Kirwan, i. 223. Brochant, i. 434. Jameson, ii. 84.
† Brochant, i. 437. Klaproth, iii. 229. Jameson, ii. 86.
‡ Klaproth.   § Jameson, ii. 89.

ceding species, as far as they have been ascertained by
analysis:

	Basalt.		Clink-stone.
	*	†	‡
Silica.................	48	.... 44·5	.... 57·25
Alumina	16	.... 16·75	.... 23·5
Lime	9	.... 9·5	.... 2·75
Magnesia	—	.... 2·25	.... —
Soda	4	.... 2·6	.... 8·1
Oxide of iron..	16	 20	.... 3·25
Oxide of mang.	—	.... 0·12	.... 0·25
Muriatic acid..	1	.... —	.... —
Water	5	 2	 3
Loss	1	.... 2·28	.... 1·9
	100	100	100

ORDER II. SALINE STONES.

Under this order are comprehended all the minerals
which have an earthy basis combined with an acid. The
minerals belonging to it are of course salts, and as such
have been described in a a former part of this work: but
as they occur native in states which cannot always be imi-
tated by art, it will be necessary to take a view of them as
they are found in the earth. They naturally divide them-
selves into five genera, as only five earths have hitherto
been discovered native in combination with an acid. These
earths are, *lime, barytes, strontian, magnesia,* and *alumina.*
The species belonging to each genus might be arranged
according to their external characters; but as their con-
stituents afford well marked and important characteristics,
it will answer our purpose better to arrange each mineral
according to its composition. The following table exhibits
a view of the different saline stones arranged in that man-
ner: §

I. GENUS. CALCAREOUS SALTS.

I. *Family of Carbonates.*

a. Nearly pure.

Slate spar.

* Kennedy, Edin. Trans. v. 89.
† Klaproth, Beitrage, iii. 253. He found also traces of muriatic
acid. ‡ Klaproth, iii. 229. § See Jameson's Mineralogy, ii. 591.

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Aphrite.
Agaric mineral.
Chalk.
Limestone.
Blue vesuvian limestone.
Lucullite
Arragonite.

b. Combined with a foreign body.

Dolomite ⎫
Miemite ⎬
Gurhofite ⎭
Brown spar.
Marl.
Bituminous marl state.

II. *Family of Phosphates.*

Apatite.
Phosphorite.

III. *Family of Fluates.*

Fluor spar.

IV. *Family of Sulphates.*

Gypsum.
Anhydrite.
Vulpinite.
Glauberite.

V. *Family of Borosilicates.*

Datolite.
Botryolite.

VI. *Family of Silicates.*

Table spar.

VII. *Family of Arseniates.*

Pharmacolite.

VIII. *Family of Tungstates.*

Tungsten.

II. GENUS. BARYTIC SALTS.

Carbonate.
Sulphate.
Hepatite.

III. GENUS. STRONTIAN SALTS.

Carbonate.
Sulphate.

IV. GENUS. MAGNESIAN SALTS.

Sulphate.
Carbonate.
Anhydrous carbonate.
Borate.

V. GENUS. ALUMINOUS SALTS.

Alum.
Subsulphate.
Mellate.
Cryolite.

The minerals belonging to this Order are distinguished without much difficulty from the last. Almost all of them are insoluble in water; but soluble in nitric acid or in hot sulphuric acid. Most of them melt before the blow-pipe. Their specific gravity varies; but it is often above 3·5 when the mineral is too soft to scratch glass. None of them have the metallic lustre.

GENUS I. CALCAREOUS SALTS.

The existence of pure uncombined lime in a native state has been questioned; but the evidence on which the belief of its existence is founded is sufficiently respectable to put the matter beyond doubt. Monnet affirms that it exists in abundance in the mountains of Upper Auvergne, mixed, however, with a little oxide of iron.* Dr. Falconer of Bath found a soft whitish mineral in the neighbourhood of that town, consisting partly of pure lime capable of dissolving sulphur,† and from which lime-water may be made. I have been informed by his son Mr. Thomas Falconer, that

* Monnet's Mineralogy, p. 515. † On Bath Waters, 156.

a gentleman, engaged in collecting the minerals about Bath, found it, though not in any great quantity. But as the pure lime in these specimens is mixed with other bodies, it can scarcely with propriety be considered as a distinct mineral.

This genus comprehends all the combinations of lime with an acid that occur in the mineral kingdom.

I. FAMILY OF CARBONATES.

No other mineral can be compared with carbonate of lime in the abundance with which it is scattered over the earth. Many mountains consist of it entirely, and hardly a country is to be found on the face of the globe where, under the names of lime-stone, chalk, marble, spár, it does not constitute a greater or smaller part of the mineral riches.

This salt is often pure or nearly so: but it is frequently also either chemically combined, or at least intimately mixed with a considerable proportion of some other substance which changes its appearance and its properties. The first eight species of this family enumerated in the preceding table are nearly pure carbonates; but the last six are compounds, or intimate mixtures of carbonate of lime with some other body.

Sp. 1. *Slate Spar*, or *Schieferspath.**
Argentine of Kirwan.

This mineral occurs in beds in primitive mountains, and has been found in Norway, Saxony, and Cornwall.

Colour milk, greenish, and reddish-white. Massive. Lustre shining, pearly. Texture curve foliated. Fragments slaty. Brittle. Translucent. May be scratched by the nail. Specific gravity 2·740. Between sectile and brittle. Easily frangible.

Sp. 2. *Aphrite, Schaumearth.*†
Silvery chalk of Kirwan.

This mineral occurs in cavities of floëtz lime-stone. It is found near Gera, in Thuringia, and in the north of

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* Kirwan, i. 105. Brochant, i. 558. Jameson, ii. 116.
† Kirwan, i. 78. Brochant, i. 557. Jameson, ii. 118. The name aphrite seems to have been imposed by Karsten from the frothy appearance of this mineral. From αφρος, *froth.*

Ireland. Colour light yellowish (nearly silver) white. Massive and disseminated, or in fine scaly particles. Lustre shining. Between semimetallic and pearly. Fracture curve foliated. Cleavage single ; passes into scaly. Fragments blunt-edged. In granular distinct concretions. Opaque. Soils a little. Very soft. Sectile. Friable. Feels fine. Creaks a little. Light.

Sp. 3. *Agaric Mineral.* *
Rock-milk—Mountain-milk.

Found in the fissures and holes of lime-stone mountains, chiefly in Switzerland, and is supposed to be deposited by the rain water that filters through the rocks. Colour yellowish white, sometimes snow and greyish white. Composed of dusty particles without lustre, which cohere but weakly. Feels fine but meagre. Stains very much. Does not adhere to the tongue. Nearly floats on water.

Sp. 4. *Chalk.*†

This mineral forms a peculiar formation, and abounds particularly in the south of England and north of France. Colour yellowish white, sometimes snow and greyish white. Lustre dull. Opaque. Soft. Specific gravity from 2·315 to 2·657. Fracture fine earthy. Fragments blunt-edged. Adheres slightly to the tongue. Feels meagre and rough. Stains the fingers, and marks. Sectile.

Sp. 5. *Lime-stone.*‡

This mineral occurs in great abundance and in a great variety of situations, and differs in its appearance according to its situation. Hence it has been divided into five subspecies, distinguished chiefly by their fracture and their geognostic position.

Subsp. 1. *Compact Lime-stone.*

This mineral is confined almost exclusively to the floëtz and coal formations. It is usually massive, and never crystallized. Its texture is compact, its fracture splintery, and

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* Kirwan, i. 76. Brochant, i. 519. Jameson, ii. 123.
† Kirwan, i. 77. Brochant, i. 521. Jameson, ii. 125.
‡ Kirwan, i. 82. Brochant, i. 523. Haüy, ii. 127. Jameson, ii 129.

it has no internal lustre. It is often used for building, and for burning to lime. There are two varieties of it; namely, *common compact lime-stone* and *roe-stone*. The first of which is much more abundant than the second.

1. *Common.* Colour various shades of grey; namely, yellowish, bluish, ash, and smoke grey; greyish black; yellowish brown, ochre yellow; also blood, flesh, and peach blossom red. Often spotted and veined. Fracture small fine splintery, passing sometimes into large flat conchoidal, and into uneven. Fragments more or less sharp-edged. Translucent on the edges. Semihard. Brittle. Easily frangible. Specific gravity 2·6 to 2·7.

2. *Roe-stone.* Colour hair and chesnut brown; but from the quantity of marl which it contains, it appears yellowish and ash grey. Fracture fine splintery, but not easily observed. Fragments very blunt-edged. Composed of small globular distinct concretions; each globule is composed of concentric lamellar concretions. Opaque or translucent on the edges. Semihard. Brittle. Very easily frangible.

Subsp. 2. *Foliated Lime-stone.*

This subspecies is distinguished from the preceding by its foliated fracture. All the calcareous crystals belong to it, except one or two, which are peculiar to the arragonite. There are two kinds of it, easily distinguished from each other by the shape of the fragments; the fragments of the first kind being indeterminate, while those of the second are always rhomboidal. The first kind is called *granular foliated*, from the granular distinct concretions of which it is composed; the second *calcareous spar*, from the shape of the fragments.

1. *Granular foliated.* This kind belongs almost exclusively to the primitive and transition mountains, where it occurs in great abundance. The marbles used in sculpture, and many of those employed in architecture, belong to it. It is never found crystallized.

Colour various shades of white; namely, snow, yellowish, greyish, greenish, reddish; bluish, greenish ash, and smoke grey; greyish black; pearl grey, flesh red; cream yellow; siskin and olive green. Sometimes spotted and clouded. Internal lustre from shining to glimmering, between pearly and vitreous. Fracture foliated, sometimes from the

fineness of the grains appears splintery. Fragments blunt-
edged. Mostly in granular distinct concretions; sometimes
they are so fine that the mineral passes into compact.
Translucent. Semihard. Brittle. Easily frangible. Spe-
cific gravity from 2·7 to 2·84.

2. *Calcareous Spar.* This kind is found in veins; and it
occurs in every formation, being indeed the most generally
distributed of all minerals. It occurs massive and in dif-
ferent particular shapes, but more frequently crystallized.
The primitive form of its crystals is a parallelopiped, whose
sides are rhombs, with angles of 74° 55′ and 105° 5′.* Its
integrant molecules have the same form. The varieties of
its crystals amount to 616. For a description and figure
of which the reader is referred to Romé de Lisle,† Haüy,‡
and Bournon.§

Werner has given a very luminous view of the varieties
of these crystals, by supposing three fundamental figures;
namely, the six-sided pyramid, the six-sided prism, and the
three-sided prism, and forming all the other crystals by
truncations of these.‖

Colours greyish, yellowish, greenish, and reddish white;
olive, asparagus, pistachio, and leek green; greenish grey;
sometimes yellow, rose red, and pale violet blue, but very
seldom. Internal lustre from splendent to glistening, vitre-
ous. Fracture perfect foliated; cleavage threefold. Frag-
ments rhomboidal. Massive. Varieties occur in granular
distinct concretions, and in prismatic and wedge-shaped con-
cretions which are oblique longitudinally streaked. Massive.
Varieties transparent or translucent. Crystals transparent.
Refracts strongly double. Semihard. Brittle. Easily fran-
gible. Specific gravity 2·693 to 2·718. Many varieties
become phosphorescent on hot coals.

Subsp. 3. *Fibrous Lime-stone.*

This subspecies is by no means so universally distributed
as the preceding. It is divided into two kinds, the *common*

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* Malus and Wollaston.   † Crystallog. i. 497.
‡ Essai d'une Theorie, &c. p. 75. Jour. de Phys. 1793, August, p.
11. and Miner. ii. 130. Jour. de Hist. Nat. 1792, February, p. 148.
Ann. de Chim. xvii. 249, &c. Jour. de Min. No. xxviii. 304.
§ Traité de Mineralogie, Toms, i. ii. and iii.
‖ See Jameson's Min. i. 489.

fibrous and *calcsinter*. The first occurs in small veins; and the second consists chiefly of stalactites, formed by the filtration and evaporation of water impregnated with carbonate of lime. None of them are crystallized.

1. *Common Fibrous.* Colours greyish, reddish, and yellowish white. Massive. Lustre shining, pearly. Fracture coarse and delicate, straight and parallel fibrous. Fragments splintery. Translucent. Semihard. In other respects similar to the last subspecies. The *satin spar* belongs to this kind.

2. *Calcsinter.* Colours snow, greyish, greenish, and yellowish white; honey yellow, yellowish brown; siskin, pistachio, asparagus, mountain, and verdigris green; the last passes into sky blue; flesh and peach blossom red, reddish brown: but the red and green varieties are rare, and owe their colour to metals. Massive and in particular shapes. Internal lustre glimmering, passing into glistening, pearly. Fracture straight scopiform and stellular fibrous. Fragments usually indeterminate; sometimes splintery and wedge-shaped. Usually in curved lamellar distinct concretions. Translucent. Semihard. Brittle. Very easily frangible.

Subsp. 4. *Pea-stone.*

This mineral is found in the vicinity of the hot springs at Carlsbad in Bohemia. It has the form of round masses composed of concentric layers, and containing each a grain of sand in their centre. Colour yellowish white, sometimes snow white and yellowish brown. The round bodies are collected together like a bunch of grapes. Lustre dull. Very easily frangible. Opaque. Semihard. Moderately heavy. Fracture even.

Subsp. 5. *Calctuff.**

This mineral occurs in alluvial land, and appears to be daily formed by means of calcareous springs. Colour yellowish grey. Generally marked with impressions of reeds, grass, or moss. Internal lustre dull. Fracture between fine-grained uneven and earthy; sometimes inclines a little to fibrous or foliated. Fragments blunt-edged. Opaque, or only translucent on the edges. Soft. Somewhat sectile. Easily frangible. Light. Almost swims in water.

* Jameson, ii. 176.

Sp. 6. *Blue Vesuvian Lime-stone.**

This species is found in loose masses among ejected minerals in the neighbourhood of Vesuvius. It appears to differ in its composition from all other known lime-stones; containing water, and being composed of two atoms carbonic acid and three atoms lime.

Colour dark bluish grey, partly veined with white. Externally appears as if it had been rolled; surface uneven. Fracture fine earthy passing into splintery. Opaque. Streak white. Semihard in a low degree. Rather heavy.

Sp. 7. *Lucullite.†*

This variety of lime-stone was first constituted into a peculiar species by Dr. John, and called by him lucullite, because Pliny informs us that Lucullus had distinguished one of its subspecies by his own name.‡ It has been divided into three subspecies.

Subsp. 1. *Compact Lucullite.*

Of this there are two varieties; *common compact* and *stink-stone.*

FIRST VARIETY. *Common black marble.* This variety is considered by several modern geologists as characteristic of the transition class of rocks. Colour greyish black. Massive. Internal lustre strongly glimmering. Fracture fine-grained uneven, and large conchoidal. Fragments undeterminate angular and rather sharp edged. Opaque. Semihard. Streak dark ash grey. Brittle. Easily frangible. Specific gravity, according to John, 3·000. When rubbed emits a sulphureous smell. When heated in an open vessel it becomes white.

SECOND VARIETY. *Stink-stone.* Colours yellowish or greyish white, smoke grey, ash grey, bluish grey, and brownish grey; pitch black and cream yellow which passes into various shades of brown. Massive and disseminated through gypsum in plates or grains. Internal lustre dull or glimmering. Fracture sometimes small splintery, sometimes imperfect conchoidal and fine grained uneven. Frag-

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* Klaproth, Beitrage, v. 96.   † Jameson, ii. 180.
‡ Marmor Luculleum. Plinii Natur. Hist. Lib. xxxvi. cap. 6.

ments indeterminate angular or slaty. Occurs sometimes in small granular distinct concretions. Opaque. The cream coloured varieties are translucent on the edges. Semihard. Streak greyish white. Brittle. Easily frangible. Specific gravity 2·750. When rubbed emits a sulphureous odour.

Subsp. 2. *Prismatic Lucullite.*

Colours greyish black, pitch black and smoke grey. Massive. External surface sometimes delicately longitudinally streaked. External lustre dull or glistening, internal shining and splendent, and intermediate between vitreous and resinous. Fracture minute curve foliated; sometimes conchoidal. Fragments indeterminate angular, sometimes inclining to rhomboidal. In prismatic distinct concretions. Opaque or translucent on the edges. Semihard. Streak grey coloured. Brittle. Easily frangible. Specific gravity from 2·653 to 2·703. When rubbed gives out a sulphureous smell.

Subsp. 3. *Foliated Lucullite.*

This subspecies occurs abundantly in the neighbourhood of Sunderland. Colours yellowish, greyish and greenish white; also bluish grey, and greyish and velvet black. Massive, disseminated and crystallized in acute six-sided pyramids. Internal lustre glimmering and shining. Fracture minute foliated. Fragments rhomboidal. In fine granular concretions. Translucent. Semihard. Brittle. Easily frangible. When rubbed it emits a sulphureous smell. But I have found it sometimes to lose that property by keeping. Specific gravity 2·650.

Sp. 8. *Arragonite.**

This mineral was first found in Arragon imbedded in gypsum; afterwards in the Pyrenees at Saltzburg and in Scotland. Colour greenish and pearl-grey; in the middle often violet and green. Always crystallized in regular six-sided prisms; or having two opposite faces larger. Longitudinally striated. Lustre glistening, glassy. Fracture between imperfect foliated and fibrous. Colour arranged in

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* Kirwan, i. 87. Brochant, i. 576. Haüy, iv. 337. Jameson, ii. 199.

the direction of the fibres; the longitudinal fibres green, the transverse violet blue. Cleavage double; one parallel to the axis, another forming with the first an angle of $116\frac{1}{2}°$. Translucent. Refracts doubly. Scratches calcareous spar. Brittle. Specific gravity 2·9468.

Arragonite has been divided into three subspecies, the common, columnar, and acicular, from the shape of the distinct concretions.

From a very careful analysis of pure carbonate of lime, I have satisfied myself that it is a compound of

Carbonic acid .. 2·75 .... 43·14
Lime .... 3·625 .... 56·86
                         _____
                           100·00

Such is the composition of calcareous spar, and the finer kinds of granular limestone. Aphrite, agaric mineral, and chalk, owe their peculiar appearance to their being mechanical deposites. This seems to be the case also, though to a less extent with compact limestone. Blue vesuvian limestone is a hydrate composed of 2 atoms water, and 3 atoms carbonate of lime. Lucullite contains sulphur and charcoal in minute quantity. Arragonite has been shown by Holme to contain water in minute quantity, and by Stromeyer to contain a little carbonate of strontian. Common arragonite he found to contain 4 per cent. of carbonate of strontian, while columnar arragonite contains only two per cent. But Bucholz analysed various species of this mineral without being able to detect any strontian whatever in it. Stromeyer is of opinion that arragonite assumes the crystalline form of carbonate of strontian. By this hypothesis he endeavours to remove the anomaly which the peculiar crystalline form of arragonite has hitherto exhibited in the theory of crystals. But I have not yet seen sufficient evidence to satisfy me that this hypothesis is correct. The following tables which exhibit the composition of the different minerals comprehended under the preceding species will enable the reader to judge what foreign bodies each of them usually contains.

	Chalk	Common compact lime-stone						Granular foliated	Calcareous spar			Calc-sinter	Aphrite	Slate spar		
	*	+	+	+	+	+	‡	§	||	**	++	‡‡	§§	|||	***	+++
Lime........	56·5	53	49·50	48	47·25	49·25	33·41	56·5	55·5	56·5	56·327	56	51·5	54·7	55	56·00
Carb. acid...	43	42·5	40	38	28·25	35	42	43	44	43·0	43·045	43	39	43·7	41·7	28·5
Water........	0·5	1·63	1·13	1	2·25	—	—	0·5	0·5	0·5	·628	1	—	0·5	—	11·00
Silica........	—	1·12	5·25	7	5·75	8·75	10·25	—	—	—	—	—	5·7	·05	—	—
Alumina	—	1	2·75	4	3·75	2·5	—	—	—	—	—	—	—	—	—	1·25
Magnesia....	—	—	—	2	—	—	9·43	—	—	—	—	—	—	—	—	—
Ox. of iron..	—	0·75	1·37	—	Trace	2·75	2·25	—	—	—	—	—	3·3	·80	3	0·50
Ox. of Man..	—	—	—	—	2·75	Trace	1·25	—	—	—	—	—	—	—	—	0·28
Charcoal....	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·25
Loss........	—	—	—	—	—	1·75	1·41	—	—	—	—	—	—	·65	0·3	0·25
	100	100	100	100	100	100	100	100	100	100	100	100	100·5	100	100	100·03

* Bucholz, Gehlen's Jour. iv. 416.   It gave traces also of alumina and iron, and of muriatic acid.   † Simon, Ibid. iv. 426.

+ Bucholz, Gehlen's Jour. Second Series, ii. 18.   The variety analysed is known in Germany by the name of Mehl bass.

§ Bucholz, Gehlen's Jour. iv. 414. || Philips, Phil. Mag. xiv. 290.

** Bucholz, Gehlen's Jour. iv. 412.   Both this and the preceding analysis were made on pure specimens of Iceland crystal.

†† Thenard and Biot, Mem. d'Arcueil, ii. 176.   ‡‡ Bucholz, Gehlen's Jour. iv. p. 425.   §§ Ibid. p. 422.

||| Philips, Phil. Mag. xiv. 292.   *** Bucholz, Gehlen's Jour. iv. 419.

††† Blue vesuvian lime-stone; Klaproth, Beitrage, v. 91.

	Lucullite.						Arragonite.		
	*	*	*	†	†	‡	§	§	§
Carbonate of strontian	—	—	—	—	—	—	3·9662	4·0836	2·0552
Lime	53·38 ⎫	87·66	53·37 ⎱	99·1	95·0 ⎰	55·5 ⎱	94·5757	94·8249	97·7227
Carbonic acid	41·50 ⎭	—	41·50 ⎰	—	— ⎱	43·7 ⎰	—	—	—
Alumina	—	3·08	1·25	Trace	—	—	—	—	—
Charcoal	0·75	0·29	1·25	—	—	—	—	—	—
Oxide of iron	0·25	1·47	1·25	—	—	—	0·7060	0·0939	—
Oxide of manganese	0·12	0·59	0·75	0·9	1·5	—	—	—	0·0098
Silica	1·13	4·12	1·25	—	—	—	—	—	—
Sulphur	0·25	—	0·25	—	—	—	—	—	—
Lime	—	0·59	—	—	—	—	—	—	—
Potash, mineral acids, &c.	2·62	2·20 ‖	2·13	—	—	—	—	—	—
Water	—	—	—	—	3·5 **	0·8	0·3000	0·9831	0·2104
Loss	—	—	—	—	—	—	0·4521	·0145	·0019
	100	100	103	100	100	100	100	100	100

* John, Jameson, ii. 182, &c. First specimen black marble, second specimen stinkstone, third specimen prismatic luculite.

† Hisinger and Berzelius, Afhandlingar, iii. 379. Both specimens appear to have been sparry lucullite.

‡ Holme, Annals of Philosophy, i. 384.

§ Stromeyer, Annals of Philosophy, iv. 243.

‖ Including some sulphur.

** Chiefly pyrites.

Sp. 9. *Dolomite.**

This and the three following species consist of carbonate of lime and carbonate of magnesia mixed or united in various proportions. They constitute in fact only one species, but I am induced to separate them in order to prevent the confusion that would ensue, from arranging so many varieties under one name.

The term *dolomite* was given to this mineral from Dolomieu, who first drew the attention of mineralogists to one of its most important varieties. One of the varieties which occurs in great abundance in Great Britain has been long distinguished by the name of *magnesian lime-stone*.

Dolomite may be subdivided into four subspecies; namely, *common dolomite*, *crystallized dolomite* or *rhomb spar* or *bitter spar*, *columnar dolomite*, and *compact dolomite* or *magnesian limestone*.

Subsp. 1. *Common Dolomite.*

Colour greyish white, sometimes inclining to yellowish white, sometimes to green. Massive. Internal lustre glistening. Fracture seems foliated, but is not easily discovered, on account of the smallness of the distinct concretions. Fragments blunt-edged. In fine granular distinct concretions. Translucent on the edges. Semihard. Easily frangible. Feels harsh and meagre. Rather heavier than limestone. Specific gravity 2·835.† Effervesces very feebly in acids.

Subsp. 2. *Rhomb Spar* or *Bitter Spar.*‡

This mineral occurs in chlorite and similar rocks in Switzerland, the Tyrol, Sweden, Scotland, &c. and is always crystallized. Its constituents indicate that it bears the same relation to the preceding subspecies that calcareous spar does to granular limestone.

Colours greyish and yellowish white, yellowish grey. Always in middle-sized rhombs, nearly similar to the primitive crystal of calcareous spar.§ Lustre splendent, between vitreous and pearly. Fracture straight foliated, with a

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* Jameson, ii. 90.   † Klaproth, Gehlen's Jour. ii. 125.

‡ Kirwan, i. 92. Brochant, i. 560. Haüy, ii. 187. Jameson, i. 516.

§ Dr. Wollaston has shown that the angle in rhomb spar is 106° 15′, while in calcareous spar it is 105° 5′. Phil. Trans. 1812, p. 159.

threefold cleavage; cross fracture uneven and imperfect flat conchoidal. Translucent. Scratches calcareous spar. Brittle. Easily frangible. Specific gravity 2·880.

Subsp. 3. *Columnar Dolomite.**

Occurs in serpentine in the Mine Tschistagowskoy on the river Mjafs in Russia. Colour pale greyish white. Massive, generally in pieces about 2 inches long, covered with an isabella yellow botryoidal crust and interwoven with fibres of asbestus. Lustre vitreous inclining to pearly. Longitudinal fracture narrow radiated with delicate cross rents. Cross fracture uneven. In thin, long, straight prismatic concretions. Fragments acicular shaped. Feebly translucent. Brittle. Specific gravity 2·765.

Subsp. 4. *Magnesian Limestone.*

This limestone occurs in great abundance in Durham, Yorkshire, and several other of the English counties. In Durham it lies over the coal formation. Colour yellowish grey and yellowish brown. Massive. Internal lustre glimmering, and between pearly and vitreous. Fracture minute foliated, often combined with splintery and even conchoidal. Fragments rather blunt-edged. In minute granular concretions. Translucent on the edges. Rather harder than calcareous spar. Brittle. Specific gravity from 2·777 to 2·823.

There is a variety of this subspecies, which occurs near Tinmouth Castle, first observed by Mr. Nicol, which possesses considerable flexibility.

The following table exhibits the composition of these different subspecies.

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* Klaproth, Mag. der Gesellsch. Naturf. Freunde, v. 402.

	Common Dolomite.					Rhomb Spar.		Magnesian Limestone.		
	*	*	*	*	*	†	‡	§	§	§
Carbonate of lime	52	52	51·5	59	65	68	73	56·8	51·50	62
Carbonate of magnesia.	46·5	48	48	40·5	35	25·5	25	40·84	44·84	35·96
Oxide of iron	0·5	0·2	—	—	—	1	} 2·25	0·36	—	—
Oxide of manganese ..	0·25	—	—	—	—	4	}	—	—	—
Clay, water, &c.	0·75	—	0·5	0·5	—	1·5	—	2·0	1·60	1·60
Loss	—	—	—	—	—	—	—	—	2·06	0·44
	100	100·2	100	100	100	100	100·25	100	100	100

* Klaproth, Gehlen's Journal, ii. 115. The first specimen was from St. Gothard, and seems to be the same as that formerly analysed by Saussure with a very different result; the second from the Appennines, near Castelamare, in the state of small sandy particles perceptibly rhomboidal; the third compact, and from the Appennines; the fourth from the Alps; the fifth from an antique marble.

† Klaproth Beitrage, i. 306.

† Klaproth Beitrage, i. 306. From Taberg in Wermeland.

‡ Klaproth Beitrage, iv. 236. From Hall in the Tyrol.

§ By my analysis, Annals of Philosophy, iv. 416. The specimens were from Sunderland. The last was flexible magnesian limestone from the neighbourhood of Tinmouth-Castle.

Sp. 10.   *Miemite.**

This mineral was first observed by Dr. Thompson, of

* Jameson, ii. 103.

Naples, and has been named from Miemo in Tuscany, where it was first found. It ought to be considered as merely a variety of rhomb spar.

Colour pale asparagus green which passes into greenish white. Occurs massive and crystallized in flat double three-sided pyramids. Internal lustre shining or splendent, and vitreous. Fracture foliated. Fragments rather blunt-edged. In granular and prismatic distinct concretions. Translucent. Semihard. Brittle. Specific gravity 2·885. Its constituents are,

$$
\begin{array}{ll}
\text{Carbonate of lime} \ldots \ldots & 53\cdot0 \\
\text{Carbonate of magnesia} \ldots & 42\cdot5 \\
\text{Carbonate of iron} \ldots \ldots & 3\cdot0 \\
\text{Loss} \ldots \ldots \ldots \ldots \ldots & 1\cdot5 \\
\hline
& 100\cdot0^*
\end{array}
$$

Sp. 11. *Gurhofite.*[†]

This mineral occurs in great abundance between Gurhof and Aggsbach in Lower Austria.

Colour snow white. Massive. Lustre dull. Fracture flat conchoidal passing into even. Fragments indeterminate, sharp-edged. Slightly translucent on the edges. Hard, bordering on semihard. Brittle. Rather tough. Specific gravity 2·760. Constituents

$$
\begin{array}{ll}
\text{Carbonate of lime} \ldots \ldots & 79\cdot5 \text{ or 2 atoms} \\
\text{Carbonate of magnesia} \ldots & 29\cdot5 \text{ —— 1 atom} \\
\hline
& 100\cdot0 \ddagger
\end{array}
$$

Sp. 12. *Brown Spar.* §
Spath perlé—Sidero-calcite.

This mineral occurs in veins, and is usually accompanied by calcareous spar and sparry iron ore. Principal colours white and red; namely, greyish, yellowish, reddish white; flesh, rose, and brownish red; brown. Some varieties ap-

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* Klaproth, Beitrage, iii. 296.

† Jameson, ii. 112; Klaproth Beitrage, v. 103.

‡ Klaproth, Beitrage, v. 103.

§ Kirwan, i. 105. Brochant, i. 563. Haüy, ii. 175. Jameson, ii. 106.

proach pearl grey, others black. Sometimes spotted. Massive, globular, and crystallized. Crystals the same as those of calcareous spar. The following have been observed: a flat and an acute double three-sided pyramid, an oblique six-sided pyramid; also in lenses and rhombs. External lustre shining; internal from shining to splendent, pearly. Fracture sometimes straight foliated, more commonly spherical curve foliated. Threefold cleavage, like calcareous spar. Fragments rhomboidal. In granular distinct concretions of all sizes, and in straight lamellar concretions. Translucent. Crystals semitransparent. Scratches calcareous spar. Easily frangible. Specific gravity 2·887. Effervesces slowly in acids.

A variety of this mineral, hitherto found only in Hungary and Transylvania, has been distinguished by Werner as a subspecies, under the name of *fibrous brown spar*. Colour flesh red. Massive. Lustre glistening. Fracture straight and diverging fibrous. Fragments splintery and wedge-shaped. In other characters it resembles common brown spar.

There is a third variety which has been distinguished by the name of *columnar* brown spar, from the shape of its distinct concretions. The constituents of brown spar are as follows:

Carbonate of lime	51·5	49·19
Carbonate of magnesia	32·0	44·39
Carbonate of iron	7·5	—
Carbonate of manganese	2·0	—
Oxide of iron	—	3·4
Oxide of manganese	—	1·5
Water	5·0	0·13
Loss	2·0	1·39
	100·0 *	100·00 †

Sp. 13. *Marl.* ‡

A mixture of carbonate of lime and clay, in which the carbonate considerably exceeds the other ingredient, is in common language called *marl*. Mr. Kirwan has divided

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* Klaproth, Beitrage, iv. 203.   † Hisinger, Afhandlingar, iv. 374.
‡ Kirwan, i. 94. Brochant, i. 569. Haüy, iv. 455. Jameson, ii. 191.

marls into two varieties: 1. Those which contain more silica than alumina; 2. Those which contain more alumina than silica. He has called the first of these *siliceous*, the second *argillaceous marls*. Attention should be paid to this distinction when marls are used as a manure. Werner divides marls into two subspecies, *earthy* and *indurated marl*.

<div align="center">Subsp. 1. Earthy marl.</div>

Colour yellowish grey. Composed of dull dusty particles. Feels rather meagre. Soils a little. Sometimes loose, sometimes cohering.

<div align="center">Subsp. 2. Indurated Marl.</div>

Occurs in the floëtz lime and coal formations. Colour grey, sometimes yellowish grey. Massive. Lustre dull; sometimes glimmering, from foreign particles. Fracture earthy; sometimes splintery, or imperfect slaty. Fragments indeterminate, partly slaty. Opaque or translucent on the edges. Yields to the nail. Not particularly brittle. Easily frangible. Specific gravity from 1·6 to 2·877. Melts before the blow-pipe into a greyish black glass. Falls in the air. Passes into limestone and indurated clay.

<div align="center">Sp. 14. Bituminous Marl Slate.*</div>

This mineral occurs in beds along with the oldest floëtz limestone. Often intermixed with ores of copper. Contains a great number of petrified fish. Colour greyish or brownish black. Massive. Fracture curved or straight slaty. Lustre dull. Fragments slaty. Opaque. Soft. Feels soft. Easily frangible. Sectile. Moderately heavy. Streak shining. Effervesces with acids. Burns before the blow-pipe, leaving black scoriæ.

The six preceding species may be considered as combinations or mechanical mixtures of carbonate of lime and corbonate of magnesia.

In dolomite, miemite, and gurhofite, nothing is present but carbonates of lime and magnesia. For any thing that

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* Kirwan, i. 103. Brochant, ii. 574. Jameson, ii. 197.

1

Book III. appears at present, these two constituents do not exist together in definite proportions, which is rather against the supposition that they are combined chemically.

In brown spar, besides carbonates of lime and magnesia, there appear to be present small quantities of carbonates of iron and manganese.

Marl and bituminous marl-slate are mechanical mixtures of carbonates of lime and clay.

II. FAMILY OF PHOSPHATES.

Family of phosphates.   This family contains only two species, namely, *apatite* and *phosphorite.*

Sp. 1. *Apatite.*

This species has been divided into two subspecies, *common apatite*, and *conchoidal apatite* or *asparagus-stone.*

Subsp. 1. *Common apatite.*[*]

This mineral occurs in tin veins, and is found in Cornwall and Germany. Werner first constituted it a new species, and gave it the name which it bears.[†]

Colours white, green, blue, and red, of various shades: as greyish, reddish, yellowish, and greenish-white; mountain, seladon, pistachio, and leek-green; rose and flesh-red; pearl-grey; violet, lavender, and indigo-blue; yellowish-brown. All the colours rather light. Mostly crystallized. The primitive form of its crystals is a regular six-sided prism. Its integrant molecule is a regular triangular prism, whose height is to a side of its base as 1 to $\sqrt{2}$.[‡] The six-sided prisms are always low, and sometimes pass into the six-sided table. Lateral edges and angles sometimes terminal, frequently truncated. Lateral faces usually longitudinally streaked; acuminating faces smooth. External lustre splendent; internal shining, resinous, approaching vitreous. Longitudinal fracture imperfect foliated; cleavage fourfold, as in the beryl. Cross fracture uneven, approaching small conchoidal. The massive in coarse granular concretions. Transparent and translucent. Causes

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[*] Kirwan, i. 128. Brochant, i. 580. Haüy, ii, 234. Jameson, ii. 208.

[†] From ἀπατάω, because it had been erroneously arranged along with other minerals.

[‡] Haüy, Jour. de Min. No. xxviii. 310.

single refraction. Semihard; scratched by fluor spar. Brittle. Easily frangible. Specific gravity 3·179. Phosphoresces on hot coals. Becomes electric by heat and by friction.

Subsp. 2. *Asparagus-stone.**

This mineral has hitherto been found chiefly at Caprera in Murcia, a province in Spain. It occurs likewise in France and in Norway. It was this species which Romé da Lisle and the other French chemists considered as a chrysolite.

Colour asparagus-green, sometimes passing to greenish-white, or pistachio-green; sometimes between orange and yellowish-brown. Always crystallized in equiangular six-sided prisms, obtusely acuminated by six planes set on the lateral planes: lateral edges truncated. Planes longitudinally streaked, also smooth. Crystals complete. Internal lustre shining, vitreous. Fracture concealed foliated, passing into uneven. Translucent, sometimes nearly transparent. Semihard, approaching soft. Easily frangible. Brittle. Specific gravity 3·098. Does not phosphoresce.

Sp. 2. *Phosphorite.†*

This mineral forms great beds in the province of Estremadura. Colour yellowish-white; often spotted yellowish-grey. Massive. Internal lustre dull or glimmering. Fracture imperfect curved foliated, inclining to the floriform foliated; sometimes passes to coarse earthy. Fragments blunt-edged. Tends to thick lamellar distinct concretions. Translucent on the edges. Soft, approaching semihard. Brittle. Specific gravity 2·814.

There is a substance found at Kobolobanya near Szigeth, in the county of Marmarosch in Hungary. It is an earthy matter which phosphoresces when heated, emitting a pale yellow-light. This property induced mineralogists to consider it as a variety of fluate of lime, till Hassenfratz analysed it, and found it to consist chiefly of phosphoric acid and lime.‡ Hence it was considered as similar to the phosphorite of Estremadura. Pelletier examined it soon

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* Brochant, i. 586. Vauquelin, Jour. de Min. No. xxxvii. 19. Jameson, ii. 212.

† Brochant, i. 584. Bertrand, Pelletier, and Donadei, Jour. de Phys. xxxvii. 161. Jameson, ii. 215. ‡ Ann. de Chim. i. 191.

after, and again restored it to the place of fluate; having found it a mixture of fluate of lime with silica and alumina, and a little phosphoric acid, muriatic acid, and iron.* Klaproth has lately analysed it, and shown that the original experiments of Hassenfratz were accurate. Of course, it must be considered as approaching the nature of the phosphorite of Estremadura. The result obtained by Klaproth has been inserted in the following table.

The composition of apatite was the first ascertained by Proust Vauquelin was the first of the French chemists who determined the composition of asparagus-stone. I do not know whether it had been previously analysed in Germany. Proust first determined the composition of phosphorite. A more exact analysis was afterwards made by Pelletier, Bertrand, and Donadei. The following table exhibits the result of these different experiments :

	Apatite.	Asparagus-stone.			Phosphorite.	Hungarian phosphorite
	†	‡	§	‖	**	††
Lime	55	53·75	53·32	92	59	47
Phosphoric acid	45	46·25	45·72		34	32·25
Carbonic acid ..	—	—	—	—	1	—
Carbon. of lime.	—	—	—	6	—	—
Muriatic acid ..	—	—	—	—	·5	—
Fluoric acid ...	—	—	—	—	2·5	2·5
Silica	—	—	—	1	2	0·5
Oxide of iron ..	—	—	—	—	1	0·75
Water	—	—	—	0·5	—	1
Quartz and rock mixed	—	—	—	—	—	11·5
Loss	—	—	0·96	0·5	—	4·5
	100	100	100	100	100	100

* Ann. de Chim. ix. 225.

+ Klaproth, Jour. de Min. No. xxxvii. p. 26.

‡ Klaproth, Beitrage, iv. 194. The specimen was from Zillerthale. It was massive, of an asparagus-green colour. Specific gravity 3·190. Principal fracture foliated, cross fracture conchoidal.

§ Vauquelin, Jour. de Min. ibid.

‖ Klaproth, Beitrage, v. 180. From Utö.

** Pelletier, Bertrand, and Donadei, Jour. de Phys. xxxvii. 161.

†† Klaproth, Beitrage, iv. 366.

III. FAMILY OF FLUATES.

This family comprehends only one species; namely, *fluor*, which Werner divides into two subspecies. The first is very rare, the second very common.

Subsp. 1. *Compact Fluor.*

It is found in veins along with the next subspecies in the Hartz. Colours greyish-white and greenish-grey; sometimes inclining to blue; sometimes marked with yellow or red spots. Massive. External lustre dull; internal glimmering, vitreous. Fracture even. Fragments sharp-edged. Scratches calcareous spar. Brittle. Easily frangible. Moderately heavy.

Subsp. 2. *Fluor Spar.*

This mineral occurs in beds in the primitive mountains, also in veins along with tin, lead, and copper.

Colours very numerous, being various shades of blue, green, yellow, white, red, black, and brown. Several frequently occur together. Massive and frequently crystallized. The primitive form of its crystals is the regular octahedron; that of its integrant molecules the regular tetrahedron.* The varieties of its crystals hitherto observed amount to nine. These are the primitive octahedron; the cube; the rhomboidal dodecahedron; the cubo-octahedron, which has both the faces of the cube and of the octahedron; the octahedron wanting the edges; the cube wanting the edges, and either one face, or two faces, in place of each. For a description and figure of these, the reader is referred to Mr. Haüy.† Surface smooth, sometimes drusy. Lustre of the first splendent; of the second glistening. Internal lustre splendent, vitreous. Fracture foliated; cleavage fourfold. Fragments tetrahedral or octahedral. Transparent and translucent. Refracts singly. In granular and prismatic distinct concretions. Semihard. Brittle. Easily frangible. Specific gravity 3·0943 to 3·1911. Its powder thrown upon hot coals emits a bluish or greenish light. Two pieces of it rubbed in the dark phosphoresce. It decrepitates when heated. Before the blow-pipe it melts into a transparent glass.‡

* Haüy, Jour. de Min. No. xxxviii. 325.
† Ibid. ii. 249.   ‡ Ibid. No. xxviii. 325.

It admits of a polish, and is often formed into vases and other ornaments.

The composition of pure fluate of lime is as follows:

	*	†	‡
Lime	32·25 ..	32·66 ..	35
Fluoric acid ...	67·75 ..	67·34 ..	65
Total	100	100	100

But if we adopt the hypothesis of Ampere and the analysis of Davy, which I am inclined to do, the constituents of fluor spar are

Fluorine... 46·69
Calcium .. 53·31

100·00 §

IV.   FAMILY OF SULPHATES.

Family of sulphates. This family consists of four species; namely, *gypsum* or *hydrous sulphate of lime*, *anhydrite* or *anhydrous sulphate of lime*, *vulpinite*, and *glauberite*.

Sp. 1.   *Gypsum.*‖

This mineral, which abounds in nature, occurs in four different situations in beds; namely, in the primitive, the transition, the oldest, and the second floëtz lime-stone. It has been divided into five subspecies.

Subsp. 1.   *Gypsum Earth.*

Rare. Found in the cavities of the other subspecies, and is supposed to be deposited from water filtering through them. Colour yellowish-white, sometimes nearly snow-white. Of the consistence of meal. Lustre dull. Opaque. Scarcely sinks in water. Is not gritty between the teeth. Feels dry and meagre. When heated below redness, it becomes of a dazzling-white.

* Klaproth, Beitrage, iv. 366.   † By my analysis.
‡ Richter, as quoted by Klaproth, Beitrage, iv. 361.
§ Davy, Phil. Trans. 1814, p. 64. Davy found that 100 grains of fluor spar, when converted into sulphate of lime, became 175·2 grains.
‖ Kirwan, i. 120. Brochant, l. 601. Haüy, ii. 266. Jameson, ii. 230.

Subsp. 2. *Compact Gypsum.*

This and the subsequent species lie over the oldest floëtz lime-stone. Colour ash-grey. Massive. Internal lustre dull. Fracture even: passing into fine splintery. Fragments blunt-edged. Translucent on the edges. Very soft. Specific gravity about 2·1679. Sectile. Easily frangible.

Subsp. 3. *Fibrous Gypsum.*

This mineral lies over the variegated sand-stone, and characterizes that formation. Colours various shades of white, grey, and red. Massive and dentiform. Internal lustre glistening; sometimes shining, pearly. Fracture parallel fibrous; sometimes bordering on radiated. Fragments mostly splintery. Translucent. Very soft. Rather sectile. Very easily frangible.

Subsp. 4. *Foliated Gypsum.*

This mineral bears some resemblance to granular lime-stone, but is much softer. Colours white, grey, and red; sometimes yellow, brown, black, of various shades. Often spotted. Massive; and sometimes in conical lenses imbedded in clay. Internal lustre shining; between pearly and vitreous. Fracture perfect (somewhat curved) foliated; single cleavage; sometimes diverging radiated. Fragments indeterminate, blunt-edged. In granular distinct concretions; the radiated in prismatic concretions. Translucent. Very soft. Rather sectile. Easily frangible. Specific gravity from 2·274 to 2·310.

Subsp. 5. *Sparry gypsum,* or *Selenite.*

This subspecies includes all the crystallized specimens of sulphate of lime. Foliated gypsum bears the same relation to it that granular lime-stone does to calcareous spar. It occurs in the oldest gypsum formation, and sometimes in veins. Fine specimens are found in Oxfordshire.

Principal colour snow-white; also yellowish and greyish-white, and various shades of grey, yellow, and brown. Massive and often crystallized. The primitive form of its crystals is a four-sided prism, whose bases are oblique parallelograms, with angles of 113° 7′ 48″ and 66° 52′ 12″. It occurs crystallized in six-sided prisms, terminated by

two-sided or four-sided summits. For a description and figure of its varieties, the reader is referred to Romé de Lisle * and Haüy.†

Internal lustre shining, pearly. Fracture perfect foliated, with one perfect and two imperfect cleavages. Fragments rhomboidal; sometimes in granular distinct concretions. Transparent. Refracts doubly. Very soft. Sectile. Easily split into plates, which are somewhat flexible. Easily frangible. Specific gravity 2·322.

This salt is a compound of 1 atom sulphate of lime and 2 atoms of water, or its constituents are

$$
\begin{array}{ll}
\text{Sulphate of lime} .. & 79\cdot32 \\
\text{Water} .... & 20\cdot68 \\
\hline
& 100\cdot00
\end{array}
$$

Sp. 2. *Anhydrite.*‡

This mineral seems to have been first noticed by the Abbé Poda, who called it *muriacite*, on the supposition that it is a combination of lime and muriatic acid. Fichtel gave an account of it in 1794. Klaproth soon after analysed it; but mineralogists did not pay much attention to it, till Haüy pointed out its characters in the fourth volume of his Mineralogy. It was soon after described by Bournon. It was first found in the salt pits at Hall in the Tyrol, afterwards in the canton of Berne, and in other places.

It has been divided into the five following subspecies.

Subsp. 1. *Compact Anhydrite.*

It occurs in the salt mines of Austria and Salzburg, and in the first floëtz gypsum on the eastern foot of the Hartz mountains. Colours various shades of white, likewise grey, blue, and red. Massive, contorted, and reniform. Feebly glimmering and dull. Fracture small splintery, passing into even and small conchoidal. Fragments sharp-edged. Translucent, at least on the edges. Scratches calcareous spar, but is scratched by fluor spar. Streak greyish white. Rather tough. Specific gravity 2·850.

* Crystallog. i. 144.   † Mineralogie, ii. 270.
‡ Jameson, ii. 247.

Subsp. 2. *Fibrous Anhydrite.*

It is found at Hall in the Tyrol, and at Ischel in Upper Austria. Colours different shades of red. Massive. Internal lustre glimmering and glistening, pearly. Fracture delicate parallel fibrous. Fragments long splintery. Feebly translucent. Rather easily frangible.

Subsp. 3. *Radiated Anhydrite.*

It is found along with the two preceding subspecies. Usual colour blue. Sometimes spotted red. Massive. Radiated fracture splendent. The splintery glistening. Fracture partly radiated, partly splintery. Fragments indeterminate, rather blunt edged. Translucent. Semihard. Specific gravity 2·940.

Subsp. 4. *Sparry Anhydrite,* or *Cube Spar.*

Colour milk-white, which sometimes passes into greyish, yellowish, and reddish-white, approaching pearl-grey. Massive, and crystallized in four-sided prisms, approaching the cube, but having two of the opposite lateral faces much broader than the other two; sometimes the lateral edges are truncated, which converts the crystal into an eight-sided prism; sometimes the truncations are so great as to destroy the narrow lateral faces, and then the crystal becomes a six-sided prism.* External lustre of the broad faces of the crystal splendent and pearly; of the narrow glistening. Internal shining, pearly. Fracture perfect foliated. Cleavage threefold and rectangular. Fragments cubical. In granular and lamellar distinct concretions. Translucent. Scratches calcareous spar. Very easily frangible. Specific gravity from 2·850 to 2·964.†

Subsp. 5. *Scaly Anhydrite.*

It is found in the salt mines of Hall in the Tyrol. Colours various shades of white, smalt-blue, and grey. Massive. Lustre splendent and pearly. Fracture confused foliated. In fine granular scaly concretions. Translucent on the edges. Easily frangible. Specific gravity 2·957.

* Bournon.   † Bournon, Haüy, and Klaproth.

This species consists of sulphate of lime without **any** water. Sometimes it contains a small proportion of common salt, probably merely mixed mechanically.

Sp. 3. *Vulpinite.**

This mineral occurs at Vulpino in Ital**y**. Hence its name. Colour greyish-white, veined with bluish grey. Massive. Internal lustre splendent. Fracture foliated with a threefold slightly oblique cleavage. Fragments rhomboidal. In granular distinct concretions. Translucent on the edges. Soft. Brittle. Easily frangible. Specific gravity 2·878. Its constituents are as follows:

Sulphate of lime 92
Silica 8
                         ——
                         100†

It ought to be considered as **merely** a subspecies of anhydrite.

Sp. 4. *Glauberite.* ‡

This mineral was discovered in Spain, at Villaruba **near** Ocana in New Castile. Its crystals are sometimes solitary, sometimes in clusters, and disseminated in masses of sal gem. Always crystallized. Crystals in the form of an oblique prism with a rhombic base. The angles of the parallelogram constituting the base are 75° 32′ and 104° 28′. The angles of incidence between the parallelogram of the base and the adjacent sides are 142°; that between the base and the edge contiguous to the acute angle of the base is 154°. The faces of the base smooth, those of the sides longitudinally striated.

The crystals are of a light topaz-yellow, and retain their solidity and transparency in the air if they have not been wetted. Harder than sulphate of lime, but softer than calcareous spar. When heated it splits; decrepitates and melts into a white enamel. Immersed in water it soon becomes white and opaque. When taken out of the water and dried, it does not resume its transparency; but the white coating falls to powder, and when rubbed off dis-

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* Jameson, ii. 254.   † Vauquelin, as quoted by Jameson.
‡ Brogniart, Nicholson's Jour. xxiv. 65.

covers the nucleus unchanged.   Specific gravity 2·73.
Composed of

<div style="text-align:center">

51 anhydrous sulphate of soda

49 anhydrous sulphate of lime

———

100

</div>

It contains no water of crystallization.

v. FAMILY OF BOROSILICATES.

This family contains two species; namely, *datholite* and *botryolite.*

<div style="text-align:right">Family of borosili-, cates.</div>

<div style="text-align:center">Sp. 1. Datholite.*</div>

This mineral was first discovered by Esmark, near Arendal in Norway. For the discovery of its composition we are indebted to Klaproth.

Colour greyish and greenish white; sometimes mountain green. Massive, and crystallized in flat rectangular four-sided prisms, having their angles truncated. Crystals small. External lustre glistening, internal shining between vitreous and resinous. Fracture small imperfect conchoidal. Fragments indeterminate. In large and coarse granular distinct concretions, which have a rough glimmering surface. Semihard in a high degree. Translucent.† Specific gravity 2·980.‡

From the analysis of Klaproth, we learn that this mineral is composed of

<div style="text-align:center">

Silica . . . . 36·5

Lime . . . . 35·5

Boracic acid 24

Water 4

———

</div>

<div style="text-align:right">100 with a trace of iron.</div>

<div style="text-align:center">Sp. 2. Botryolite.§</div>

This mineral was first described by Abilgaard under the name of *semiglobular zeolite.* Its chemical properties were observed by Esmark, and Assessor Gahn ascertained that it contains lime, silica, and boracic acid. Klaproth subjected it to a rigid analysis, and Haussman, from its shape, gave

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* Klaproth, Gehlen's Jour. vi. 107.

† See Karsten, Gehlen's Jour. vi. 108.   ‡ Klaproth.

§ Jameson, ii. 259.

Book III. it the name by which it is now distinguished. It occurs near Arendal in Norway.

Colours externally pearl and yellowish-grey; internally greyish, milk, and reddish-white in concentric stripes. Botryoidal. Surface rough and dull. Internal lustre glimmering and pearly. Fracture delicate stellular fibrous. In thin concentric lamellar distinct concretions. Translucent on the edges. Semihard. Brittle. Specific gravity 2·885. Before the blowpipe froaths and melts into a white glass. Its constituents are

Silica	36
Boracic acid	39·5
Lime	13·5
Oxide of iron	1
Water	6·5
Loss	3·5
	100·0 *

VI. FAMILY OF SILICATES.

Family of silicates. This family contains only one species; namely, *table spar*.

Sp. 1. *Table Spar* or *Schalstone*.†

This mineral has been hitherto found only in the Bannat of Tameswar, and in cinnamon-stone rock from Ceylon. Colour greyish-white, passes into greenish and yellowish-white, and reddish-white. Massive. Lustre of the principal fracture shining, pearly. Principal fracture foliated, with a slight tendency to splintery and coarse fibrous. Cleavage single. In straight thin lamellar distinct concretions, collected into large brown prismatic distinct concretions. Translucent. Semihard. Brittle. Easily frangible. Specific gravity 2·86. When put into nitric acid it effervesces for a moment and then falls into grains. Infusible before the blowpipe. Phosphoresces when scratched by a knife. Its constituents are

Silica	50
Lime	45
Water	5
	100 ‡

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* Klaproth, Beitrage, v. 125.   † Jameson, ii. 114. Klaproth, iii. 289.
‡ Klaproth, Beitrage, iii. 291.

It is therefore a bisilicate of lime, and consists of 3 atoms of bisilicate united to 1 atom of water.

VII. FAMILY OF ARSENIATES.

This family contains only one species; namely, *pharma-colite.*

Sp. 1. *Pharmacolite,** *Arsenic bloom.*

This salt was first found in the mine Sophia, near Wittichen in Suabia, where it occurs in the rents of a granite rock accompanied by cobalt ore. It has since been observed at Andreasberg in the Hartz and in other places. Colour reddish and snow-white. Occurs as a coating and in delicate capillary crystals. Internal lustre glimmering, silky. Fracture delicate radiated. Fragments indeterminate, and sometimes wedge-shaped. In granular distinct concretions. Translucent on the edges. Very soft. Easily frangible. Its constituents are as follows:

Arsenic acid	50·54	45·68
Lime	25·00	27·28
Water	24·46	23·86
Loss	—	3·18
	100·00†	100·00‡

VIII. FAMILY OF TUNGSTATES.

This family contains only one species; namely, *tungstate of lime.*

Sp. 1. *Tungsten.* §

This mineral which is scarce, has hitherto been found only in Cornwall, Sweden, and Germany. It is usually massive, sometimes crystallized; and, according to Bournon, the primitive form of its crystals is an acute octahedron; the solid angle at the summit of which measures 48° on the faces, and 64° 22′ on the edges. For a description of the varieties of crystallization, the reader is referred to Bournon.‖

Colour yellowish and greyish-white; sometimes verges

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* Brochant, ii. 523. Haüy, ii. 293. Klaproth, iii. 280. Jameson, iii. 543. † Klaproth, Beitrage, iii. 281.
‡ John, Gehlen's Journal, Second Series, iii. 539. Specimen from Andreasberg. § Jameson, iii. 545. ‖ Jour de Min. No. lxxv. p. 167.

on snow-white; passes into yellowish-grey, yellowish-brown, and approaches orange-yellow. Lustre shining, vitreous. Translucent. Fracture foliated. Fragments indeterminate, rather blunt-edged. Sometimes in granular distinct concretions. Not particularly brittle. Easily frangible. Soft. Specific gravity 5·8 to 6·0665. Becomes yellow when digested with nitric or muriatic acid. Infusible by the blowpipe. With borax forms a colourless glass, unless the borax exceed, and then it is brown. With microcosmic salt it forms a blue glass, which loses its colour by the yellow flame, but recovers it in the blue flame.* Its constituents are as follows :

Tungstic acid	77·75	.... 75·25	.... 80·417
Lime	17·60	.... 18·70	.... 19·400
Ox. of iron	—	.... 1·25	.... —
Ox. of mangan.	—	.... 0·75	.... —
Silica	3·00	.... 1·50	.... —
Loss	1·65	.... 2·55	.... 0·183
	100· †	100· †	100·000 ‡

GENUS II.   SALTS OF BARYTES.

This genus comprehends only two species, namely, the *carbonate and sulphate.*

Sp. 1.   *Carbonate of Barytes* §—*Witherite.*

This mineral occurs at Anglesark in Lancashire in veins, which traverse the independent coal formation. It was discovered by Dr. Withering; hence Werner has given it the name of *Witherite.* Usually massive, but sometimes crystallized. The crystals are very small and rare. Hence their primitive form has not been ascertained. They are six-sided prisms, terminated by six-sided pyramids, or double six-sided pyramids. Colour yellowish-grey. Principal fracture intermediate between foliated and radiated; cross fracture uneven. Fragments wedge-shaped. Lustre of the principal fracture glistening; of the cross glimmer-

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* Scheele and Bergman.   † Klaproth, Beitrage, iii. 44.
‡ Berzelius, Afhandlingar, iv. 305.
§ Kirwan, i. 134. Brochant, i. 613. Haüy, ii. 309. Jameson, ii. 265.

ing, resinous. Massive varieties composed of wedge-shaped distinct concretions, passing into coarse granular. Translucent. Soft. Brittle. Specific gravity 4·3 to 4·338. Easily frangible. When heated it becomes opaque. Its powder phosphoresces when thrown on burning coals.*

According to the analysis of Klaproth, the constituents of this mineral are as follows:

Carbonate of barytes .. 98·246
Carbonate of strontian . 1·703
Alumina with iron .... 0·043
Carbonate of copper .. 0·008
_____
100·000 †

Sp. 2. *Sulphate of Baryies* ‡—*Ponderous Spar—Baroselenite.*

This mineral is found almost always in veins, and frequently accompanies metallic ores; sometimes, however, it occurs in beds and imbedded. It is sometimes in powder, often in amorphous masses, and often crystallized. The primitive form of its crystals is a rectangular prism, whose bases are rhombs, with angles of 101° 30' and 78° 30'.§ The varieties of its crystals amount to 14. For a description and figure of them I refer to Romé de Lisle || and Haüy.** The most common varieties are, the octahedron with cuneiform summits, the six or four-sided prism, the hexangular table with bevelled edges. Sometimes the crystals are needle-form.

Lustre from dull to glistening. Transparency from translucent to opaque; in some cases transparent. Soft. Specific gravity from 4·4 to 4·5. Colour commonly white, with a shade of yellow, red, blue, or brown. When heated it decrepitates. It is fusible *per se* by the blue flame of the blow-pipe, and is converted into sulphuret of barytes. Soluble in no acid except the sulphuric; and precipitated from it by water. Werner divides this species into eight subspecies; namely, *earthy, compact, granular, curved lamellar,*

* Haüy.   † Beitrage, ii. 86.
‡ Kirwan, i. 138. Brochant, i. 617. Haüy, ii. 295. Jameson, ii. 268.   § Haüy, Essai d'une Theorie, p. 119. || Crystal. i. 588.
** Crystal. i. 588, and Ann. de Chim. xii. 3. and Miner. ii. 298.

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straight lamellar, columnar, prismatic, and *bolognese.* For a minute description of these subspecies I refer the reader to Professor Jameson's Mineralogy.

The granular subspecies is one of the rarest. It has considerable resemblance to granular lime-stone; but is easily distinguished by its greater specific gravity, which amounts to 4·380. A specimen from Peggau, analysed by Klaproth, was composed of

> Sulphate of barytes 90
> Silica 10
> ____
> 100 *

GENUS III. STRONTIAN SALTS.

This genus contains only two species; namely, the *carbonate* and *sulphate.*

Sp. 1. *Carbonate of Strontian—Strontianite.*

This mineral was first discovered in the lead mine of Strontian in Argyleshire; and since that time it is said to have been discovered, though not in great abundance, in other countries. It is found amorphous and also crystallized in needles, which, according to Haüy, are regular six-sided prisms.

Colour between asparagus and apple-green, sometimes greenish-white. Principal fracture is radiated, the rays diverging; cross fracture uneven. Lustre of principal fracture shining, of cross fracture glistening, pearly. Translucent. Soft. Specific gravity from 3·4 to 3·675. Does not decrepitate when heated. Before the blowpipe becomes opaque and white, but does not melt. With borax it effervesces, and melts into a transparent colourless glass. Effervesces with muriatic acid, and is totally dissolved. The solution tinges flame purple. Contains about 2 per cent. of carbonate of lime.

Sp. 2. *Sulphate of Strontian—Celestine.*

This mineral has been found in Pennsylvania, in Germany, in France, in Sicily, and Britain. It was first dis-

* Klaproth's Essays, i. 376, Eng. Trans.

covered near Bristol by Mr. Clayfield. There it is found in such abundance, that it has been employed in mending the roads. It occurs often massive, but frequently crystallized. The primitive form of its crystals is a four-sided prism, whose bases are rhombs, with angles of 104° 48′ and 75° 12′. The varieties of its crystals, as described by Haüy, amount to seven.* They may be referred to four or six-sided prisms, terminated by two, four, or eight-sided summits. Scratches calcareous spar, is scratched by fluor spar. Specific gravity from 3·5827 to 3·9581. Causes a double refraction. It may be divided into three subspecies. †

Subsp. 1.   *Compact Sulphate.*

This mineral is found in Montmartre near Paris. Colour yellowish grey. Found massive in round pieces. Lustre dull. Fracture fine splintery. Opaque. Easily frangible. Sectile. Specific gravity 3·5 to 3·596.   Contains, according to Vauquelin,

$$
\begin{array}{ll}
91\cdot42 & \text{sulphate of strontian} \\
8\cdot33 & \text{carbonate of lime} \\
0\cdot25 & \text{oxide of iron} \\
\hline
100\cdot00\ \ddagger &
\end{array}
$$

Subsp. 2.   *Fibrous Sulphate.*

Colour between indigo-blue and bluish-grey; sometimes passes into milk-white. Massive and crystallized. Lustre of longitudinal fracture shining; of cross fracture glistening, between pearly and resinous. Longitudinal fracture foliated; cross fracture fibrous. Fragments splintery. Has a tendency to prismatic distinct concretions. Easily frangible. Translucent. Specific gravity 3·83.

Subsp. 3.   *Foliated Sulphate.*

Colour milk-white, often falling into blue. Found massive and in crystals. Crystals grouped. Lustre of the crystals shining. Their texture straight foliated. Translucent. Found in Sicily and in Britain. This subspecies has lately been divided by Werner into two varieties, the

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* Miner. ii. 315.   † Brochant, i. 642.
‡ Jour. de Min. No. liii. 355.

tabular and the prismatic; for a description of which the reader is referred to Professor Jameson.

GENUS IV. MAGNESIAN SALTS.

This genus contains three species; namely, *sulphate, anhydrous carbonate* or *magnesite*, and *borate*.

Sp. 1. *Sulphate of Magnesia.*

This salt is frequently found effloresced on the surface of rocks, walls, &c. in different parts of the world.   Klaproth has shown that the substance from Idria, distinguished by the Germans by the name of *Haarsalz*, is sulphate of magnesia nearly pure.*   But the most perfect specimen of this mineral which I have seen is found at Calutayud in Arragon.   Its colour is snow-white, its texture fibrous, and it has very much the aspect of fibrous gypsum.   The fibres are small four-sided prisms.   Lustre shining, silky.   Translucent. Soft.   Brittle.   Very easily frangible.   Specific gravity 1·5577.   Taste intensely bitter.   Not altered by exposure to the air.   Very soluble in water.   I found its constituents

Sulphate of magnesia ...	48·6
Sulphate of soda ؛	1·4
Water	50·0
	100·0 †

Sp. 2. *Anhydrous Carbonate* or *Magnesite.*

This species was discovered by Dr. Mitchell in serpentine rocks in Moravia.   Colour yellowish-grey, passing into cream-yellow.   Marked with blackish-brown spots.   Massive, tuberous.   Internal lustre dull.   Fracture *in the great* large flat conchoidal, *in the small* splintery.   Fragments sharp-edged.   Scratches carbonate of lime; scratched by fluate of lime.   Opaque.   Somewhat sectile.   Not particularly easily frangible.   Feels rather meagre.   Adheres strongly to the tongue.   Specific gravity 2·915.   When rubbed on woollen cloth it acquires positive electricity.   Infusible before the blow-pipe.

* Beitrage, iii. 104.   † Annals of Philosophy, ix. 483.

The following table exhibits the result of the different analyses of this mineral hitherto made :

Carbonic acid	49	52	51·00	47	50·7643
Magnesia	48	48	46·59	45·42	47·6334
Silica	—	—	—	4·5	—
Alumina	—	—	1·00	0·5	—
Lime	—	—	0·16	0·08	—
Oxide of iron	—	—	0·25	0·5	—
Oxide of manganese	—	—	—	—	0·2117
Water	3	—	1·00	2·0	1·3906
	100*	100†	100 †	100 †	100 ‡

From these analyses we see that the mineral is a combination of 1 atom of carbonic acid and 1 atom of magnesia.

Sp. 3.　*Borate of Magnesia.*§

Boracite.

This mineral has been found at Kalkberg, near Luneburg, seated in a bed of gypsum, and likewise near Kiel. It is crystallized. The primitive form of its crystals is the cube.‖ In general, all the edges and angles of the cube are truncated; sometimes, however, only the alternate angles are truncated.** The size of the crystals does not exceed half an inch; usually much less.

Internal lustre glistening, between adamantine and vitreous. Fracture between imperfect small conchoidal and fine-grained uneven. External lustre shining; internal glistening, greasy. Translucent. Semihard. Specific gravity 2·566. Colour yellowish, smoke, and greyish-white; sometimes passing into greenish-white and asparagus-green. When heated it becomes electric; and the angles of the cube are alternately positive and negative.†† Before the blowpipe it froths, emits a greenish light, and is converted

* Klaproth, Beitrage, v. 100.
† Bucholz, Ann. de Chim. lxxiv. 76.
‡ Stromeyer, Schweigger's Jour. xiv. 1.
§ Kirwan, i. 172. Brochant, i. 589. Haüy, ii. 337.
‖ Haüy, Jour. de Min. No. xxviii. 325.　** Haüy and Westrumb.
†† Haüy, Westrumb, and Ann. de Chim. ix. 59.

into a yellowish enamel, garnished with small points, which, if the heat be continued, dart out in sparks.*

Besides borate of magnesia, Westrumb found in it lime in a considerable quantity; but a more recent analysis of Vauquelin and Schmidt has shown, that the lime was merely mixed in the state of a carbonate.

The following table shows the constituents of this species, according to the best analyses hitherto made:

Boracic acid	68·00....	83·4....	55·68
Magnesia......	13·50....	16·6....	32
Lime	11·00	———	—
Silica..........	2	100‡	2·27
Alumina........	1	....	—
Oxide of iron. ..	0·75	....	0·45
Loss..........	3·75	....	9·60
	———		———
	100 †		100 §

GENUS V.   ALUMINOUS SALTS.

This genus contains four different species ; namely, *alum, subsulphate of alumina* or *aluminite, mellate of alumina,* and *cryolite* or *fluate of soda-and-alumina.*

Species 1.   *Alum.*

This salt occurs in capillary crystals on slate clay. I have a specimen of octahedral crystals of alum, picked up by my friend, Mr. Macintosh of Glasgow, from the alum-slate at Whitby. The capillary crystals I consider as not perfect alum; but there can be no doubt respecting the octahedral crystals.

Sp.   *Aluminite,* or *Subsulphate of Alumina.*‖

This mineral was first found in the alluvial strata round Halle in Saxony. Mr. Webster, and Mr. Smithson Tennant more lately found it at New Haven, near Brighton, in the south of England.

Colour snow-white. In small reniform pieces. Dull. Fracture fine earthy. Opaque. Soils slightly. Streak

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* Le Lievre, Jour. de Min. and Ann. de Chim. ix. 59.
† Westrumb.   ‡ Vauquelin.
§ Pfaff, Schweigger's Journal, viii. 131.   ‖ Jameson, i. 405.

glistening. Adheres feebly to the tongue. Very soft. Chap. II.
Feels fine, but meagre. Specific gravity 1·669. Its constituents are as follows:

Sulphuric acid......	19·25	.... 21·5
Alumina	32·50	.... 31·0
Water	47	.... 45·0
Silica.............	0·45	
Lime.............	0·35	 2
Oxide of iron	0·45	
Loss	—	.... 0·5
	100·00 *	100·0 †

It is a compound of 1 atom sulphuric acid and 4 atoms alumina. It contains exactly the same weight of water as alum. Or it is a compound of 1 atom subquadrosulphate of alumina and 10 atoms of water.

Sp. 3. *Mellite.*‡

Honeystone—Mellate of Alumina.

This mineral was first observed in Thuringia, between layers of bituminous wood and earth coal. It has since been found at Langenbogen, in the circle of Saal. It is of a honey-yellow colour (hence its name,) and is usually crystallized in small octahedrons, whose angles are often truncated. Surface smooth. Lustre splendent. Translucent. Refracts doubly. Fracture perfect conchoidal. Soft. Specific gravity, according to Abich, 1·666. When heated it whitens; and in the open air burns without being sensibly charred. A white matter remains, which effervesces slightly with acids, and which at first has no taste, but at length leaves an acid impression upon the tongue.

Its constituents are

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* Simon, Scherer's Journal, ix. 162.
† Bucholz, as quoted by Jameson, 406.
‡ Emmerling's Lehrbuch, ii. 89. Wiedeman's Handbuch, p. 639. Abich, Crell's Annals, 1797, ii. 3. Vauquelin, Ann. de Chim. xxxvi. 23. Klaproth, Beitrage, iii. 115. Kirwan's Min. ii. 68. Karsten, Mus. Loch. ii. 335. Brochant, ii. 73. Haüy, iii. 335. Jameson, ii. 409.

Mellitic acid .. 46
Alumina 16
Water 38
____
100*

Sp. 4.   *Cryolite.*†

This mineral has been hitherto found only at Arksut, about 30 leagues from the colony of Juliana Hope in West Greenland.   From this spot it was brought to Copenhagen, where it lay for eight or nine years unnoticed, till at last it was analysed by Abilgaard.   Many specimens of it were collected by Giesecké.   They were captured on their passage to Copenhagen, and fell into the hands of Colonel Imrie and Mr. Thomas Allan of Edinburgh.   The primitive form of its crystals seems to be an octahedron, whose faces are isosceles triangles.   Its colour is greyish-white. Fracture imperfect foliated.   Fragments cubic or tabular. Translucent.   Hardness inferior to that of fluor spar. Brittle.   Specific gravity 2·949.   Melts before it reaches a red heat, and when simply exposed to the flame of a candle.‡ Abelgaard analysed it, and obtained fluoric acid and alumina.   Klaproth proved that it contains also soda.   The result of his analysis is as follows :

40·5 fluoric acid and water
36·0 soda
23·5 alumina
____
100·0

This analysis has been confirmed by Vauquelin.

CLASS II.   SALTS.

Under this class I comprehend all the combinations of alkalies with acids which exist in the mineral kingdom. They constitute the following genera and species :

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* Klaproth, Beitrage, iii. 114.   + Jameson, ii. 299.
  ‡ Hence its name from κρυος and λιθος, as if it melted as easily as ice.

GENUS I. POTASH.

Sp. 1. Nitrate of potash.

GENUS II. SODA.

Sp. 1. Carbonate of soda.
  2. Sulpate of soda.
  3. Common salt.
  4. Borax.
  5. Reissite.

GENUS III. AMMONIA.

Sp. 1. Muriate of ammonia,
  2. Sulphate of ammonia.

GENUS I. SALTS OF POTASH.

Sp. 1. *Nitrate of Potash.*

This salt is found native, mixed with nitrate of lime, muriate of potash, and other impurities, encrusting the surface of the earth, in different parts of India, the Cape of Good Hope, Peru, Spain, Molfetta, &c. It is most commonly in fine capillary crystals. Sometimes, though rarely, massive, or in six-sided prisms. A specimen of native nitre from Molfetta, analysed by Klaproth, contained

Nitrate of potash...... 42·55
Sulphate of lime ...... 25·45
Carbonate of lime .... 30·40
Muriate of potash .... 0·20
Loss .... 1·40

100·00*

GENUS II. SALTS OF SODA.

Sp. 1. *Carbonate of Soda.*

This salt is found in Egypt on the surface of the earth, and on the margin of certain lakes which become dry during the summer. It has often the appearance of a rough dusty powder, of a grey colour and alkaline taste. It occurs in China, where it is called *kien;* near Tripoli, where it is denominated *trona;* and likewise in Hungary, Syria, Persia, and India.†

* Beitrage, i. 317.   † Kirwan's Min. ii. 6.

There are two kinds of it; the *carbonate*, which is in greyish or yellowish-white flakes, and the *bicarbonate*, which forms solid radiated masses composed of acicular crystals, and has hitherto been found only in Africa.

A specimen of the first kind from Egypt was found by Klaproth to consist of

Dry carbonate of soda..	32·6
Dry sulphate of soda....	20·8
Dry muriate of soda....	15·0
Water	31·6
	100·0*

A specimen of the second, or fibrous carbonate, from the interior of Africa, yielded the same chemist

Soda	37·0
Carbonic acid	38·0
Water.......	22·5
Sulphate of soda ..	2·5
	100·0†

Sp. 2. *Sulphate of Soda.*

This salt is found in Austria, Hungary, Stiria, Switzerland, and Siberia, always in the neighbourhood of a mineral spring. It occurs usually in the state of powder, sometimes massive, and even crystallized in needles and six-sided prisms. Colour greyish or yellowish-white.

A specimen from Eger, analysed by Reuss, contained

Sulphate of soda	67·024
Carbonate of soda......	16·333
Common salt	11·000
Carbonate of lime......	5·643
	100·000 ‡

Sp. 3. *Reissite.*§

This is a complicated salt found in the neighbourhood of

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* Beitrage, iii. 80.   † Ibid. iii. p. 87.
‡ Jameson, ii. 318.   § Jameson, ii. 319.

Sedlitz, and first analysed by Reuss. Hence the name given it by Karsten.

It occurs as a mealy efflorescence in loose, earthy, dull particles, and likewise crystallized in needles, and in flat six-sided prisms. Its colour is snow-white. Its constituents, according to the analysis of Reuss, are as follows :

Sulphate of soda	66·04
Sulphate of magnesia	31·35
Muriate of magnesia	2·19
Sulphate of lime	0·42
	100·00*

Sp. 4. *Muriate of Soda.*

Common salt is found in immense masses under the earth's surface in many countries, particularly in Poland, Hungary, England, &c. Near Cordova, in Spain, there is said to be a mountain of common salt 500 feet high, and nearly three miles in circumference. It occurs in beds, which are usually very short and thick, and lie over the oldest floëtz gypsum formation.† Werner divides it into two subspecies ; namely, *rock salt* and *lake salt*. The latter is salt deposited at the bottom of lakes. *Rock salt* he subdivides into two varieties, from the fracture and appearance; namely, *foliated* and *fibrous*. For a particular description of these the reader is referred to Professor Jameson's Mineralogy.‡

Sp. 5. *Borax.*

This mineral is found in different parts of Thibet, &c. It is usually mixed with foreign bodies; that of Persia is in large crystals, enclosed in a fatty matter. The primitive form of its crystals is a rectangular prism, but it occurs usually in six-sided prisms, whose edges are variously truncated. Its colour is greyish, yellowish, or greenish-white. Fracture foliated or conchoidal. Translucent. Refracts doubly.§ Tastes sweet and somewhat acrid.

Its constituents, according to the analysis of Klaproth, are

* Karsten's Tabellen, p. 57.   + Jameson's Min. ii. 13.
‡ Vol. ii. p. 320.   § Haüy, ii. 366.

Boracic acid .. 37
Soda .... 14·5
Water........ 47·0
Loss .... 1·5
──────
100·0*

GENUS III.   SALTS OF AMMONIA.

Sp. 1.   *Muriate of Ammonia.*

This salt occurs near volcanoes, of which it is a product. It is found also in Persia. It is found usually in the state of power in the middle of lava; sometimes in mass, and even in very irregular crystals. Colour white, often with a shade of yellow or green. Very soft.

A specimen of this salt from Tartary yielded Klaproth

Muriate of ammonia .... 97·5
Sulphate of ammonia .... 2·5
──────
100·0†

Sp. 2.   *Sulphate of Ammonia* or *Muscagnine.*‡

This occurs among the lavas of Ætna and Vesuvius. Colours yellowish-grey and lemon-yellow. In mealy crusts. Dull. Fracture uneven or earthy. Semitransparent or opaque. Taste sharp and bitter.

CLASS III.   COMBUSTIBLES.

This class comprehends all the combustible substances which constitute a part of the mineral kingdom, except the diamond and the mellite, which have been already described, and the metals which belong to the fourth class of minerals. They have been divided into four genera; namely,

1. Sulphur.   3. Bitumen.
2. Resin.   4. Graphite.

GENUS I.   SULPHUR.

This genus comprehends only one species, namely, *native sulphur;* though perhaps *orpiment*, usually placed

* Beitrage, iv. 350.   † Beitrage, iii. 94.
‡ Jameson, ii. 339.

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among the ores of arsenic, might, without impropriety, be referred to it.

Sp. 1. *Native Sulphur.**

This mineral occurs commonly in masses of gypsum, lime-stone, and marl. It is sometimes found in veins traversing primitive rocks; and Humboldt observed it in South America in mica slate, constituting a bed along with quartz. Colour sulphur yellow, passing into honey, lemon, and wax yellow, with a mixture of grey or brown. Massive, disseminated, and crystallized. The primitive form of its crystals is an octahedron, composed of two four-sided pyramids, joined base to base. The sides of these pyramids are scalene triangles, and so inclined that the plane where the bases of the pyramids join is a rhomb, whose long diagonal is to its short as 5 to 4.[†] Sometimes the apices of the pyramids, to use the language of Romé de Lisle, are truncated; sometimes they are separated from each other by a prism; sometimes they are truncated near their bases, and a low four-sided pyramid rises from the truncature: this pyramid is also sometimes truncated near its apex. Finally, one of the edges of the pyramids is sometimes truncated. For figures of these varieties, and for the laws of their formation, the reader is referred to Mr. Lefroy. [‡]

Surface of the crystals smooth. Lustre splendent; internal lustre shining, adamantine. Fracture small-grained uneven, passing into splintery. Fragments blunt-edged. Translucent. Crystals transparent. Refracts doubly. Very soft. Very easily frangible.

The sulphur in the neighbourhood of volcanoes differs somewhat in its properties from common native sulphur.

GENUS II. RESIN.

This genus comprehends three species; namely, *amber*, *retinasphaltum*, and *Highgate resin*.

Sp. 1. *Amber.*

This substance, called *electrum* by the ancients, is found in different countries; but most abundantly in Prussia, either on the sea-shore, or under ground at the depth of

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* Kirwan, ii. 69. Brochant, ii. 37. Haüy, iii. 277. Jameson, ii. 349.
† Romé de Lisle, i. 292. Haüy and Lefroy, Jour. de Min. No. xxix. 337. ‡ Jour. de Min. No. xxix. 337.

about 100 feet, reposing on *wood coal.** It is in lumps of different sizes. Werner divides it into subspecies: namely, *white* and *yellow amber*.

Subsp. 1. *White Amber.*

Colour straw-yellow; sometimes inclining to yellow-white. Massive. Lustre shining, resinous. Fracture conchoidal. Fragments sharp-edged. Translucent. In other respects agrees with the succeeding.

Subsp. 2. *Yellow Amber.*

Colour wax-yellow, passing into honey-yellow, yellowish-brown, and hyacinth-red. In blunt-edged pieces with a rough surface. External lustre dull; internal splendent; between resinous and vitreous. Fracture perfect large conchoidal. Fragments very sharp-edged. Transparent. Soft. Rather brittle. Easily frangible. Specific gravity from 1·078 to 1·085.

Sp. 2. *Retinasphaltum.*

This mineral, found at Bovey, and described and analysed by Mr. Hatchett, belongs to the resin genus, and connects this genus with that of the bitumens; retinasphaltum being a compound of resin and bitumen. For a description of it, see Vol. II. p. 389.

In the year 1811 Bucholz pulished an analysis of a substance, which he found in kidney-shaped masses in the town ditch of Halle, which is probably only a variety of the retinasphaltum of Hatchett. Its colour is brownish yellow. Its lustre resinous. It is opaque. Very easily frangible. When heated it melts and emits a resinous odour mixed with the odour of storax. Bucholz found it a compound of

Resin soluble in alcohol 91
Resin insoluble in alcohol (similar to amber) .. 9
                                              ———
                                              100†

Sp. 3. *Highgate Resin.*

This substance was found at Highgate near London, while work men were engaged in digging out the new road through the hill.

Colour muddy yellowish-brown. Occurs in irregular roundish pieces. Lustre resinous. Semitransparent. Sur-

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* Kirwan, Mineralogy, ii. 66.   † Schweigger's Journal, i. 290

face smooth. Brittle. Less frangible than common resin, more frangible than copal. Softer than copal. Specific gravity 1·046. When heated melts into a limpid fluid, and gives out a resinous and aromatic odour. Takes fire at the flame of a candle, and burns all away without leaving any residue. Insoluble in potash ley and acetic acid; soluble in ether and partially in alcohol.

GENUS III. BITUMEN.

This genus contains four species; namely, *petroleum*, *mineral pitch*, *brown coal*, and *black coal*.

Sp. 1. *Petroleum* or *Mineral Oil.**

This substance usually flows from rocks of the coal formation, and generally from the immediate vicinity of coal. Colour brownish-black. Liquid, but viscid. Translucent. Lustre shining, resinous. Feels greasy. Wets. Smell bituminous.

Sp. 2. *Mineral Pitch.*

The substances arranged under this species occur chiefly in veins. Werner divides it into three subspecies, *earthy*, *slaggy*, and *elastic mineral pitch*.

Subsp. 1. *Earthy Mineral Pitch.*

This is the substance commonly known by the names of *mineral pitch* and *maltha*. Colour blackish-brown. Massive. Lustre dull; of streak shining, resinous. Fracture earthy or small grained uneven; sometimes nearly splintery. Fragments blunt-edged. Very soft. Sectile. Easily frangible. Feels greasy. Light; almost swims on water. Smell bituminous.

Subsp. 2. *Slaggy Mineral Pitch.*

Colour velvet-black; sometimes approaching brownish black. Massive. Internal lustre splendent to glistening, resinous. Fracture imperfect, or perfect conchoidal. Fragments pretty sharp-edged. Very soft. Opaque. Sectile. Retains its lustre in the streak. Easily frangible. Feels greasy. Specific gravity from 1·07 to 1·165. Smell bituminous.

Subsp. 3. *Elastic Mineral Pitch*, or *Mineral Caoutchouc.*

Found in Derbyshire. Colour blackish-brown; some-

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* Kirwan, ii. 42. Hatchett. Linnæan Trans. iv. 131. Brochant, ii. 59. Haüy, iii. 312. Jameson, ii. 356.

Book III. times inclining to brownish black, sometimes reddish brown. Internal lustre shining and glistening, resinous; of streak shining. Fracture curved slaty; cross fracture conchoidal. Fragments slaty. Translucent on the edges. Very soft. Sectile. Flexible and elastic. Specific gravity from 0·9053 to 1·233. For a minute description of the varieties of this substance, the reader is referred to Mr. Hatchett's paper in the Linnæan Transactions. *

Sp. 3. *Brown Coal.*

This important species has been divided by Werner into five subspecies; namely, *bituminous wood, earth-coal, alum-earth, common brown coal,* and *moor-coal.*

Subsp. 1. *Bituminous Wood.*†

This mineral, which in its shape resembles the stems and branches of trees a little flattened, occurs along with common brown coal, usually in the floëtz trap and alluvial formations. It is found at Bovey in Devonshire, and in Iceland is known by the name of *surturbrand.* Colour light or dark-brown, approaching wood-brown or brownish-black. Lustre of principal fracture glimmering; of cross fracture shining; of the streak shining. Fracture *in the great* slaty, *in the small* fibrous; cross fracture sometimes imperfect conchoidal. Fragments commonly splintery. Opaque. Soft. Sectile. Flexible and somewhat elastic. Light.

Subsp. 2. *Earth Coal.*‡

Found along with bituminous wood in the county of Mansfield, and on the Saal often in thick strata. It is kneaded with water in troughs, formed in moulds into the shape of bricks, and dried; in this state it is used as fuel. Colour blackish-brown; sometimes passes into yellowish-grey. Nearly loose. Particles dusty; soils a little. Internal lustre scarce glimmering; streak nearly shining. Falls to powder.

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* Under the denomination of *asphaltum*, in Vol. II. p.386 of this Work, I include the two first subspecies of mineral pitch.

† Kirwan, ii. 60. Brochant, ii. 44. Jameson, ii. 368. Von Troil's Letters on Iceland, p. 42. Hatchett, Phil. Trans. 1804. Parkinson's Remains of a Former World, p. 104.

‡ Jameson, ii. 371. Klaproth, iii. 319.

Subsp. 3. *Alum-earth.*[*]

Occurs in beds in alluvial land, and in the floëtz trap formation. Colour blackish-brown. Massive. Lustre dull; sometimes glimmering, from mica; of streak shining. Fracture earthy with a tendency to slaty. Fragments tabular. Feels meagre and sometimes greasy. Sectile. Between very soft and friable. Its constituents as determined by the analysis of Klaproth, are as follows:

Charcoal .... 19·65
Sulphur .... 2·85
Silica .... 40·00
Alumina .... 16·00
Oxide of iron ...... 6·40
Sulphate of iron .... 1·80
Sulphate of lime .... 1·50
Magnesia .... 0·50
Sulphate of potash .. 1·50
Muriate of potash .. 0·50
Water .... 10·75

101·45 [†]

Subsp. 4. *Common Brown Coal.* [‡]

This mineral is found abundantly at Bovey. Colour light brownish-black. Massive. Internal lustre shining, resinous. Streak lighter. Fracture imperfect large conchoidal. Fragments sharp-edged. Soft. Sectile. Not very brittle. Easily frangible. Light.

Subsp. 5. *Moor Coal.* [§]

Found in Bohemia and other parts of Germany. Colour dark blackish-brown. Massive. Internal lustre glistening, resinous; of streak shining. Principal fracture imperfect slaty; cross fracture even, approaching flat conchoidal. Fragments trapezoidal, approaching cubical. Soft. Sectile. Very easily frangible. Light. When exposed to the air it bursts and falls to pieces.

Sp. 4. *Black Coal.* [||]

Under this species are included almost all the varieties of coal that are used in this country for fuel. It is divided

[*] Brochant, i. 383. Jameson, ii. 373. Klaproth, Gehlen's Jour. vi. 44.   [†] Gehlen's Jour. vi. 44.

[‡] Mills, Phil. Trans. li. 534. Brochant, ii. 47. Scammell, Parkinson's Remains of a Former World, p. 126. Jameson, ii. 375. Hatchett, Phil. Trans. 1804.   [§] Jameson, ii. 378.   [||] Ibid. 379.

Book III. into six subspecies; namely, *pitch, columnar, slate, cannel, foliated,* and *coarse coal.*

Subsp. 1. *Pitch Coal—Jet.*

Occurs in all the three coal formations, but most commonly in that which belongs to the floëtz trap. Colour velvet-black; sometimes brownish-black. Massive, in plates; sometimes in the shape of branches of trees, but without a regular woody texture. Internal lustre shining, resinous. Fracture perfect large conchoidal. Fragments sharp-edged. Soft. Rather brittle. Easily frangible. Specific gravity 1·308.

Subsp. 2. *Columnar Coal.*

Hitherto found only in the Meissner in Hessia along with other subspecies. Colour between velvet and greyish-black; sometimes inclining to iron-blue. Massive. Internal lustre shining, resinous, or inclining to semimetallic. Fracture imperfect conchoidal. Occurs in thick columnar distinct concretions with glimmering surfaces. Soft. Rather brittle. Very easily frangible. Light. Burns without flame, leaving a greyish-white ash.

Subsp. 3. *Slate Coal.*

This is the common coal of England and Scotland, occurring most commonly in the independent coal formation. Colour between velvet and dark greyish black. Massive. Lustre shining, resinous. Principal fracture nearly perfect slaty; cross fracture small-grained uneven, passing into even and imperfect conchoidal. Fragments sometimes trapezoidal. Soft. Approaching to sectile. Easily frangible. Specific gravity from 1·250 to 1·370. *

Subsp. 4. *Cannel Coal.*

Accompanies the preceding subspecies. Found at Wigan in Lancashire, and in various parts of Scotland. Colour dark greyish-black. Massive. Internal lustre glistening; resinous. Fracture sometimes flat large conchoidal, sometimes even. Fragments sometimes cubical. Easily frangible. Specific gravity from 1·232 to 1·275. Often cut into various vessels and ornaments.

Subsp. 5. *Foliated Coal.*

Found in Saxony and Silesia in the independent coal

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* Kirwan.

formation. Colour between velvet and greyish black.
Massive. Lustre of principal fracture splendent; of cross
fracture glistening, resinous. Longitudinal fracture straight
foliated, with a single cleavage; cross fracture slaty. Frag-
ments approaching to cubical. Soft. Approaches Sectile.
Very easily frangible. Light.

Subsp. 6. *Coarse Coal.*

Occurs in the neighbourhood of Dresden. Colour dark
greyish-black. Massive. Lustre glistening. Cross frac-
ture coarse-grained uneven; longitudinal generally slaty.
Fragments rather blunt-edged. Semihard; the hardest
subspecies of coal. Rather brittle. Easily frangible.
Heavier than the preceding subspecies.

The following table exhibits a view of the constituents of
such of the preceding subspecies of brown and black coal
as have been hitherto analysed :

Bituminous Wood.*

Vegetable earth	54
Sulphur	0·8
Sulphate of iron	10·7
Oxide of iron	12·7
Sulphate of lime	·7
Silica	·2
Loss	20·9
	100·0

Earth Coal.†

Volatile matter ..	62·25
Charcoal	20·25
Lime	2·0
Sulphate of lime .	2·5
Oxide of iron	1·0
Alumina........	0·5
Sand	11·5
	100·0

Alum Earth.‡

Charcoal	19·65
Sulphur	2·85
Silica	40·00
Alumina..........	16·00
Oxide of iron	6·40
Sulphate of iron ..	1·80
Sulphate of lime ..	1·50
Magnesia	0·50
Sulphate of potash .	1·50
Muriate of potash ..	0·50
Water	10·75
	91·45

Bovey Coal. §

Charcoal	45
Volatile matter	55
	100

* Vauquelin, Jameson, ii. 55.   † Klaproth, iii. 319.
‡ Klaproth, Gehlen's Jour. vi. 44.   § Hatchett, Phil. Trans. 1804.

Slate Coal

	Of Walden.	Of Salrze.	Of Bielschowitz.
	*	*	*
Charcoal	57·99	63·31	58·17
Bitumen	36·87	32·93	37·89
Earth	5·82	3·90	3·94
Loss	1·32		
	102·00	100·14	100

GENUS IV. GRAPHITE.

This genus contains three species; namely, *glancecoal*, *graphite*, and *mineral charcoal*.

Sp. 1. *Glance Coal.*

Glance coal, so called by the Germans on account of its great lustre, is divided by Werner into two subspecies, the first of which is much more uncommon than the second.

Subsp. 1. *Conchoidal Glance Coal.*

Hitherto has been found only in the newest floëtz trap formations. Colour iron-black, rather inclining to brown. Surface tarnished like tempered steel. Massive and vesicular. Internal lustre shining, metallic. Fracture large and small conchoidal. Fragments sharp-edged. Soft. Rather brittle. Easily frangible. Light. Burns without flame or smell.

Subsp. 2. *Slaty Glance Coal—Anthracite—Kilkenny Coal.*

Supposed peculiar to primitive and transition rocks till Professor Jameson discovered it in the independent coal formation in the island of Arran. Colour dark iron-black, seldom inclining to brown. Massive. Lustre shining, between metallic and semimetallic. Principal fracture more or less perfect slaty; cross fracture small flat conchoidal. Fragments pretty sharp-edged; sometimes trape-

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* Richter, Jameson, ii. 73. A table of the constituents of several varieties of slate coal, and of cannel coal, according to Kirwan's and Mushet's experiments, has been given in Vol. ii. p. 390.

† Jameson, ii. 390.

zoidal. Soft. Easily frangible Between sectile and, brittle. Specific gravity from 1·415 to 1·800.

This species consists of charcoal destitute of bitumen, either with or without an admixture of earthy matter.

Sp. 2. *Graphite.**

Plumbago.

This species, like the last, is divided into two subspecies; namely, *scaly* and *compact graphite*.

Subsp. 1. *Scaly Graphite.*

Colour dark steel-grey, approaching to light iron-black. Massive. Lustre glistening, metallic; of the streak shining, metallic. Fracture scaly foliated; sometimes passing into large conchoidal; sometimes slaty and uneven. Fragments trapezoidal. In granular distinct concretions. Very soft. Sectile. Rather tough. Writes and soils. Feels very greasy. Specific gravity from 1·987 to 2·267.†

Subsp. 2. *Compact Graphite.*

Colour rather blacker than the preceding. Internal lustre glimmering, metallic. Fracture fine-grained uneven, passing into even; also large flat conchoidal. In other characters agrees with the preceding subspecies.

Sp. 3. *Mineral Charcoal.*‡

Occurs along with the varieties of coal. Colour greyish-black. In angular pieces inclining to a cubic form. Lustre glimmering, silky. Fracture fibrous; sometimes shows the woody texture. Fragments blunt-edged; sometimes splintery. Soils strongly. Soft; passing into friable. Light.

CLASS IV. ORES.

This class comprehends all the mineral bodies, composed either entirely of metals, or of which metals constitute the most considerable and important part. It is from the minerals belonging to this class that all metals are extracted; for this reason they have obtained the name of *ores*.

As the metals at present known amount to 27, I should

* Jameson, ii. 396. † Kirwan. ‡ Jameson, ii. 401.

Book III. divide this class into 27 orders, allotting a distinct order for the ores of every particular metal; but there are several metals which have been hitherto found only in other ores. Hence the orders are reduced to 23.

Metals exist in ores in one or other of the five following states: 1. In a metallic state, and either solitary or combined with each other; 2. Combined with sulphur; 3. In the state of oxides; 4. In the state of chlorides; 5. Combined with acids. Each order therefore may be divided into the five following genera:

1. Alloys.	4. Chlorides.
2. Sulphurets.	5. Salts.
3. Oxides.	

It must be observed, however, that every metal has not hitherto been found in all these five states, and that some of them are hardly susceptible of them all. Some of the orders, therefore, want one or more genera, as may be seen from the following table:

Orders.

ORDER I. *Gold.*
 1. Alloys.
ORDER II. *Platinum.*
 1. Alloys.
ORDER III. *Palladium.*
 1. Alloys.
ORDER IV. *Iridium.*
 1. Alloys.
ORDER V. *Tellurium.*
 1. Alloys.
ORDER VI. *Mercury.*
 1. Alloys.
 2. Sulphurets.
 3. Oxides.
 4. Chlorides.
ORDER VII. *Silver.*
 1. Alloys.
 2. Sulphurets.
 3. Oxides.
 4. Chlorides.
 5. Salts.
ORDER VIII. *Copper.*
 1. Alloys.

 2. Sulphurets.
 3. Oxides.
 4. Salts.
ORDER IX. *Iron.*
 1. Alloys.
 2. Sulphurets.
 3. Oxides.
 4. Salts.
ORDER X. *Manganese.*
 1. Oxides.
 2. Salts.
ORDER XI. *Uranium.*
 1. Oxides.
ORDER XII. *Cerium.*
 1. Oxides.
 2. Salts.
ORDER XIII. *Tantalum.*
 1. Oxides.
ORDER XIV. *Cobalt.*
 1. Alloys.
 2. Sulphurets.
 3. Oxides.
 4. Salts.

ORDER XV. *Nickel.*
  1. Alloys.
  2. Oxides.
ORDER XVI. *Molybdenum.*
  1. Sulphurets.
ORDER XVII. *Tin.*
  1. Sulphurets.
  2. Oxides.
ORDER XVIII. *Titanium.*
  1. Oxides.
  2. Salts.
ORDER XIX. *Zinc.*
  1. Sulphurets.
  2. Oxides.
  3. Salts.
ORDER XX. *Bismuth.*
  1. Alloys.

  2. Sulphurets.
  3. Oxides.
ORDER XXI. *Lead.*
  1. Sulphurets.
  2. Oxides.
  3. Chlorides.
  4. Salts.
ORDER XXII. *Antimony.*
  1. Alloys.
  2. Sulphurets.
  3. Oxides.
  4. Salts.
ORDER XXIII. *Arsenic.*
  1. Alloys.
  2. Sulphurets.
  3. Oxides.
  4 Salts.

ORDER I.   ORES OF GOLD.

No metal, perhaps, if we except iron, is more widely Situation. scattered through the mineral kingdom than gold.* Hitherto it has been found only in a metallic state; most commonly in grains, ramifications, leaves, or small crystals. Occurs in gneiss, mica-slate, clay-slate, also in veins. It is generally mixed with quartz, though there are instances of its having occurred in calcareous rocks. It is not uncommon also to find it disseminated through the ores of other metals; especially iron, mercury, copper, and zinc. The greatest quantity of gold is found in the warmer regions of the earth. It abounds in the sands of many African rivers, and is very common in South America and India. Europe, however, is not destitute of this metal. Spain was famous in ancient times for its gold mines, and several of the rivers in France contain it in their sands.† But the principal gold mines in Europe are those of Hungary, and next to them those of Saltzburg. Gold also has been discovered in Sweden and Norway, and more lately in the county of Wicklow in Ireland.‡

* Bergman.   † Reaumur, Mem. Par. 1713, p. 68.
  ‡ Lloyd, Phil. Trans. 1796, p. 36. Mills, ibid. p. 38. Nicholson's Journal, ii. 224.

Sp. 1. *Native Gold.*[*]

Found disseminated in grains, plates, and small crystals; commonly in cubes, octahedrons, and rhomboidal dodecahedrons. Fracture hackly. Soft. Ductile. Flexible, but not elastic. Very heavy. Native gold is never completely pure; it is alloyed with some silver or copper, and sometimes with iron. In the native gold found in Ireland, indeed, the quantity of alloy appears to have been exceedingly small. Werner divides this species into three subspecies, according to the metal with which the gold is alloyed.

Subsp. 1. *Pure Gold.*

Colour gold-yellow. It contains only a very minute proportion of silver or copper. Specific gravity from 17·0 to 19·0.[†]

Subsp. 2. *Brass-yellow Native Gold.*

Colour brass-yellow. Alloyed with a greater proportion of silver or copper. I found the specific gravity of a specimen in my possession 14·4567. On picking out the larger pieces and weighing them separately, I found their specific gravity only 13·6986. A proof that they were not quite free from interstices. On analysing this specimen, I obtained the following constituents :

Gold 78
Copper .. 11·8
Silver.... 9·48
Loss .... 0·72
_____

100·00

On dissolving the copper in sulphuric acid, I found it not quite free from iron. But as it had been precipitated by a metallic plate, I have not ventured to place iron among the constituents of the ore.

Subsp. 3. *Greyish-yellow Native Gold.*

Colour between steel-grey and brass-yellow. Supposed

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[*] Brochant, ii. 89. Haüy, iii. 374. Jameson, iii. 8.
[†] Fabroni affirms that it sometimes occurs in the state of pure gold. See Ann. de Chim. lxxii. 25.

to contain a portion of platinum. Sometimes it contains palladium.*

<h3 style="text-align:center">Sp. 2.   *Electrum.*†</h3>

The term *electrum*, applied by the ancients to a mixture of gold and silver, has been given by Klaproth to an ore from Schlangenberg in Siberia, which he found by analysis to be a compound of these two metals.

Its colour is pale golden-yellow. It occurs in solitary plates, needles, or imperfect cubes, scattered sometimes in a grey-coloured sulphate of barytes, sometimes in horn-stone. It is composed of

Gold 64
Silver ... 36
———
100

ORDER II.   ORES OF PLATINUM.‡

Hitherto no mine of platinum has been discovered. It is found in small scales or grains in the sands of the river Pinto, at Choco, Popayen, and Quito in Peru, and near Carthagena in South America. Repository unknown. It occurs also in Brazil in the silver mines of that country, and in the same state of small grains as in Peru. It is also accompanied by the four new metals which are found in the Peruvian platinum.§

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* Cloud, Ann. de Chim. lxxiv. 99.   † Klaproth, Beitrage, iv. 1.

‡ See Brownrigg, Phil. Trans. xlvi. 584. Lewis, ibid. xlviii. 638 ; and l. 148. Margraff, Mem. Berlin, 1757, p. 314. Macquer, Mem. Par. 1758, p. 119. Buffon, Jour. de Phys. iii. 324. Morveau, ibid. vi. 193. Bergman, Opusc. ii 166. Tillet, Mem. Par. 1779, p. 373, 385, and 545. Crell, Crell's Annals, 1784, 1 Band. 328. Willis, Manchester Memoirs, ii. 467. Mussin Puschkin, Ann. de Chim. xxiv. 205. Morveau, ibid. xxv. Proust, ibid. xxxvi. 146. Brochant, ii. 86. Haüy, iii. 368. Jameson, ii. 100.

§ Wollaston, Phil. Mag. xxxiii. 250. Vauquelin has lately detected platinum in the silver mine of Guadalcanal in Estremadura, a province of Spain. In the ore of that mine it is in the metallic state, sometimes in very minute quantity, sometimes in the proportion of 10 per cent. In this ore it is not mixed with the four newly discovered metals which accompany American platinum. This is the first well authenticated instance of the discovery of platinum in the Old Continent. Ann. de Chim. lx. 317.

GENUS I.   ALLOYS OF PLATINUM.

Sp. 1.   *Native Platinum—Platina.*

Colour very light steel-grey, which approaches silver-white. Occurs in small grains, sometimes a little convex on one side. Lustre shining metallic. Fracture not determined. Soft. Malleable. Flexible. Specific gravity never exceeds 17·7.* Soluble in nitromuriatic acid.

ORDER III.   ORE OF PALLADIUM.

Native palladium was detected by Dr. Wollaston in the native platinum from Brazil. It occurs in small plates similar in colour to native platina, but is easily distinguished by its texture, which is diverging fibrous. It contains a small portion of platinum and iridium united to it. †

ORDER IV.   ORE OF IRIDIUM.

Situation.

Hitherto this ore has been found only mixed with that of platinum, in grains so nearly similar to those of that ore as scarcely to be distinguishable by the eye. It was first discovered by Dr. Wollaston, who treated crude platina in considerable quantities with nitro-muriatic acid. The ore of iridium remained behind, not being in the least acted on by that menstruum.

The ore of iridium is harder than crude platina, is not malleable, appears to be composed of plates of a peculiar lustre. Specific gravity 19·5. Composed of osmium and iridium alloyed together. ‡

ORDER V.   ORES OF TELLURIUM. §

Hitherto tellurium has only been found in Transylvania. It occurs in the mines of Fatzbay, Offenbanya, and Nagyag; which are considered as gold mines, because they contain less or more of that metal. Tellurium has been found only in the metallic state, combined with gold, silver, or lead. There are four ores of it, distinguished from each other since the analysis of Klaproth; namely,

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* Wollaston.   † Wollaston, Phil. Trans. 1809, p. 189.
‡ Wollaston, Phil. Trans. 1805.   § Klaproth, iii. 1.

I. ALLOYS.

1. Native tellurium.   3. White or yellow ore.
2. Graphic ore.   4. Foliated or black ore.

GENUS I.   ALLOYS.

Sp. 1.   *Native Tellurium.**
Aurum Paradoxicum, Problematicum.

This mineral has been found only in the mine of Mariahilf, in the Fatzbay mountains in Transylvania.   It occurs massive and disseminated; and also crystallized, it is said.   Lustre shining, metallic.   Fracture foliated.   In small granular distinct concretions.   Soft.   Easily frangible.   Specific gravity 5·73 to 6·115.†

Sp. 2.   *Graphic Ore.* ‡
Schrifterz.   Aurum Graphicum.

This species has been found only in the mine called Franciscus, at Offenbanya in Transylvania.   It is usually in the state of small six-sided prismatic crystals, grouped together in rows, and often disposed in such a way as to have a resemblance to written characters.   Colour light steel grey.   External lustre splendent; internal glistening, metallic.   Fracture fine-grained uneven.   Fragments sharp-edged.   Soft.   Brittle.   Specific gravity 5·723.

Sp. 3.   *White* or *Yellow Ore.*§   *Gelberz* of Klaproth.

This ore has been found only in the mine of Nagyag in Transylvania.   It seems to bear a strong resemblance to the last species.   Found disseminated, or crystallized in small four-sided prisms.   Colour silver-white, passing into brass-yellow.   Lustre of the principal fracture splendent, of the cross fracture glistening, metallic.   Fracture in one direction foliated, in another small-grained uneven.   Soft.   Somewhat sectile.   Specific gravity 10·678.

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* Klaproth, iii. 2.   Brochant, ii. 480.   Haüy, iv. 325.   Jameson, iii. 461.   † Klaproth.

‡ Klaproth, iii. 16.   Brochant, ii. 482.   Haüy, iv. 327.   Jameson, iii. 464.

§ Klaproth, iii. 20.   Brochant, ii. 484.   Jameson, iii. 466.

Were we to suppose the lead accidentally mixed, the composition of this ore would agree with that of the last.

Sp. 4. *Foliated* or *Black Ore.* *

This ore is found at Nagyag, and is wrought for the gold which it contains. It occurs in plates, or in six-sided tables somewhat elongated. Colour between lead-grey and iron-black. External lustre splendent; internal glistening, metallic. Fracture foliated. Fragments tabular. In granular distinct concretions. Stains a little. Soft. Leaves slighty flexible. Specific gravity 8·918. Soluble in acids with effervescence.

The following table exhibits a view of the constituents of these ores, according to the analysis of Klaproth.

	Native. †	Graphic. ‡	Yellow. §	Foliated. ‖
Tellurium ..	92·55	60	44·75	32·2
Gold	0·25	30	26·75	9·0
Iron	7·20	—	—	—
Silver	—	10	8·50	0·5
Lead	—	—	19·50	54·0
Copper	—	—	—	1·3
Sulphur	—	—	0·50	3·0
	100	100	100	100

ORDER VI. ORES OF MERCURY.

Mercury is found in Europe, particularly in Spain, Germany, and Hungary: it is found also in China, ** the Philippines, †† and in Peru, and perhaps Chili ‡‡ in South America. The most productive mines of mercury are those of Idria; §§ of Almaden, near Cordova in Spain, which were wrought by the Romans; ‖‖ of the Palatinate; *** and of Guanca Velica in Peru. †††

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  * Klaproth, iii. 26.   Brochant, ii. 486.   Jameson, iii. 468.
  † Beitrage, iii. 8.   ‡ Ibid. p. 20.   § Ibid. p. 25.   ‖ Ibid. p. 32.
  ** See Entrecolle's Lettres Edificantes.   ++ Carreri's Voyages.
  ‡‡ See Molina's Natural History of Chili.
  §§ Scopoli, Jour. de Min. No. xxxiv. p. 915.
  ‖‖ See Bowle's Natural History of Spain, and Jour. de Min. No. xxxi.
p. 355.   *** Jour. de Min. Nos. vi. and vii.
  ††† See Ulloa's Memoirs concerning America.

5

Mercury has never been found in Britain, nor has any mine worth working been discovered in France.

The following table exhibits a view of all the ores of this metal hitherto observed.

I. ALLOYS.
   1. Native.
   2. Amalgam of silver.
II. SULPHURETS.
   1. Cinnabar.

   2. Carbo-sulphuret.
III. CHLORIDES.
   1. Horn mercury.

It is from the sulphuret that most of the mercury of commerce is extracted. Mercury occurs in two distinct formations; namely, in beds among rocks of clay slate, talc slate, and chlorite slate, in primitive mountains; and in the independent coal formation.

GENUS I.   ALLOYS.

Sp. 1.   *Native Mercury.**

Native mercury is found in most mercurial mines; it is in small globules, scattered through different kinds of stones, clays, and ores.

Fluid. Colour tin white. Specific gravity about 13·6.

Sp. 2.   *Amalgam of Silver.*† *Native Amalgam.*

This mineral has been found in the lead mine of Sala, ‡ in the province of Westmannland in Sweden; in the mines of Deux Ponts, § in the Palatinate; and in other places. It is in thin plates, or grains, or crystallized in octahedrons and dodecahedrons.

Its colour is silvery white or grey. Fracture conchoidal. Lustre metallic. Creaks when cut. Very soft. Specific gravity above 10. Tinges gold white. Before the blowpipe the mercury evaporates and leaves the silver.

A specimen of this amalgam, analysed by Klaproth, contained

* Brochant, ii. 96. Haüy, iii. 423. Jameson, iii. 20.
† Kirwan, ii. 223. Brochant, ii. 99. Haüy, iii. 432. Jameson iii. 23.   ‡ Cronstedt's Min.
§ Heyer, Crell's Annals, 1790.

$$\begin{array}{c}
\text{Mercury 64} \\
\text{Silver .. 36} \\
\hline
\text{100 *}
\end{array}$$

According to Cordier,

$$\begin{array}{c}
\text{Mercury 72·5} \\
\text{Silver .. 27·5} \\
\hline
\text{100·0 †}
\end{array}$$

Sometimes it contains a mixture of alumina, and sometimes the proportion of mercury is so great that the amalgam is nearly as soft as paste.

GENUS II. SULPHURETS.

Sp. 1. *Native Cinnabar.* ‡

This ore, which is found in almost all mercurial mines, is sometimes in veins, sometimes disseminated, sometimes in grains, and sometimes crystallized. It is divided into two subspecies, distinguished chiefly by their colour.

Subsp. 1. *Dark Red Cinnabar.*

Colour cochineal-red; sometimes falling into lead-grey, sometimes passing into carmine-red. Massive, disseminated, and crystallized in obtuse rhombs, six-sided tables, six-sided prisms, tetrahedrons, and octahedrons. § Primitive form, according to Haüy, the regular six-sided prism. Internal lustre glistening, adamantine. Fracture sometimes fine-grained uneven; sometimes even and conchoidal; also foliated. Fragments indeterminate, blunt-edged. Massive varieties opaque; crystals translucent. Streak scarlet red; and shining. Very soft. Sectile. Very easily frangible. Specific gravity from 6·902 to 8·160.

Subsp. 2. *Bright Red Cinnabar.*

Colour scarlet red. Massive and disseminated. Internal

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* Beitrage, i. 183.   † Phil. Mag. xiv. 41.

‡ Kirwan, ii. 228. Brochant, ii. 106. Haüy, iii. 437. Jameson, iii. 32.   § Romé de Lisle, iii. 154.

lustre glimmering; of the cross fracture dull. Fracture between earthy and fibrous; cross fracture earthy. Fragments indeterminate, blunt-edged. Opaque. Streak shining. Soils. Very soft. Sectile. Very easily frangible. Heavy.

Sp. 2. *Hepatic Ore or Carbosulphuret.**

This ore is divided into two subspecies, distinguished chiefly by their fracture.

Subsp. 1. *Compact Hepatic Ore.*

This ore, which is the most common in the mines of Idria, is always amorphous, and is often mixed with native mercury and cinnabar. Found massive. Colour between dark cochineal and dark lead grey. Its streak cochineal red and shining. Fracture even. Opaque. Internal lustre glistening, semimetallic. Soft. Sectile. Very easily frangible. Specific gravity from 7·100† to 7·186.‡ When heated the mercury evaporates. It is insoluble in nitric, and soluble in muriatic acid. §

Subsp. 2. *Slaty Hepatic Ore.*

Occurs in Idria, Almadin in Spain, and in Siberia. Colour as the preceding. Massive. Lustre of principal fracture shining; of cross fracture glimmering, semimetallic. Principal fracture curved thick slaty; cross fracture uneven. Fragments slaty. Very easily frangible. In other respects agrees with the preceding.

Dobereiner considers this ore as a compound of mercury with sulphuret of carbon.‖ Its constituents nearly correspond to the supposition, that it is a compound of 2 atoms of sulphuret of carbon and 1 atom of mercury.

The following table exhibits a view of the constituents of these species, according to the most recent analysis.

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* Kirwan, ii. 224. Brochant, ii. 104. Jameson, iii. 29. Klaproth, Gehlen's Jour. v. 437.　　　† Klaproth.　　　‡ Kirwan.
§ See Jour. de Phys. xxiv. 61.
‖ Schweigger's Journal, xii. 220.

| | Cinnabar. | | | Hepatic Ore. |
	*	†	‡	§
Mercury....	81·0	84·50	85·00	81·80
Sulphur....	15·2	14·75	14·25	13·75
Charcoal....	—	—	—	2·30
Silica......	—	—	—	0·65
Alumina....	—	—	—	0·55
Iron	4·7	—	—	0·20
Copper.....	—	—	—	0·02
Water......	—	—	—	0·73
Loss	—	0·75	0·75	—
	100·9	100	100	100

GENUS III. CHLORIDES.

Sp. 1. *Corneous Mercury.*||

This ore was first discovered by Woulfe in the mines of the Palatinate: it has since been observed at Idria, Spain, and other places. Colour ash-grey, which passes into yellowish-grey, greyish-white, and sometimes inclines to greenish-grey. Usually in small vesicles crystallized within. Crystals rectangular four-sided prisms, terminated by four-sided rhomboidal summits. Very small. Internal lustre splendent, adamantine. Fracture straight foliated; sometimes in fine granular distinct concretions. Translucent, at least on the edges. Streak similar. Soft. Sectile. Easily frangible. Volatilized before the blow-pipe.

Mr. Woulfe discovered that this ore generally contains some sulphuric acid.** The constituents of this mineral according to the analysis of Klaproth are,

Oxide of mercury .... 76·0
Muriatic acid .... 16·4
Sulphuric acid............. 7·6

100·0 ††

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* Lampadius, Handbuch zur Chem. Anal. p. 260.
† From Japan. Klaproth, Gehlen's Jour. v. 435.
‡ From Neumarktel. Klaproth, Ibid. p. 436.
§ From Idria. Klaproth, Ibid. p. 440.
|| Scopoli, Jour. de Min. No. xxxvi. 919. Kirwan, ii. 266. Brochant, ii. 101. Haüy, iii. 447. Jameson, iii. 26.   ** Phil. Trans. lxvi. 618.
†† Quoted by Professor Jameson; Mineralogy, iii. 28.

ORDER VII. ORES OF SILVER.

Silver, like gold, is found most abundantly in the tropical regions. It occurs usually in the newest primitive formations, and most of the species have been observed only in veins. The following table exhibits a view of the ores of this metal at present known.

I. ALLOYS.	Antimonial.
Native silver.	White silver ore.
Auriferous, &c.	III. OXIDES.
Antimonial.	Red silver ore.
Arseniacal.	IV. CHLORIDES.
Bismuthic.	Horn silver.
II. SULPHURETS.	V. SALTS.
Common sulphuret.	Carbonate.

GENUS I.   ALLOYS OF SILVER.

Sp. 1.   *Native Silver.**

Native silver, so called because the silver is nearly in a state of purity, forms the principal part of some of the richest silver mines in the world. It is sometimes in small lumps; sometimes crystallized in cubes, hexahedrons, octahedrons, or dodecahedrons; sometimes in leaves, or threads, often so connected with each other as to resemble branches of trees, and therefore called *dendrites.* The silver in the famous mines of Potosi has this last form. When newly extracted, it is not unlike small branches of fir.†

The colour of native silver is white; often tarnished. Lustre metallic. Fracture hackly. Harder than gold. Malleable. Specific gravity from 10 to 10·338.

The silver in this species is almost constantly alloyed with from ·03 to ·05 of some other metal, frequently gold or arsenic, or antimony.

Sp. 2.   *Auriferous Silver.*‡

This alloy is uncommon. It has been observed at Konigsberg in Norway, and at Schlangenberg in Siberia. Its

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* Kirwan, ii. 108. Calling. Act. Liter. Sveciæ, 1738, p. 420. Brochant, ii. 114. Haüy, iii. 384. Jameson, iii. 43.

† Bergman, Phys. Geogr. Jour. de Min. No. xvi. p. 26.

‡ Brochant, ii. 216. Jameson, iii. 52.

colour is yellowish-white. Its lustre metallic. Soft. Malleable. Specific gravity above 10·6.

Sp. 3. *Antimonial Silver Ore.*[*]

This alloy is found in the silver mines of Spain and Germany, and is sometimes in grains or lumps, and sometimes crystallized in four and six-sided prisms, whose sides are longitudinally streaked.[†]

Colour between silver and tin white. Its lustre metallic. Soft. Specific gravity from 9·4406[‡] to 10.[§] Fracture perfect foliated. In granular distinct concretions. Sectile. Rather easily frangible. Before the blow-pipe the antimony evaporates in a grey smoke, and leaves a brownish slag, which tinges borax green. If borax be used at first a silver bead may be obtained.

This alloy was supposed to contain arsenic, till Bergman examined it, and found only silver and antimony.[||]

Sp. 4. *Arsenical Silver Ore.*[**]

This ore is very rare, and has hitherto been found chiefly at Andreasberg in the Hartz. Colour tin white. Found disseminated in round masses, and crystallized in six-sided prisms and pyramids. Lustre metallic. Fracture foliated. Soft. Sectile. Easily frangible. Very heavy. Before the blow-pipe arsenic flies off, and a button of silver remains.

Sp. 5. *Bismuthic Silver Ore.*[††]

This ore has been hitherto found only in the mine of Friedrich-Christian in the Schapbach in the Black Forest.

Colour pale lead-grey. Disseminated and sometimes crystallized in capillary crystals. Lustre glistening and metallic. Fracture fine grained uneven. Soft. Sectile. Easily frangible.

The following table exhibits the constituents of such of the preceding species as have been subjected to chemical analysis.

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[*] Kirwan, ii. 110. Brochant, ii. 119. Klaproth, iii. 173. Haüy, iii. 391. Jameson, iii. 53.   [†] Romé de Lisle, iii. 461.
[‡] Haüy, Jour. de Min. No. xxx. 473.   [§] Kirwan, ii. 11.
[||] Opusc. ii. 415.
[**] Kirwan, ii. 111. Brochant, ii. 122. Haüy, iii. 396. Jameson, iii. 56.   [††] Jameson, iii. 58.

	Auriferous Silver.	Antimonial Silver Ore.				Arsenical Silver.	Bismuthic Silver Ore.
	*	†	†	†	‡	§	‖
Silver	72	84	77	76	78	12·75	15
Gold	28	—	—	—	—	—	—
Antimony ..	—	16	23	24	22	4	—
Lead	—	—	—	—	—	—	33
Arsenic	—	—	—	—	—	35	—
Bismuth	—	—	—	—	—	—	27
Iron	—	—	—	—	—	44·25	4·3
Copper	—	—	—	—	—	—	0·9
Sulphur	—	—	—	—	—	—	16·3
Loss	—	—	—	—	—	4	3·5
	100	100	100	100	100	100	100

GENUS II. SULPHURETS.

Sp. 1. *Common Sulphuret of Silver.*[**]
Vitreous Silver Ore—Silver Glance.

This ore occurs in the silver mines of Germany and Hungary. It is sometimes in masses, sometimes in threads, and sometimes crystallized. Its crystals are either cubes or octahedrons, or rhomboidal dodecahedrons, whose angles and edges are often variously truncated. For a description of the varieties produced by these truncatures, the reader is referred to Romé de Lisle[††] and Haüy.[‡‡]

Its colour is dark blackish lead-grey, often tarnished. Internal lustre metallic. Fracture small-grained uneven. Soft. May be cut with a knife like lead. Flexible and malleable. Specific gravity 6·909[§§] to 7·215.[‖‖] In a gentle heat the sulphur evaporates. Melts when heated to redness.

Sp. 2. *Antimonial sulphuret* [***]—*Brittle silver Ore.*
This ore occurs chiefly in Saxony and Hungary, always

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[*] Fordyce, Phil. Trans. 1776, p. 532.
[†] Klaproth, Beitrage, ii. 301, and iii. 175.
[‡] Vauquelin, Haüy, iii. 392.   [§] Klaproth, Beitrage, i. 187.
[‖] Klaproth, Beitrage, ii. 297.
[**] Kirwan, ii. 115. Brochant, ii. 134. Haüy, iii. 398. Jameson, iii. 68.   [††] Crystall, iii. 441.   [‡‡] Miner. iii. 399.
[§§] Brisson.   [‖‖] Gellert.
[***] Kirwan, ii. 117. Brochant, ii. 138. Haüy, iii. 416. Jameson, iii. 74.

in veins, and usually accompanies dark-red silver ore. Colour between iron-black and dark lead-grey. Massive, and crystallized in six-sided prisms, lenses, and four-sided tables variously truncated. External lustre splendent; internal shining, metallic. Fracture coarse and fine grained uneven; of the crystals imperfect small conchoidal. Streak retains the colour and lustre. Soft. Brittle. Very easily frangible. Specific gravity 7·208.* Before the blow-pipe the sulphur and antimony exhale, leaving a bead, which may be freed from iron by fusion with nitre and borax.

Sp. 3. *White Silver Ore.*†

This ore occurs in considerable quantities in the mine of Himmelfurst in Saxony. Colour light lead-grey. Massive. Internal lustre glistening, metallic. Fracture usually even. Soft. Slightly sectile. Very easily frangible. Specific gravity 5·322, according to Gmelin.

The following table exhibits the analysis of the species belonging to this genus:

Constituents.	Sulphuret.			Antimonial Sulphuret.	White Silver Ore.	
	‡	‡	§	‖	‖	**
Silver	84·81	85	84	66·5	20·40	9·25
Sulphur	14·19	15	16	12·0	12·25	22
Antimony	—	—	—	10·0	7·88	21·5
Lead	—	—	—	—	48·06	41
Iron	—	—	—	5·0	2·25	1·75
Arsenic	—	—	—	0·5	—	—
Silica	—	—	—	1	0·25	0·75
Alumina	—	—	—	—	7	1
Loss	1·00	—	—	5	1·91	2·75
	100	100	100	100	100	100

* Gellert.   † Kirwan, ii. 119. Brochant, iii. 150. Jameson, ii. 174.
‡ Klaproth, Beitrage, i. 172.   § Sage, Haüy, iii. 398.
‖ Klaproth, Beitrage, i. 166. Under the arsenic a little iron is included.   ** Ibid. p. 172 and 175.

GENUS III. OXIDES.

Sp. 1. *Red Silver Ore.**

This ore is very common in several German silver mines. It occurs in masses, disseminated, and crystallized. Werner subdivides it into two subspecies, distinguished by their colour and geognostic situation: the second being usually accompanied by native arsenic and white cobalt ore, orpiment, and sulphate of barytes; the first by galena, antimonial sulphuret of silver, quartz, calcareous spar, and pyrites.

Subsp. 1. *Dark Red Silver Ore.*

Colour between cochineal red and lead-grey. Massive, disseminated, and crystallized in equiangular six-sided prisms, often variously truncated. Primitive form an obtuse rhomboid, whose plane angles are 104° 28′ and 75° 32′, and the inclination of the faces 109° 28′ and 70° 32′.† External lustre splendent; sometimes metallic, sometimes adamantine. Internal lustre shining, metallic or semimetallic. Fracture usually coarse and small grained uneven. Crystallized varieties imperfect small conchoidal. Fragments indeterminate, blunt-edged. Massive varieties opaque, crystals semi-transparent. Streak cochineal red. Soft. Sectile. Easily frangible. Specific gravity from 5·563 to 5·608. Before the blow-pipe decrepitates, melts with slight bubbling, emitting a dense smoke, which colours the charcoal yellow, and leaves a button of silver.

Subsp. 2. *Light Red Silver Ore.*

Colour passes from carmine red to a medium between cochineal red and lead grey. Massive, disseminated, and crystallized in acute six-sided prisms, often variously truncated. Internal lustre from splendent to glistening, adamantine. Fracture usually imperfect small conchoidal;

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* Kirwan, ii. 123. Scopoli de Minera Argenti Rubra. Sage, Jour. de Phys. xxxiv. 331 and xli. 370.; and Nouv. Jour. de Phys. ii. 284. Westrumb, Jour. de Phys. xliii. 291. Klaproth, Beitrage, i. 141. Brochant, ii. 143. Haüy, iii. 402. Proust, Jour. de Phys. lix. 403. Jameson, iii. 77.   † Haüy, iii. 403.

Book III. sometimes passing into coarse and small grained uneven, sometimes to imperfect foliated. Fragments indeterminate, pretty sharp-edged. Massive varieties translucent on the edges, crystals transparent. Streak aurora-red. Soft. Sectile. Very easily frangible. Specific gravity 5·443 to 5·592. Becomes electric by friction, but only when insulated.* Soluble in nitric acid with effervescence.† Before the blow-pipe melts, blackens, burns with a blue flame, gives out a white smoke with a slight garlic smell, and leaves a silver bead.‡

The composition of this ore was long ambiguous. The older chemists considered it as a combination of silver, arsenic, and sulphur; and Bergman, in several parts of his works, has given us these bodies as its constituents.§ Klaproth analyzed it in 1793, and found only silver, sulphur, antimony, and oxygen.‖ Vauquelin confirmed this discovery soon after, and showed from his experiments, that the metals in the ore were in the state of oxides.** His opinion was founded upon the solution of the ore in nitric acid without effervescence, which has been lately denied by Proust. This last chemist has shown that there are two kinds of red silver ore, the one containing arsenic, the other antimony.†† Though he has not described the specimens which he subjected to analysis, yet it is probable, from several circumstances, that the first of our subspecies is that which contains the arsenic, and the second subspecies the antimony.

The following table exhibits a view of the different analyses of this ore hitherto made:

* Haüy, Jour. de Min. xxx. 476.   † Ibid. xxxi. 518.
‡ Vauquelin, ibid.
§ Sciagraphia, Eng. Trans. p. 80. Opusc. ii. 298.
‖ Beitrage, i. 141.   ** Jour. de Min. No. xvii. 1.
†† Jour. de Phys. lix. 403.

	*	*	†	†	‡	§	§
Silver	60	62	54·27	56·67	61	—	—
Antimony..........	20·3	18·5	16·13	16·13	19	—	—
Arsenic	—	—	—	—	1·9	—	—
Sulphur.	11·7	11	17·75	15·07	11·1	—	—
Oxygen	—	—	11·85	12·13	—	—	—
Sulphuric acid......	8·0	8·5	—	—	7	—	—
Sulph. of silver.....	—	—	—	—	—	58	74·35
——— antimony....	—	—	—	—	—	33	—
——— arsenic......	—	—	—	—	—	—	25
Oxide of iron	—	—	—	—	—	3	·65
Sand........	—	—	—	—	—	3	—
Water and loss... ..	—	—	—	—	—	3	—
	100	100	100	100	100	100	100

The analyses of Proust differ essentially from all the others, in exhibiting the metallic constituents, not in the state of oxides, but of pure metals.

GENUS IV. CHLORIDES.

Sp. 1. *Horn Silver.*||

This ore occurs at Johanngeorgenstadt in Saxony, in South America, &c. always in veins, and usually in the upper part. It is often amorphous, sometimes nearly in powder, and sometimes crystallized in cubes or parallelopipeds.

Most frequent colour pearl grey of all degrees of intensity; when exposed to the light it acquires a brownish tarnish. Internal lustre shining, resinous; external splendent. Acquires a gloss when scraped with a knife. Translucent. Fracture between imperfect flat conchoidal and fine-grained uneven. Soft. Flexible. Malleable. Easily frangible. Specific gravity 4·745** to 4·804.†† Before the blow-pipe it instantly melts, and gradually evaporates, but may be reduced by adding an alkali.

That this ore contains muriatic acid has been long known. Mr. Woulfe first showed that it contained also

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* Klaproth, Beitrage, i. 155.

+ Vauquelin, Jour. de Min. No. xvii. p. 4 and 7.

‡ Lampadius, Handbuch, zur Chemischen Analyse der Mineral Korper. § Proust, Jour. de Phys. lix. 407 and 409.

|| Kirwan, ii. 113. Laxmann, Nov. Comm. Petropol. xix. 482. Monnet, Mem. Scav. Etrang. ix. 717. Brochant, ii. 127. Haüy, iii. 418. Jameson, iii. 60. ** Brisson. †† Gellert.

sulphuric acid;* and this discovery has been confirmed by Klaproth, according to whose analysis this ore is composed of

> 67·75 silver.
> 6·75 oxygen.
> 6·00 oxide of iron.
> 14·75 muriatic acid.
>   ·25 sulphuric acid.
> 1·75 alumina.
> _____
>
> 97·25†

The alumina can only be considered as mixed with the ore. Sometimes its quantity amounts to ·67 of the whole.‡ Klaproth has published the analysis of a variety of this ore from Peru, which differs a good deal in its properties from the preceding.

Its colour is greyish and greenish-white, passing into light olive-green. Massive. Lustre splendent, adamantine. Fracture conchoidal. Fragments indeterminate. In large and small granular distinct concretions. Translucent. Very soft. Perfectly malleable. Very heavy. By Klaproth's analysis it is composed of

> 76·0 silver.
> 7·6 oxygen.
> 16·4 muriatic acid.
> _____
>
> 100·0§

GENUS V.   SALTS.

Sp. 1.   *Carbonate of Silver.*||

This ore was discovered in 1788 by Mr. Selb in the mine of Winceslas in Suabia. It is sometimes in masses, sometimes disseminated through other minerals.

Its colour is greyish-black. Its streak bright. Its lustre metallic. Its fracture uneven. Soft. Brittle. Specific gravity considerable. Effervesces with acids. Melts easily before the blow-pipe. Froths with borax.

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* Phil. Trans. 1776.   † Beitrage, i. 134.   ‡ Ibid. p. 137.
§ Beitrage, iv. 10.
|| Kirwan, ii. 112.   Brochant, ii. 155.   Jameson, iii. 89.

According to Selb, it contains

> 72·5 silver.
> 15·5 carbonate of antimony.
> 12·0 carbonic acid.
> ———
> 100·0 and a little copper.

ORDER VIII. ORES OF COPPER.

Copper is one of the most generally distributed metals, and occurs in a great variety of states. It is found in almost every formation, but is more frequent in the newer primitive than in any of posterior date. It is most common in veins, but exists also abundantly in beds. The following table exhibits a view of all the ores of this metal hitherto described:

I. ALLOYS.
  1. Native copper.
II. SULPHURETS.
  1. Common sulphuret.
  2. Variegated copper ore.
  3. Copper pyrites.
  4. White copper ore.
  5. Grey copper ore.
  6. Black copper ore.
III. OXIDES.
  1. Red copper ore.
  2. Tile ore.
  3. Copper black.
IV. SALTS.
  1. Anhydrous carbonate.

2. Blue carbonate.
3. Malachite.
4. Mountain green.
5. Iron shot mountain green.
6. Silicate.
7. Carbo-silicate.
8. Arseniate.
    Lamellar arseniate.
    Lenticular.
    Olive-coloured.
9. Martial arseniate.
10. Muriate.
11. Phosphate.
12. Sulphate.

GENUS I. ALLOYS.

Sp. 1. *Native Copper.**

Native copper occurs now and then in the greater number of copper mines; sometimes it is in masses, sometimes in plates and threads, which assume a variety of forms; and sometimes, as in Siberia, it is crystallized in cubes, octahedrons, cubo-octahedrons, and six-sided prisms terminated by six-sided pyramids,† and in tetrahedrons.

* Kirwan, ii. 127. Brochant, ii. 158. Haüy, iii. 518. Jameson, iii. 95.   † Haüy, Jour. de Min. No. xxxi. 509.

Colour commonly that of copper, but sometimes dark brown. Lustre metallic. Streak brighter. Fracture hackly. Flexible and malleable. Harder than silver. Specific gravity from 7·6 * to 8·5844. †

GENUS II. SULPHURETS.

Sp. 1. *Common Sulphuret.*‡

Vitreous Copper Ore. Copper Glance.

This ore occurs in veins and beds both in primitive and floëtz rocks. Werner divides it into two subspecies, distinguished chiefly by their fracture.

Subsp. 1. *Compact Sulphuret.*

Colour dark lead grey, passing into blackish grey. Has often a tempered steel tarnish. Massive and disseminated, and rarely crystallized in cubes, six-sided prisms, double six-sided pyramids, and octahedrons. External lustre shining, internal glistening, metallic. Fracture small-grained uneven; passing into conchoidal. Fragments indeterminate, sharp-edged. Streak unaltered. Soft. Sectile. Easily frangible. Specific gravity from 4·129 to 5·452.§

Subsp. 2. *Foliated Sulphuret.*

Colour as the preceding. Massive and disseminated. Has not been observed in crystals. Lustre of principal fracture shining; of cross fracture glimmering, metallic. Principal fracture pretty straight foliated with a single cleavage; cross fracture fine grained uneven. Fragments indeterminate, blunt-edged. Always in granular distinct concretions. In other characters agrees with the preceding.

This species before the blow-pipe melts easily; and while in fusion exhibits a green pearl, which, on cooling, is covered with a brown crust. Tinges borax green.

Sp. 2. *Variegated Copper Ore.*|| *Buntkupfererz.*

This ore is found in masses, or plates, or disseminated;

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* Kirwan, Miner. ii. 128.   † Haüy, Jour. de Min. No. xxxi. 509.
‡ Kirwan, ii. 144. Brochant, ii. 162. Haüy, ii. 551. Jameson, iii. 103.   § Kirwan.
|| Kirwan, Min. ii. 142. Brochant, ii. 166. Haüy, iii. 56. Jameson, iii. 110.

sometimes also it is said to be crystallized in octahedrons. Colour intermediate between copper-red and pinchbeck-brown; but when exposed to the air, it becomes first red, and then successively violet, azure, and sky-blue, and at last green; and all these colours appear often together. Internal lustre shining, metallic. Fracture small imperfect conchoidal. Streak similar. Soft. Specific gravity 4·956 to 4·983.* Somewhat sectile. Easily frangible.

Effervesces with nitric acid, and tinges it green. Deflagrates with nitre. Before the blow-pipe melts readily without smoke, vapour, or smell; but is not reduced. Tinges borax a bright green.

Sp. 3. *Copper Pyrites.*†

This is by far the most common of all the ores of copper. It occurs both in veins and beds in almost every formation. Found massive, or disseminated, or crystallized. The primitive form of its crystals is the tetrahedron; sometimes the angles are truncated; sometimes it is crystallized in octahedrons and dodecahedrons. Colour brass-yellow, passing on the one hand to golden-yellow, on the other to steel-grey. Surface usually tarnished. Internal lustre shining, metallic. Fracture uneven. Soft; scarcely gives fire with steel. Brittle. Easily frangible. Specific gravity 4·315. Before the blow-pipe on charcoal decrepitates, emits the odour of sulphur, and melts into a black globule, which gradually assumes the colour of copper. Tinges borax green.

Sp. 4. *White Copper Ore.*‡

This species, first noticed by Henkel, is one of the rarest among the copper ores. It occurs in the primitive mountains, and has been observed in Cornwall, in different parts of Germany, &c. Colour between silver-white and bronze-yellow. The fracture soon acquires a greyish-yellow tarnish. Massive and disseminated. Internal lustre glistening, metallic. Fracture small-grained uneven. Soft, passing into semihard. Brittle. Easily frangible. Specific

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* Kirwan.

† Kirwan, ii. 140. Brochant, ii. 169. Haüy, iii. 529. Jameson, iii. 114.

‡ Kirwan, ii. 152. Brochant, ii. 173. Jameson, iii. 120.

gravity 4·500.* Before the blow-pipe yields a white smoke, which has an arsenical smell, and then melts into a greyish black slag. Said to be composed of copper, iron, arsenic, and sulphur, and to contain about 40 per cent. of copper.

Sp. 5. *Grey Copper Ore* +—*Fahl Ore.*

This ore is found in Cornwall, Saxony, Hungary, &c. It occurs massive and disseminated, and often also crystallized. The primitive form of its crystals is the regular tetrahedron; but, in general, either the angles or the edges, or both, are truncated or bevelled.‡

Colour steel-grey; often tarnished, and then dark-grey. Streak sometimes unaltered, sometimes reddish brown. Powder blackish; sometimes with a tint of red. Internal lustre glistening, metallic. Fracture coarse and small grained uneven; sometimes inclines to imperfect conchoidal. Semihard. Brittle. Specific gravity 4·8648.§ Deflagrates with nitre. Before the blow-pipe crackles, but at last melts, especially if assisted by borax. The bead gives a white smoke, without any particular smell; tinges borax yellow or brownish red, but does not unite with it.

Sp. 6. *Black Copper Ore.*‖

Graugiltigerz. Schwarzgiltigerz.

This species occurs at Cremnitz in Hungary, and in other places. Colour steel grey. Massive and crystallized in tetrahedrons, seldom perfect, usually truncated in the edges or angles; sometimes the tetrahedrons are double, constituting a hexahedron. Crystals small. Lustre of crystals splendent, metallic. Fracture small conchoidal. Semihard. Brittle. Specific gravity 4·842.

The following table exhibits a view of the constituents of such of the preceding ores as have been subjected to chemical analysis.

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* Lametherie, as quoted by Jameson.

+ Kirwan, ii. 146. Klaproth's Beitrage, i. 177, and Gehlen's Jour. v. 3. Brochant, ii. 175. Haüy, iii. 537. Jameson, iii. 122.

‡ Romé de Lisle, iii. 315, and Haüy's Miner. iii. 539.

§ Haüy, Jour de Min. No. xxxi. 512.

‖ Klaproth, Beitrage, i. 177, and Gehlen's Jour. v. 14. Kirwan, ii. 143. Brochant, ii. 180. Jameson, iii. 127.

	Common Sulphuret					Variegated Copper Ore		Copper Pyrites		Grey Copper Ore				Black Copper Ore					
	*	‡	†	††	§	‖	‖	**	††	‡‡	‡‡	‡‡	§§	‖	***	***	***	***	***
Copper	78·5	47	74·5	76·5	73	58	69·5	41·0	30	41	48	42·5	19·2	31·56	37·75	39	40·25	37·5	26
Iron	2·25	9·3	1·5	0·5	1	18	7·5	17·1	31	22·5	25·5	27·5	51	3·3	3·25	7·5	13·5	6·5	7·0
Arsenic	—	—	—	—	—	—	—	—	—	24·1	14	15·6	15·7	—	—	—	0·75	—	—
Antimony	—	—	—	—	—	—	—	—	—	—	—	1·5	—	34·09	22	19·5	23	29	27
Silver	—	—	—	—	—	—	—	—	—	0·4	0·5	0·9	—	14·77	0·25	—	0·3	3	13·25
Sulphur	18·5	13	20·5	22	24·5	19	19	45·1	36·5	10	10	10	14·1	11·5	28	26	18·5	21·5	25·5
Oxygen	—	—	—	—	—	5	4	—	—	—	—	—	—	—	5	—	—	—	—
Zinc	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—
Mercury	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6·25	—	—	—
Silica	0·75	25	—	—	1·28	—	—	—	—	—	—	—	—	0·3	—	—	—	—	—
Alumina	—	7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Lime	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Earthy matter	—	—	3·5	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Loss	—	—	—	—	0·22	—	—	—	0·5	2	2	2	—	4·68	3·75	1·75	3·7	2·5	1·25
	100	101·3	100	100	100	100	100	103·2	100	100	100	100	100	100	100	100	100	100	100

* Klaproth, Beitrage, ii. 279.   † Gueniveau, Nicholson's Jour. xxi. 145.   ‡ Klaproth, Beitrage, iv. 37.

§ By my analysis. The specimen was from Nova Scotia.   ‖ Klaproth, Beitrage, ii. 283 and 286.

** Lampadius, Handbuch, p. 263.   †† Gueniveau, Nicholson's Jour. xxi. 146.

‡‡ From Freyberg. Klaproth, Gehlen's Jour. v. 9, 11, and 13.

§§ From Airthrey near Stirling. By my analysis, Trans. Edin. vi. 264. It contained iron and arsenical pyrites which could not be completely separated. Hence probably the small proportion of copper compared with that obtained by Klaproth.

‖ Klaproth, Beitrage, i. 180.   *** Klaproth, Gehlen's Jour. v. 20, 23, 25, 28, and 30.

From this table, it appears probable that the common sulphuret consists essentially of copper and sulphur. In the variegated copper ore iron is also present, and the copper seems to be in the state of protoxide; copper pyrites contains also iron, but the sulphur exists in it in a much greater proportion than in the preceding. Grey copper ore appears to be a compound of copper, iron, arsenic, and sulphur; the constituents of black copper ore are the same, except that antimony is substituted in place of arsenic.

GENUS III. OXIDES.

Sp. 1. *Red Copper Ore.**

This ore seems to be peculiar to the primitive mountains. It is most common in veins, and is found in Cornwall, various parts of Germany, Sweden, &c. It has been subdivided into three subspecies, distinguished chiefly by their fracture.

Subsp. 1. *Compact.*

Colour dark cochineal red, inclining a little to lead grey. Massive and disseminated. Internal lustre glistening, semi-metallic. Fracture even. Opaque. Hardly ever in distinct concretions. Streak tile red, and of diminished lustre. Semihard. Brittle. Easily frangible. Heavy.

Subsp. 2. *Foliated.*

Colour as the preceding. Crystals are redder, and sometimes pass into dark carmine-red. Massive, disseminated, and crystallized in cubes and octahedrons which are often truncated.† Internal lustre, shining adamantine. Fracture imperfect foliated. Very seldom in granular distinct concretions. Massive varieties opaque: crystals transparent or translucent. Streak dirty tile red. Semihard. Brittle. Easily frangible. Specific gravity 5·600.‡

Subsp. 3. *Capillary.*

Colour carmine-red, sometimes approaching cochineal-

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* Kirwan, ii. 135. Brochant, ii. 181. Haüy, iii. 555. Jameson, iii. 132.

† For a description of the crystals the reader is referred to Mr. Philips' Memoir in the Transactions of the Geological Society of London, Vol. I.   ‡ Philips.

red. In small capillary crystals, and in tables. Lustre shining, adamantine. Translucent.

Red copper ore is soluble with effervescence in nitric acid, and in muriatic acid without effervescence. Before the blow-pipe melts easily, and is reduced.

Sp. 2. *Tile Ore.**

This mineral occurs in veins, and is divided into two subspecies; namely, *earthy* and *indurated tile ore.*

Subsp. 1. *Earthy.*

Colour hyacinth-red, sometimes brownish-red. Between friable and solid. Massive, disseminated, and incrusting copper pyrites. Composed of dull dusty particles. Soils slightly. Heavy.

Subsp. 2. *Indurated.*

Colour between hyacinth and brownish-red, passing into lead-grey and blackish-brown. Massive and disseminated. Internal lustre glimmering. Fracture between even and large conchoidal, and sometimes passes into small conchoidal. Semihard. Rather brittle. Easily frangible. Specific gravity 3·572.

Infusible before the blow-pipe, but acquires a black colour.

Sp. 3. *Black Oxide of Copper.†*

This species occurs at Carraract and Tincroft mines in Cornwall, and in other places. Colour between bluish and brownish black. Friable. Massive. Composed of dusty particles which scarcely soil. Always more or less cohering. Heavy. It is considered as a mixture of oxide of copper and oxide of iron.

GENUS IV. SALTS.

Sp. 1. *Anhydrous Carbonate.‡*

This species was observed by Dr. Heyne in the Peninsula of Hindostan, near the eastern border of the Mysore country, where it appears to occur in nests in primitive rocks. It was first described and analysed by me in 1813. Colour dark blackish-brown when the specimen is pure;

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* Kirwan, ii. 137.   Brochant, ii. 187.   Jameson, iii. 141.
† Jameson, iii. 130.   ‡ Phil. Trans. 1814, p. 45.

but generally a mixture of green, red, and brown, from a mixture of malachite and red oxide of iron. Often traversed by small veins of malachite. Fracture small conchoidal; sometimes has a tendency to foliated. Soft. Sectile. Streak reddish-brown. Specific gravity 2·620. Dissolves in acids letting fall a red powder. Its constituents are as follows :

Carbonic acid	16·70
Peroxide of copper	60·75
Peroxide of iron	19·50
Silica	2·10
Loss	0·95
	100·00

Sp. 2. *Blue Carbonate of Copper.**

Mountain blue. Azur de Cuivre. Blue Calx of Copper. Kupfer-lazur. Copper Azure.

This ore, which occurs in the copper mines of Siberia, Sweden, Germany, Hungary, Britain, &c. is more common in the floëtz than in the primitive mountains. It is divided into two subspecies.

Subsp. 1. *Earthy.*

Colour smalt blue. Usually friable; seldom massive. Composed of dull dusty particles. Scarcely soils. Approaching heavy.

Subsp. 2. *Radiated.*

Principal colour azure-blue. Occurs also berlin-blue, and sometimes inclines to smalt-blue. The colours have a slight tint of red. Seldom massive; more frequently botryoidal and stalactitic; most frequently crystallized. The crystals are small, and difficult to examine. Their primitive form is an octahedron, the sides of which are scalene triangles, and two of them more inclined than the others. The crystals are often rhomboidal prisms, terminated by four-sided summits. The edges are often variously truncated.† Internal lustre shining, between vitreous and resi-

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* Kirwan, ii. 129. Morveau, Mem. Dijon, 1782. 1. Semestre, p. 100. Brochant, ii. 190. Haüy, iii. 562. Jameson, iii. 146.

† Romé de Lisle observed, that the crystals obtained from the solution of copper in ammonia have the same forms with those of this ore; and this observation has been confirmed by Haüy.

nous. Fracture narrow, straight, and scopiform radiated; sometimes imperfect foliated. Seldom in granular distinct concretions. Crystals translucent. Streak similar. Soft. Rather brittle. Specific gravity 3·608.* It effervesces with nitric acid and gives it a blue colour. Before the blow-pipe it blackens, but does not melt. Tinges borax green with effervescence.

Sp. 3. *Malachite.*†

This ore occurs in the newer primitive and in the floëtz mountains. It has been divided into two subspecies, distinguished by the fracture.

Subsp. 1. *Fibrous.*

Colour emerald-green; sometimes inclines to grass-green, sometimes to dark leek green. Seldom massive; sometimes disseminated, and often crystallized in short capillary prisms. Internal lustre shining, silky. Fracture usually very delicate fibrous; sometimes coarse fibrous. Fragments wedge-shaped and splintery. Occurs in granular distinct concretions. Crystals translucent. Massive. Varieties translucent on the edges. Soft. Streak lighter. Approaching sectile. Specific gravity 3·571.‡

Subsp. 2. *Compact.*

Colour emerald-green, inclining to verdigris-green. Often tarnished greenish-white, and is marked with stripes of a darker colour. Massive, in various particular shapes, and crystallized in four-sided prisms terminated by four-sided pyramids. Internal lustre glistening, silky. Fracture sometimes very delicate fibrous, which passes into even; this into flat and small conchoidal, which sometimes passes into small-grained uneven. Fragments indeterminate. Usually in thin lamellar distinct concretions; surface of the concretions rough, and covered with a thin green film. Opaque. Soft. Not particularly brittle. Very easily frangible. Streak similar. Specific gravity 3·683.§
Before the blow-pipe it decrepitates and blackens, but

* Brisson.
† Kirwan, ii. 131. Fontana, Jour. de Phys. xi. 509. Klaproth's Beitrage, ii. 287. Brochant, ii. 197. Haüy, iii. 571. Jameson, iii. 154.
‡ Brisson.   § Kirwan.

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does not melt. Tinges borax yellowish green. Tinges flame green.

Sp. 4. *Mountain Green.**

Found in the same situations as the preceding species. Colour verdigris-green; sometimes passing into emerald-green, and sometimes inclining to leek-green. Massive, disseminated, and botryoidal. Internal lustre shining, resinous. Fracture small conchoidal. Fragments indeterminate, more or less sharp-edged. Never in distinct concretions. Translucent. Soft. Not particularly brittle. Easily frangible. Specific gravity 3·371. Blackens before the blow-pipe, but does not melt. Dissolves in acids with scarcely any effervescence.

Sp. 5. *Iron Shot Mountain Green.*†

This species is usually accompanied by the two preceding. It is divided into two subspecies.

Subsp. 1. *Earthy.*

Colour olive-green; sometimes passing into pistachio-green. Massive and disseminated. Dull. Fracture earthy. Soils a little. Fragments indeterminate, blunt-edged. Opaque. Streak nearly similar. Very soft. Easily frangible. Rather heavy.

Subsp. 2. *Slaggy.*

Colour dark olive and pistachio-green, which passes into dark blackish-green. Massive and disseminated. Internal lustre shining, resinous. Fracture small conchoidal. Fragments indeterminate, more or less sharp-edged. Opaque. Streak paler. Soft. Easily frangible. Rather heavy.

Sp. 6. *Silicate of Copper* ‡—*Dioptase, Emerald Copper Ore.*

This mineral, which at first was confounded with the emerald, is found in the north of Asia. Colour emerald-green. Crystallized in six-sided prisms terminated by three-sided pyramids. Primitive form of the crystals an obtuse

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* Kirwan, ii. 134. Brochant, ii. 203. Jameson, iii. 167.
† Kirwan, ii. 151. Brochant, ii. 205. Jameson, ii. 237.
‡ Jameson, iii. 174.

rhomboid. Lustre shining vitreous. Fracture foliated with a threefold cleavage. Fragments indeterminate, blunt-edged. Translucent. Scratches glass with difficulty. Brittle. Specific gravity 3·3.* Before the blow-pipe becomes chesnut-brown, but is infusible. Tinges the flame green. It is a trisilicate of copper.

Sp. 7. *Carbosilicate.*†

This mineral occurs in Mexico, but in what situation I do not know. The only specimens I have seen were in possession of Mr. Mawe, who had received them from Vera Cruz.

Colour verdigris-green with a tint of blue. Form botryoidal. Lustre vitreous and varying much in intensity. External lustre often dull, internal shining. Fracture compact and conchoidal. Fragments rather rounded with blunt edges. In granular distinct concretions. Translucent on the edges. Nearly as hard as calcareous spar; readily scratched by the knife. Brittle. Distinct concretions easily separable from each other. Specific gravity 2·238. Does not effervesce in nitric acid when in lumps; but effervesces when in powder, and dissolves, leaving a white siliceous powder behind.

Sp. 8. *Arseniate of Copper.*

Hitherto this species has been found only in Cornwall. It was discovered above 30 years ago in the Carrarach mine; but it had become exceedingly scarce, till it was lately found in abundance in the Huel Garland mine. A great variety of specimens were carried to London; and they have been admirably described and analysed by the Count de Bournon and Mr. Chenevix.‡ It has been divided into three subspecies, distinguished chiefly by the figure of their crystals.

Subsp. 1. *Foliated Arseniate* §—*Copper Mica.*

Colour emerald-green. Massive, disseminated, and sometimes crystallized. Crystals thin hexahedral laminæ;

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* Haüy.   † Annals of Philosophy, vii. 321.
‡ Phil. Trans. 1801, p. 169.
§ Bournon, Phil. Trans. 1801. Jameson, iii. 184.

the six faces inclined alternately towards the opposite sides of the plates, so that three lie one way and three another. Two of these three are inclined at angles of 135°; the other at an angle of 115°. Divisible into thin plates like mica. Lustre splendent, pearly. Fragments indeterminate and tabular. In granular distinct concretions. Massive varieties translucent, crystals transparent. Scratches gypsum, but not calcareous spar. Sectile. Specific gravity 2·548. Decrepitates when heated.

Subsp. 2. *Lenticular Arseniate.**

Colour sky-blue, which sometimes passes into verdigris green. Crystallized in obtuse octahedrons, composed of two four-sided pyramids with isosceles triangular faces, two of which are more inclined than the other two. The two most inclined meet at the apex at an angle of 130°, and form at the base angles of 50°: the two least inclined meet at the apex in an angle of 115°, and form at the base angles of 65°. Sometimes the apex is converted into a ridge; the octahedron being lengthened parallel to the less inclined planes. External lustre shining. Fracture foliated. Translucent. Scratches calcareous spar, but not fluor spar. Rather brittle. Very easily frangible. Specific gravity 2·882.

Subsp. 3. *Oliven Ore.†*

Of this subspecies two varieties have been distinguished.

1. Foliated. Colour perfect olive-green; sometimes inclining to oil-green and leek-green. Seldom massive; usually in drusy crusts; and crystallized in very acute rhomboids, sometimes having their angles truncated. Faces of the crystals smooth; lustre shining. Internal lustre glistening, adamantine. Fracture imperfect foliated. Fragments indeterminate. The massive varieties occur in granular distinct concretions. Translucent. Streak straw yellow. Very soft. Sectile. Specific gravity 4·2809.

2. Fibrous. Colour olive-green. Massive varieties pass into liver-brown and into greenish-white. Massive, reniform, and crystallized in acicular four-sided prisms.

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* Bournon, Phil. Trans. 1801.
† Kirwan, ii. 151. Brochant, ii. 208. Haüy, iii. 575. Bournon and Chenevix, Phil. Trans. 1801. Klaproth, iii. 187.

Internal lustre glistening, adamantine. Fracture delicate scopiform fibrous. Fragments wedge-shaped; sometimes in coarse granular, and in curved lamellar distinct concretions. Translucent on the edges. Sometimes scratches fluor spar. Rather brittle. Specific gravity 4·281.

Sp. 9. *Martial Arseniate.**

Found in Tincroft and some other mines in Cornwall. Colour pale sky-blue. Massive and crystallized in oblique rhomboidal four-sided prisms. Internal lustre shining and pearly. Fracture scopiform radiated. Transparent. Scratches calcareous, but not fluor spar. Specific gravity 3·4.

Sp. 10. *Muriate of Copper* †—*Green Sand of Peru.*

This ore, which was brought from Peru by Dombey, is a green powder mixed with grains of quartz. When thrown on burning coals, it communicates a green colour to the flame. It is soluble both in nitric and muriatic acids without effervescence. The solution is green. This mineral was first proved to contain muriatic acid by Berthollet.‡ Afterwards Proust analysed it; § but Vauquelin announced that he considered it merely as an oxide of copper mixed with common salt. ‖ However, a subsequent examination convinced him that his opinion was unfounded; and that the mineral was really a muriate, as had been affirmed by Berthollet and Proust.** This conclusion has been confirmed by Klaproth.

Colour sometimes between leek and emerald-green; sometimes between emerald and olive. Massive and crystallized in flat six-sided prisms, bevelled at the extremities, and in oblique four-sided prisms. Surface smooth; lustre splendent, adamantine. Internal lustre shining, resinous. Fracture foliated. Massive. Opaque. Crystals transparent. Soft. Streak pale apple-green. Rather sectile. Easily frangible. Specific gravity 3·570.††

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* Jameson, iii. 194.
† Kirwan, ii. 149. Brochant, ii. 545. Haüy, iii. 560. Jameson, iii. 176. ‡ Mem. Par. 1786, p. 4 and 62.
§ Ann. de Chim. xxxii. 26. ‖ Jour. de Min. No. xxxi. 519.
** Haüy, iii. 562. †† Lametherie.

<center>Sp. 11. *Phosphate of Copper.*[*]</center>

This ore has been found at Rheinbreiderbach near
Cologne, and was considered as a variety of malachite, till
Klaproth ascertained its composition.   Found massive,
disseminated, and crystallized in small oblique hexahedrons.
They occur in groups, often so small as to resemble moss.
Colour externally greyish black; but within, between ver-
digris and emerald green.   External lustre splendent,
vitreous; internal glimmering, silky. Fracture fibrous;
fibres diverging. Opaque. Streak apple-green. Sectile.
Soft.   Specific gravity 3·5142.

<center>Sp. 12. *Sulphate of Copper.*</center>

This salt occurs occasionally in the neighbourhood of
copper mines, either massive, in particular shapes, or in
capillary and cubic crystals.   Its properties have been
already detailed in the first part of this work.

The following table exhibits a view of the constituents
of such of the preceding species as have been analysed:

[*] Klaproth, iii. 201.   Brochant, ii. 544.   Jameson, iii. 179.

	Blue Carbonate *	Blue Carbonate †	Malachite ‡	Mountain Green §	Silicate ‖	Carbo-silicate **	Foliated Arseniate ††	Foliated Arseniate ‡‡	Lenticular Arseniate ††	Oliven Ore ††	Oliven Ore ††	Oliven Ore ††	Oliven Ore ††	Oliven Ore §§	Arseniate ‖‖	Arseniate ‖‖	Martial Arseniate ***	Muriate †††	Muriate †††	Muriate ‡‡‡	Phosphate §§§
Ox. of copper	77	70	70·5	50	55	54·46	58	39	50	54	60	51	50	50·62	26	28	22·5	76·6	70·5	73	68·13
Oxide of iron	—	24	18	7	—	—	—	—	—	—	—	—	—	—	—	—	27·5	—	—	—	—
Carbonic acid	19	—	—	—	—	14·98	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Arsenic acid	—	—	—	—	—	—	21	43	14·3	30	39·7	29	29	45	69	72	33·5	—	—	—	—
Muriatic acid	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	10·6	11·4	10·1	—
Phosphor. acid	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	30·95
Silica	2	6	—	26	33	25·31	21	17	—	16	—	—	—	—	—	—	3	—	—	—	—
Water	—	—	11·5	17	12	—	—	1	35·7	—	0·3	18	21	3·5	—	—	12	12·8	18·1	16·9	—
Loss	—	—	—	—	—	5·25	—	—	—	—	—	2	—	0·88	5	—	1·5	—	—	—	0·92
	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

* Pelletier, Ann. de Chim. xiii. 54. † Klaproth, Beitrage, iv. 31. The specimen analysed was from Siberia, and belonged to the radiated subspecies. ‡ Ibid. ii. 290. § Ibid. iv. 34. From Siberia. ‖ Lowitz, Nov. Act. Petross. 13. ** Annals of Philosophy, vii. 322. ‡‡ Chenevix, Phil. Trans. 1801, p. 207. §§ Vauquelin. ‖‖ This is the result stated in the Philosophical Magazine (Vol. xxxiii. p. 332) to have been obtained by Mr. Gregor from the analysis of two specimens of native arseniate of copper from Cornwall of a pale yellow colour. Unless there be some mistake in the account, they must have belonged to a subspecies very different from any known before. *** Chenevix, Phil. Trans. 1801, p. 220. §§ Klaproth. †† Proust, Ann. de Chim. xxxii. 49. ††† Ibid. p. 200. ‡‡‡ Klaproth, iii. 49. §§§ Ibid. p. 201.

ORDER IX. ORES OF IRON.

Iron is the most abundant of metals; it exists in every formation, and assumes the most different and even opposite shapes. This renders it a more difficult task to bring its ores under a regular arrangement than those of any other metal. The following table exhibits a view of the different ores of this metal, arranged according to their component parts:

Table of
the species.

I. ALLOYS.
  1. Native iron.
II. SULPHURETS.
  1. Magnetic pyrites.
  2. Cubic pyrites.
III. OXIDES.
  1. Magnetic iron-stone.
  2. Specular iron-stone.
  3. Red iron-stone.
  4. Hydrate of iron.

5. Hydrate of iron-and-manganese.
IV. SALTS.
  1. Carbonate.
  2. Phosphate.
  3. Arseniate.
  4. Chromate.
  5. Silicate.
  6. Tungstate.
  7. Sulphate.

GENUS I. ALLOYS.

Sp. 1. *Native Iron.*

This mineral is rare, but it has been observed in different parts of the world. A specimen, weighing about 4lbs. was found in the mine of Hackenberg.* Colour bluish white. Fracture hackly. Lustre metallic. Malleable. Magnetic. Hard. Specific gravity 7·8. The masses of iron observed by Pallas in Siberia, by Rubin de Celis in South America, &c. are now considered as depositions from meteors. They are distinguished from native iron by containing nickel, of which the true specimens of native iron are destitute. A specimen of native iron from the mine Johannes, near Kamsdorf in Saxony, analysed by Klaproth, contained

Iron ...... 92·5
Lead ...... 6·0
Copper .... 1·5
———
100·0†

* Cramer, Phil. Mag. xiii. 32.   † Gehlen's Jour. i. 36.

GENUS II. SULPHURETS.

Sp. 1. *Magnetic Pyrites.**

This occurs chiefly in the primitive mountains, and has hitherto been observed only in beds. Colour between bronze-yellow and copper-red, and sometimes inclines to pinchbeck-brown. Acquires a brownish-tarnish. Massive and disseminated. Internal lustre shining, metallic. Fracture uneven. Fragments indeterminate, blunt-edged. Never in distinct concretions. From hard to semihard. Brittle. Easily frangible. Specific gravity 4·518.† Attracted by the magnet.

Sp. 2. *Iron Pyrites.* ‡

This mineral is one of the most abundant in nature, occurring in almost every rock and vein. Its forms, too, are equally varied. It is massive, disseminated, globular, oviform, &c. and very often crystallized. The most common figures of its crystals are the cube, the octahedron, the rhomboidal dodecahedron, and the icosahedron; but the angles and edges are often variously truncated. The cubes are sometimes smooth and sometimes striated: the striæ are parallel to the edges of the faces, and in three different directions. Romé de Lisle showed, that its primitive form was sometimes a cube and sometimes an octahedron. Haüy considers the cube as the primitive form. But when we attempt to ascertain the natural joints of the crystals, we, in some cases, obtain a cube, in others an octahedron. Hence Bournon considers these two forms as distinct, and constituting two species of pyrites; which he thinks chemical analysis will one day demonstrate to differ in their composition. The striated cubes, according to him, constitute a third species. For a description and figure of the different crystals of this mineral, the reader may consult Romé de Lisle, § Haüy,‖ and Bournon.** It has been divided into four subspecies, and even these scarcely include all the varieties of this mineral which have been observed.

* Kirwan, ii. 79. Brochant, ii. 232. Jameson, iii. 218.
† Hatchett.
‡ Kirwan, ii. 76. Brochant, ii. 221. Haüy, iv. 65. Bournon, Jour. de Min. No. lxxv. 170. Jameson, iii. 204. § Crystallog. iii. 208.
‖ Miner. iv. 67. ** Jour. de Min. No. lxxv. 170.

Subsp. 1. *Common Pyrites.*

Colour bronze-yellow. Massive and crystallized in cubes, either perfect or truncated, in octahedrons, dodecahedrons, and even icosahedrons. Surface sometimes smooth, sometimes streaked. Lustre from splendent to shining, metallic. Fracture uneven. Hard. Brittle. Easily frangible. Specific gravity 4·830.*

Subsp. 2. *Radiated Pyrites.*

Colour bronze-yellow; sometimes inclining to brass-yellow. Surface tarnished. Massive, reniform, and crystallized in octahedrons, either perfect or truncated, and in cubo-octahedrons. External lustre from shining to glimmering. Fracture radiated. Passes into fibrous and into compact. Fragments wedge-shaped. In granular, lamellar, and columnar distinct concretions. Hard. Brittle. Very easily frangible. Specific gravity from 4·698 to 4·775.†

Subsp. 3. *Hepatic Pyrites.*

Colour pale-brass-yellow, inclining to steel-grey. Fresh fracture becomes brown when exposed. Massive, tuberose, &c. and crystallized in tetrahedrons and six-sided prisms. Internal lustre glimmering, metallic. Fracture usually even. Fragments indeterminate, sharp-edged. In distinct concretions. In other respects the same as the preceding. Very subject to decomposition.

Subsp. 4. *Cellular Pyrites.*

Colour bronze-yellow, inclining very much to steel-grey, and a little to green. Acquires a grey tarnish. Massive, but most frequently cellular. Surface of the cells drusy. Internal lustre glimmering. Fracture even and flat conchoidal. Fragments indeterminate, pretty sharp-edged. In other characters agrees with the preceding.

As far as has been hitherto observed, pyrites consist essentially of two distinct species. 1. Magnetic pyrites, composed of 1 atom iron, and 1 atom sulphur. 2. Cubic pyrites, composed of 1 atom iron, and 2 atoms sulphur. The first is a sulphuret, ths second a bisulphuret of iron.

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* Hatchett. † Ibid.

GENUS III. OXIDES.

Sp. 1. *Magnetic Iron-Stone* *—*Fer Oxidulé* of Haüy.

This species, characterized in some measure by its magnetic properties, is divided by Werner into two subspecies.

Subsp. 1. *Common Magnetic Iron-stone.*

This ore occurs most frequently in primitive mountains, and usually in gneiss, mica-slate, chlorite-slate, and primitive lime-stone; but sometimes also in rocks of the floëtz trap formation. It is found in beds, and sometimes composes whole mountains. It is very common in Sweden; it is found also in Switzerland, Norway, Russia, &c. It occurs massive, in plates, grains, and crystallized. The primitive form of its crystals is a regular octahedron.† Sometimes two opposite sides of the pyramids are trapeziums, which renders the apex of the pyramids cuneiform; sometimes in cubes; sometimes the crystals pass into rhomboidal parallelopipeds, and into dodecahedrons with rhomboidal faces.‡

Colour iron-black. Powder black. § Streak unaltered. External lustre shining; internal glistening metallic. Fracture uneven; sometimes approaches even, also imperfect straight foliated. Hard. Sometimes in granular distinct concretions. Brittle. Specific gravity from 4·200 to 4·939.‖ Attracted by the magnet, and generally possessed of more or less magnetic virtue.** To this species belongs the magnet. Before the blow-pipe it becomes browner, but does not melt. Tinges borax dark-green. By the analysis of Bucholz, this ore is composed of a mixture of the two distinct oxides of iron and a little quartz.††

Subsp. 2. *Iron-sand.*

Occurs imbedded in basalt and wacka, and in the sand of rivers. Colour dark-iron-black. In small angular and roundish grains, and in octahedral crystals. Surface

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* Kirwan, ii. 158. Brochant, ii. 235. Haüy, iv. 10. Jameson, iii. 223. † Romé de Lisle, iii. 178. ‡ Ibid.
§ Haüy, Jour. de Min. No. xxxiii. 659. ‖ Kirwan's Min. ii. 159.
** Haüy, Jour. de Min. No. xxxi. 527.
†† Gehlen's Jour. Second Series, iii. 106.

rough and feebly glimmering. Internal lustre, shining, metallic. Fracture perfect conchoidal; very rarely imperfect foliated. Fragments indeterminate, sharp-edged. Semihard. Brittle. Easily frangible. Specific gravity 4·600 * to 4·76. Strongly attracted by the magnet.

Magnetic iron-stone according to the analysis of Berzelius is composed of

$$\text{Protoxide of iron .. 31 .. 1 atom}$$
$$\text{Peroxide of iron .. 69 .. 2 atoms}$$
$$\overline{}$$
$$100 \dagger$$

Iron-sand contains some titanium. I found the constituents of a specimen from Aberdeenshire, as follows:

$$\text{Oxide of iron .... 85·3}$$
$$\text{Oxide of titanium 9·5}$$
$$\text{Oxide of arsenic.. 1·0}$$
$$\text{Silica and alumina 1·5}$$
$$\text{Loss .... 2·7}$$
$$\overline{}$$
$$100·0$$

Sp. 2. *Specular Iron Ore.*‡

Iron Glance—Fer Oligiste.

This ore appears to be confined to the primitive and transition mountains. It occurs both in veins and beds. It is divided into two subspecies.

Subsp. 1. *Common.*

This ore is found abundantly in the Isle of Elba near Tuscany, in Germany, France, Russia, &c. It is either in masses or crystallized. The primitive form of its crystals is a rhomboid, which differs very little from a cube; the angles of the rhombs being 87° and 93°. It occurs in a variety of forms: the most common are the rhomboidal parallelopiped; the cube, with three triangular faces in-

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* Kirwan.

† Attempt to establish a New System of Mineralogy, p. 125.

‡ Kirwan, ii. 162. Coudrai, Jour. de Phys. iv. 52. Brochant, ii. 142. Haüy, iv. 38. Jameson, iii. 232.

stead of two of its angles diagonally opposite; two six-
sided pyramids, applied base to base, wanting the summits,
and sometimes the angles at the bases, and sometimes the
alternate edges of the pyramid; a polyhedron of 24 sides,
resembling a cube with three triangular faces for two angles
diagonally opposite, and two triangles for the rest of its
angles; thin octagonal plates, bounded by six linear tra-
peziums, alternately inclined different ways.

Colour steel-grey; often tarnished, and beautifully
iridescent, reflecting yellow, blue, red. Streak cherry-
red. Powder blackish-red. External lustre splendent to
glistening; internal shining, metallic. Hard. Fracture
sometimes compact, sometimes foliated. The compact is
uneven, and sometimes passes into imperfect small con-
choidal; the foliated has a fourfold rectangular cleavage.
Fragments octahedral or pyramidal; sometimes indeter-
minate; usually unseparated. Rather tough. Brittle.
Specific gravity 5·0116 * to 5·218.† Slightly magnetic.
Does not attract iron filings, as is the case with the last
species. Little altered by the blow-pipe. Tinges borax
an obscure yellow.

Subsp. 2. *Micaceous Iron Ore—Iron Mica.*

Occurs in Perthshire and other parts of Scotland, &c.
Colour iron-black. The thin plates, when held between
the eye and the light, appear blood-red. Massive, and
crystallized in thin six-sided tables. Surface of the crystals
smooth and splendent. Internal lustre splendent, metallic.
Fracture perfect curve-foliated. Cleavage single. Frag-
ments sometimes indeterminate; sometimes tabular. The
massive occurs in granular distinct concretions. Translucent
on the edges; in thin plates translucent. Streak cherry-red.
Semihard. Brittle. Very easily frangible. Specific gra-
vity 3·50 to 5·07.‡ According to the analysis of Bucholz
this subspecies consists entirely of peroxide of iron.§

A specimen of the first subspecies analysed by Hisinger,
contained

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* Brisson.   + Kirwan.   ‡ Ibid.
§ Gehlen's Jour. Second Series, iii. 104.

Peroxide of iron .... 94·38
Phosphate of lime ...... 2·75
Magnesia .... 0·16
Stony matter .... 1·25
Lost by exposure to heat . 0·50
Loss .... 0·96
_____
100·00 *

Sp. 3. *Red Iron-stone.* †

This is one of the most common iron ores. It occurs in great abundance in Lancashire, and in different parts of Germany. It is found both in beds and veins, and both in the primitive and floëtz mountains.

Colour red. Streak blood-red. Specific gravity from 2·952 to 5·005. Before the blow-pipe blackens, but does not melt. Tinges borax yellowish olive-green. When digested in ammonia, it becomes black, and often magnetic. It is usually divided into four subspecies.

Subsp. 1. *Red Scaly Iron Ore—Eisenrham—Iron Froth.*

Colour between cherry and brownish-red, often passing into steel-grey. Usually friable. Lustre glimmering, semimetallic. Feels greasy. Very soft. Brittle. Moderately heavy. Composed of scaly friable parts, which soil strongly. This subspecies is rare: it occurs in different parts of Germany and Hungary and Britain.

Subsp. 2. *Red Ochre.*

Found sometimes in powder, sometimes indurated. Composed of dusty particles, which have a faint glimmering lustre. Colour light blood-red. Soils. Feels meagre. Not particularly brittle. Specific gravity 2·952. Very soft. Accompanies the other subspecies.

Subsp. 3. *Compact.*

Found massive and disseminated, and in various imitative forms; sometimes crystallized in cubes or four-sided pyramids, having their apex truncated. Colour between

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* Afhandlingar, iii. 321.

† Kirwan, ii. 158. Brochant, ii. 249. Jameson, iii. 243.

brown-red and steel-grey. Fracture usually even, rarely passes into coarse-grained uneven, large conchoidal and slaty. Lustre glimmering, semimetallic. Hard. Not particularly brittle. Specific gravity 3·423 to 3·76. * Sometimes invested with a rosy-red ochre. Found abundantly in Germany, France, &c.

<div align="center">Subsp. 4. Red Hæmatites.</div>

Found in masses, and all the variety of forms of stalactites, in kidney-form balls, &c. Colour between brownish-red and steel-grey. Powder red. Internal lustre glistening, semimetallic. Fracture fibrous. Fragments usually splintery or wedge-shaped. In angular granular distinct concretions. Hard. Brittle. Rather easily frangible. Specific gravity 4·74 † to 5·005. ‡

Like the last species it consists essentially of peroxide of iron. The following table exhibits the result of the analyses hitherto made.

	Iron Froth.	Compact red Iron-stone.	Red Hematite.	
Peroxide of iron	94·5	100	90	94
Oxide of manganese .	—	—	Trace	Trace
Silica	4·25	—	2	2
Alumina	1·25	—	—	—
Lime	—	—	1	Trace
Water	—	—	3	2
Loss	—	—	4	2
	100 §	100 ‖	100 **	100 **

<div align="center">Sp. 4. Hydrate of Iron.</div>

This species was established in consequence of the investigations of D'Aubuisson †† and Haussmann ‡‡, and has contributed to remove a good deal of confusion, observable in

* Kirwan. † Gellert. ‡ Kirwan.
§ Henry, Nicholson's 4to. Jour. iii. 456.
‖ Bucholz, Gehlen's Journal, Second Series, iii. 158.
** D'Aubuisson, Ann. de Chim. lxxv. 237. Specific gravity of the first specimen 4·8, of the second 5·0.
†† Ann. de Chim. lxxv. 225. ‡‡ Gilbert's Annalen, xxxviii. 1.

Book III. the mineralogical arrangement of the iron ores that must now be placed under this species.

Hydrate of iron may be divided into five subspecies, depending chiefly upon the fracture and texture.

Subsp. 1. *Fibrous Hydrate—Brown Hematite.*

The name hematites (bloodstone) was probably applied by the ancients to those ores only which are of a red colour, and have some resemblance to clotted blood; but by the moderns it is applied to all the ores of iron which give a reddish-coloured powder, provided they be of a fibrous texture.

Brown hematite occurs rarely massive, usually in imitative forms of various kinds, and sometimes in pseudo-crystals, consisting of six-sided acute-angled pyramids. Colour clove-brown; sometimes passing into steel-grey, bluish-brown or ochre-yellow; sometimes iridescent. External lustre splendent; internal glistening, between silky and resinous. Fracture fibrous. Fragments splintery, wedge-shaped, indeterminate. In granular distinct concretions. Hard. Brittle. Opaque. Specific gravity 3·789 * to 3·951.† Not magnetic. Streak ochre-yellow.

Subsp. 2. *Compact Hydrate—Compact Brown Iron-stone.*

This subspecies occurs in masses of very various, and often fantastical shapes; sometimes in pseudo-crystals. Colour clove brown. Internal lustre glimmering, semimetallic. Fracture commonly even. Fragments indeterminate, blunt-edged. Streak yellowish-brown. Easily frangible. Hard. Brittle. Specific gravity 3·4771 ‡ to 3·75

Subsp. 3. *Globular Hydrate.*

Of this the three following varieties have been distinguished.

Variety 1. *Lenticular Clay Iron-stone—Acinose Iron-stone.*

Occurs in transition and floëtz mountains. Colour brownish-red, passing into steel-grey, and into reddish, yellowish, and blackish-brown. Massive. Internal lustre glistening, semimetallic. Fracture apparently earthy, and

* Gellert.   † Kirwan.   ‡ Brisson.   § Kirwan.

sometimes slaty. Fragments indeterminate, blunt-edged. In granular and lenticular distinct concretions. Red variety yields a light red streak, the yellowish a yellowish-brown, and the black a greyish-black streak. Soft. Sectile. Very easily frangible. Specific gravity 3·770.

Variety 2. *Kidneyform Clay Iron-stone.*
Oetites or *Eagle-stone.*

Occurs imbedded in iron-shot clay in the newest floëtz rocks. Common in Scotland and other countries. Colour yellowish-brown, varying in intensity in the same specimen; externally being darker, and internally lighter. Sometimes it includes an ochre-yellow kernel. In roundish masses, from the size of a walnut to that of a man's head. Fracture near the surface even, near the centre earthy. Lustre of external layers glimmering, semimetallic; of the centre dull. Fragments indeterminate. In concentric lamellar distinct concretions, inclosing a nodule often loose. Surface of concretions rough and glimmering. External layers soft, internal very soft. Brittle. Easily frangible. Adheres to the tongue. Specific gravity 2·574.

Variety 3. *Pisiform Iron-stone.*

Supposed to occur in the second floëtz lime-stone formation, and in clay beds. Found in Scotland, and in various parts of Germany, &c. Colour within yellowish-brown; without reddish, yellowish, and liver-brown, and sometimes yellowish-grey. In small, round, and spherical grains. Internally it passes from dull to glistening; the centre of the grain being dull, and the lustre increasing as we approach the surface. Lustre resinous. Fracture towards the centre fine earthy, near the surface even. In thin concentric lamellar distinct concretions, having a smooth glistening surface. Streak yellowish-brown. Soft. Not very brittle. Easily frangible. Specific gravity 5·207.

Subsp. 4. *Ochrey Hydrate—Ochrey Brown Iron-stone.*

It occurs both massive and disseminated. Colour very light yellowish-brown. Between solid and friable. Composed of coarse earthy particles, dull or faintly glimmering. Soils strongly. Very soft. Between brittle and sectile. When slightly heated reddens.

Reddle or *red chalk* seems to belong to this subspecies. It occurs chiefly in the newer clay slate and is chiefly used for drawing. Found massive. Colour light brownish-red. Principal fracture slaty. Cross fracture fine earthy. Lustre of the principal fracture glimmering; of the cross fracture dull. Fragments usually splintery. Streak lighter, and more shining than the fracture. Soils strongly. Very soft. Sectile. Easily frangible. Adheres to the tongue. Feels meagre. Specific gravity 3·931 to 3·1391.*

Subsp. 5. *Bog Iron Ore.*†

This subspecies belongs to the newest formation, and is supposed to be daily deposited from water in morassy grounds. It is divided into three varieties.

Variety 1. *Morass Ore.*

Colour yellowish-brown. Sometimes friable; sometimes nearly cohering. The friable composed of dull dusty particles; the coherent massive, corroded, and in grains. Lustre dull. Fracture earthy. Soils pretty strongly. Feels meagre. Light.

Variety 2. *Swamp Ore.*

Colour dark yellowish-brown. Corroded, vesicular, and amorphous. Internal lustre glimmering. Fracture earthy, passing into fine-grained uneven. Streak yellowish-brown. Very soft. Sectile. Easily frangible. Specific gravity 2·944. ‡

Variety 3. *Meadow Ore.*

Colour, when fresh broken, blackish-brown. Massive, in grains, perforated, &c. Internal lustre shining, resinous. Fracture imperfect small conchoidal; sometimes passes into small-grained uneven. Fragments indeterminate, blunt-edged. Streak light yellowish-grey. Soft. Rather brittle. Very easily frangible. Heavy.

The following table exhibits the constituents of these different hydrates according to the most accurate analyses hitherto made.

* Blumenbach and Brisson.
† Kirwan, ii. 179. Brochant, ii. 282. Jameson, ii. 334.
‡ Kirwan.

	Brown Hematite.		Compact brown Iron-stone.		Etites.		Lenticular Iron-ore.	Ochre.	Meadow Ore.
Perox. of iron .	79	82	84	81	76	78	73	83	61
Oxide of manganese.....	2	2	1	—	2	Trace	1	Trace	7
Water........ .	15	14	11	12	14	13	14	12	19
Silica..........	3	1	2	4	5	7	9	5	6
Alumina.......	—	Trace	—	—	—	1	—	—	2
Loss..........	1	1	2	3	3	1	3	—	5
	100*	100*	100*	100*	100*	100 *	100 *	100*	100 *

Sp. 5. *Hydrate of Iron and Manganese* †—*Umber.*

This mineral which is used as a paint, occurs in beds in the island of Cyprus. Colour clove-brown. Massive. Internal lustre glimmering and resinous. Fracture flat conchoidal. Fragments blunt edged. Very soft. Rather sectile. Soils strongly. Very easily frangible. Feels meagre. Adheres strongly to the tongue. Readily falls to pieces in water. Specific gravity 2·06. Its constituents are,

Oxide of iron 48
Oxide of manganese .. 20
Silica 13
Alumina 5
Water 14
        ————
        100‡

GENUS IV. SALTS.

Sp. 1. *Carbonate.*

Of this salt there are two subspecies, namely *sparry iron ore* and *common clay iron-stone.*

Subsp. 1. *Sparry Iron Ore.* §

This ore is common in Germany, France, and Spain, and occurs in small quantities in Britain. It is found sometimes in amorphous masses, and sometimes crystallized in rhombs, lenses, octahedrons, and dodecahedrons.

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* D'Aubuisson, Ann. de Chim. lxxv. 237.
† Jameson, iii. 266.   ‡ Klaproth, Beitrage, iii. 140.
§ Kirwan, ii. 190. Bergman, ii. 184. Bayen, Jour. de Phys. vii. 213. Razowmoski, Mem. Lausanne, 1783, p. 149. Brochant, ii. 264. Jameson, iii. 271.

Colour light yellowish-grey, passing into yellowish-brown and blackish-brown. Sometimes intermediate between yellowish-brown and greenish-grey. On exposure to the air or heat the colours change into brown or black. Internal lustre from splendent to glimmering, pearly. Fracture more or less perfect foliated. Cleavage threefold. Fragments rhombs with angles of 107°.* Translucent, sometimes opaque. In granular distinct concretions. Streak yellowish brown. Harder than calcareous spar. Not particularly brittle. Easily frangible. Specific gravity 3·640 to 3·810.† Becomes black before the blow-pipe.

The following table exhibits the constituents of this subspecies.

	Sparry Iron-stone.								
	‡	‡	‡	§	§	‖	‖	**	**
Oxide of iron..	52·75	42·38	42·38	49	50·5	55	73·75	57·5	58
Ox. of mangan.	—	—	—	1·5	10	10	10·5	3·5	4·25
Silica.........	—	—	0·8	—	2	—	—	—	—
Lime.........	—	—	—	0·3	0·5	—	2·75	1·25	0·5
Magnesia......	5	14	13·6	12·5	2	—	—	—	0·75
Carbonic acid..	42·25	43·62	43·22	37·5	34·5	35	13	36	25
Loss..........	—	—	—	—	0·5	—	—	1·75	1·5
	100	100	100	100·8	100	100	100	100	100

Subsp. 2. *Common Clay Iron-stone.*

Occurs in beds in floëtz mountains. Found abundantly both in Scotland and England. Colour light yellowish-grey, inclining to ash-grey; it passes into bluish-grey, and, into yollowish, reddish, and clove-brown, and brownish-red. The light varieties change their colour on exposure; they become yellowish, then brown, and at last black. Massive and in various extraneous shapes, especially of shells. Internal lustre dull. Fracture usually earthy, sometimes flat conchoidal and even. Fragments indeterminate, blunt-edged. Soft. Rather brittle. Easily frangible. Adheres a little to the tongue. Feels meagre. Specific gravity from 2·936 to 3·471.

* Wollaston.   † Kirwan.
‡ Drappier, Gehlen's Jour. Second Series, ii. 471.
§ Collet Descotils, ibid. p. 476.   ‖ Bucholz, ibid. iii. 114.
** Klaproth, Beitrage, iv. 107.

The following table exhibits the constituents of this sub-species.

	Common Clay Iron-stone.							
	*	*	†	†	†	†	†	†
Oxide of iron.......	35	39	33 5	42·5	39·1	33·9	20·1	20·2
Oxide of manganese.	—	—	1·5	3	1·1	1·1	1	0·5
Silica.............	11	5	14·3	13·8	11·9	23·9	19·9	29·9
Alumina	39	40	22·6	13·6	15·8	13	30·2	25·4
Magnesia	2	6	—	—	—	—	—	—
Carbonic acid......	—	—	28·1	27·1	32·1	28·1	28·8	24·0
Water.............	10	9	—	—	—	—	—	—
Sulphur	3	1	—	—	—	—	—	—
	100	100	100	100	100	100	100	100

Sp. 2. *Phosphate.*

Of this species there are two subspecies, the *crystallized phosphate,* and *earthy phosphate,* or *native prussian blue.*

Subsp. 1. *Phosphate of Iron.* ‡

This mineral has been found in Brazil, and in the Isle of France. Some fine specimens from Cornwall are in the possession of Mr. Heuland. Its composition was first detected by Vauquelin. Specimens brought by Mr. Roch from the Isle of France were subjected to chemical analysis by Cadet and Laugier.

It is said to be found imbedded in a species of clay, in round pieces. Fracture radiated. Composed of capillary crystals diverging from a centre. Crystals apparently four-sided prisms.§ Individual crystals translucent. They are nearly colourless, but a blue powder coats them, which gives a blue appearance to the whole mineral. The constituents both of the crystals and powder the same. Specific gravity 2·539, according to Cadet; 2·6, according to Laugier.

* Lampadius. Jameson, ii. 323 and 328.
† Richter, Crell's Annals, 1796, i. 550.
‡ Cadet, Jour. de Phys. lvii. 259. Fourcroy, Ann. de Chim. l. 200.
§ The Cornish specimens are in large flat four-sided prisms.

Subsp. 2. *Blue Iron-earth.** *Native Prussian Blue.*

This mineral is considered at present as a phosphate of iron, in consequence of the analysis of Klaproth. It occurs in nests among the strata of clay, bog iron ore, or in mosses. It is massive, composed of earthy particles without lustre, and friable. At first its colour is greyish-white, but when exposed to the air it becomes indigo or smalt-blue. Soils slightly. Feels harsh. Moderately heavy. Before the blow-pipe becomes reddish brown, and melts into a black brilliant globule, which tinges borax deep yellow. Dissolves readily in acids. But becomes insoluble by exposure to a red heat.

The constituents of these minerals are as follows:

	Phosphate of Iron.		Blue Iron-earth.
	†	‡	§
Oxide of iron	41·25 ..	42·1 ..	47·5
Phosphoric acid	19·25 ..	26·9 ..	32
Silica	1·25 ..	3 ..	—
Alumina	5 ..	5·8 ..	—
Lime	— ..	9·1 ..	—
Water	31·25 ..	13·1 ..	20
Loss	2 ..	— ..	0·5
	100	100	100

Sp. 3. *Arseniate of Iron—Cube Ore.*

This ore was first mentioned by Klaproth, but mistaken by him for arseniate of copper containing iron: ‖ it has been found in Carrarach and in Muttrell mines in Cornwall. For the description of it we are indebted to Bournon, and for its analysis to Chenevix.

This ore is crystallized in cubes, which are sometimes a little flattened, and in some cases the angles are truncated, and small equilateral triangular faces substituted for them. Sometimes the alternate angles only are truncated. Colour

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* Kirwan, ii. 185. Brochant, ii. 288. Haüy, vi. 119.—Jameson, iii. 304.

† Laugier, Ann. de Chim. l. 214.   ‡ Cadet, Jour. de Phys. lviii. 261.

§ Klaproth, Beitrage, iv. 120.

‖ Klaproth's Observations on the Minerals of Cornwall, p. 29. English Translation.

olive-green. Internal lustre glistening, between pearly and adamantine. Fracture imperfect foliated. In granular distinct concretions. Translucent. Streak straw-yellow. Brittle. Soft. Specific gravity 3·00. Sometimes in the state of a powder of a reddish-yellow colour.*

Its constituents are as follows :

	Arseniate of Iron.	
	†	‡
Oxide of iron	48 ..	45·5
Oxide of copper	— ..	9
Arsenic acid	18 ..	31
Silica	— ..	4
Lime	2 ..	—
Water	32 ..	10
	100	99·5

Sp. 4.   *Chromate of Iron.*§

This mineral, which has been found near Gassin in the department of Var in France, in Siberia, and near Baltimore, is in irregular masses and crystallized in octahedrons.

Colour brown, not unlike that of brown blende. Powder ash-grey. Fracture uneven. Opaque. Lustre slightly metallic. Hardness sufficient to scratch glass. Specific gravity 4·0326. Does not melt before the blow pipe *per se ;* but melts with borax, and forms a fine green bead. Insoluble in nitric acid. Melted with potash and dissolved in water, the solution assumes a beautiful orange yellow colour. Its constituents are as follows :

	‖	**	††
Oxide of chromium	43·0 ..	53 ..	55·5
Oxide of iron	34·7 ..	34 ..	33·0
Alumina	20·3 ..	11 ..	6·0
Silica	2·0 ..	1 ..	2·0
Loss	— ..	1 ..	3·5
	100	100	100

* Phil. Trans. 1801, p. 190.   + Vauquelin.

‡ Chenevix, Phil. Trans. 1801, p. 221.

§ Brochant, ii. 554. Haüy, iv. 129.

‖ Vauquelin, Jour. de Min. No. lv. 523. Specimen from the Var.

** Laugier, Phil. Mag. xxiv. 7. Specimen from Siberia.

†† Klaproth, Gehlen's Jour. Second Series, i. 192.

Sp. 5. *Silicate.*

We are acquainted with three different silicates of iron. The first is a hydrous silicate to which Berzelius has given the name of *hedenbergite*. The second is a double silicate of iron and lime, to which the French mineralogists have given the name of *yenite*. The third is a double silicate of iron and manganese, distinguished by Haussmann by the name of *pyrodmalite*.

1. *Hedenbergite.**

This mineral was first described and analysed in 1807 by Hedenberg in the second volume of the Afhandlingar. It occurs at Tunaberg in Sudermannland in the mine called Mormors. It is associated with white calcareous spar in which it forms thin layers. Its surface is often sprinkled with cubic pyrites; and masses of quartz and mica often intersect it.

Colour greenish-black; sometimes passing into brown. Massive and composed of shining plates; by the fracture of which rhombs may be obtained, having angles nearly similar to those of calcareous spar. Fracture fibrous. Fragments indeterminate, sharp-edged. Streak olive-green. Scratched by fluor spar but not by calcareous spar. Powder olive-green inclining to brown. Phosphoresces both by heat and friction; but does not become electric. Specific gravity 3·154. Before the blow-pipe it loses its lustre and becomes magnetic. Its constituents according to the analysis of Hedenberg are as follows:

Silica	40·62
Black oxide of iron.	35·25
Water	16·05
Lime.	3·37
Alumina.	0·37
Oxide of manganese	0·75
Carbonic acid	1·56
Loss	2·03
	100·00

2. *Yenite†—Lievrite* of Werner.

This mineral was discovered and brought from the isle

* Afhandlingar, ii. 164.　　　　　† Jameson, ii. 75.

of Elba by Mr. Le Lievre. Its colour is sometimes velvet-black, sometimes brownish-black. It occurs both massive and crystallized. The form of the crystals is a rectangular four-sided prism, terminated by a flat four-sided pyramid, the sides of which are set upon the lateral sides of the prism at angles of 104°. Sometimes the edges of the prism are truncated. The sides of the first variety are longitudinally streaked. Fracture uneven. Lustre resinous. Cleavage threefold, two of them parallel to the sides of the prism, the third parallel to the shorter diagonal of the rhombs. Opaque. Semihard. Scratches glass, but not felspar. Specific gravity from 3·82 to 4·06. When exposed to the air its surface acquires a brownish or ochre-yellow colour. Before the blow-pipe it melts into a black glass, attracted by the magnet. Soluble in muriatic acid.

It forms beds in a rock which appears intermediate between actinolite and hornblende.

Its constituents are as follows:

	*	†
Oxide of iron	55	.... 57·5
Oxide of manganese ..	3	.... —
Silica	28	 30
Alumina	0·6	... —
Lime	12	.... 12·5
Loss	1·4	.... —
	100	100

3. Pyrodmalite.‡

This mineral was discovered by Messrs. Clason and Henry Gahn, in the iron mine of Bjelke in Wermeland. It was named by Haussman from the strong smell of chlorine which it emits when heated by the blow-pipe.

Colour liver-brown. It is crystallized in six-sided prisms, which are sometimes very short and sometimes truncated on their terminal edges. Terminal planes of the crystals shining and pearly; lateral planes shining and vitreous. Principal fracture foliated with a four-fold cleavage; the

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* Descotils, Gehlen's Jour. Second Series, iii. 87.
† Vauquelin, ibid. ‡ Afhandlingar, iv. 317. Jameson, iii. 311.

most distinct is that parallel to the terminal planes. The other three are parallel to the lateral faces and are less distinct. Lustre of the principal fracture shining, of the cross fracture glimmering. In straight lamellar distinct concretions. Translucent on the edges. Semihard. Streak brownish-white. Powder light-green. Specific gravity 3·081. Before the blow-pipe it gives out vapours of muriatic acid and melts into a bead which is attracted by the magnet. Its constituents according to the analysis of Hisinger are as follows:

Silica	35·850
Oxide of iron	35·480
Oxide of manganese....	23·444
Muriatic acid	2·905
Lime	1·210
Loss	1·111
	100·000*

Sp. 6.   *Tungstate—Wolfram.*†

This species is found in different parts of Germany, in Sweden, Cornwall, France, and Spain; and is almost constantly accompanied by ores of tin. It occurs both massive and crystallized. The primitive form of its crystals, according to the observations of Mr. Haüy, is a rectangular parallelopiped, whose length is 8·66, whose breadth is 5, and thickness 4·33.‡ In many cases, the angles, and sometimes the edges, of the crystal are truncated.

Colour between dark-greyish and brownish-black. Streak reddish-brown. Powder stains paper with the same colour. Lustre glistening, metallic. Fracture foliated. Cross fracture coarse and small grained uneven. Easily separated into plates by percussion. In lamellar distinct concretions. Opaque. Soft. Brittle. Specific gravity from 7·006§ to 7·333.‖ Moderately electric by

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* Afhandlingar, iv. 324.

+ Kirwan, ii. 316. De Luyart, Mem. Thoulouse, ii. 141. Gmelin, Crell's Jour. Eng. Trans. iii. 127, 205, and 293. La Perouse, Jour. de Min. No. iv. p. 23. Brochant, ii. 456. Haüy, iv. 314. Jameson, iii. 549.   ‡ Jour. de Min. No. xix. 8.

§ Kirwan.   ‖ Haüy.

communication. Not magnetic. Infusible by the blow-
pipe. Forms with borax a greenish globule, and with mi-
crocosmic salt a transparent globule of a deep red.*
Its constituents are as follows:

Tungstic acid	67	.... 78·775
Protoxide of iron............	18	.... 18·320
Protoxide of manganese....	6·25	.... 6·220
Silica	1·5	.... 1·250
Loss........................	7·25	.... ———
	100·0†	104·565‡

Sp. 7. *Sulphate.*

This salt is found sometimes along with iron pyrites. Its
properties have been described in a former part of this
work.

The mineral usually called native vitriol is a mixture of
the sulphates of iron, copper, and zinc.

Sp. 8. *Subsulphate?—Pitchy Iron Ore.*§

This mineral occurred formerly at Freyberg and has
been lately found in Upper Silesia. Colour greyish-black,
which passes into dark liver-brown. Occurs in crusts.
Internal lustre splendent and resinous. Fracture imperfect
conchoidal. Fragments indeterminate, sharp-edged. Soft.
Streak lemon-yellow. Specific gravity 2·407. When
placed in water it becomes red, semi-transparent and vi-
treous.

Its constituents are as follows:

Peroxide of iron	67
Sulphuric acid	8
Water	20
Loss........................	5
	100‖

* Vauquelin, Jour. de Min. No. xix. 11.
† Vauquelin and Hecht, Jour. de Min. No. xix. p. 11.
‡ Berzelius, Afhandlingar, iv. 302. § Jameson, iii. 229.
‖ Klaproth, Beitrage, v. 221.

ORDER X. ORES OF MANGANESE.*

Ores of manganese occur both in primitive and transition mountains. They are very common, having been found abundantly in Germany, France, Spain, Britain, Sweden, Norway, Siberia, and other countries.

Hitherto manganese has been only found in the state of oxide. La Perouse, indeed, suspected that he had found it in a metallic state; but the quantity was too minute to admit of decisive experiments. The following table exhibits the ores of this metal which have been described:

I. Oxides.
      1. Grey ore.
      2. Black ore.
      3. Sulphureted oxide.

II. Salts.
      1. Phosphate.
      2. Silicate.

GENUS I. OXIDES.

Sp. 1. *Grey Ore.*†

This mineral is found in great abundance in different parts of the earth. It is divided into four subspecies by Werner.

Subsp. 1. *Radiated Grey Ore.*

Colour steel-grey. Found massive and disseminated, and crystallized in four-sided prisms, either terminated by four-sided or by two-sided summits. The faces of the prisms are longitudinally streaked. Internal lustre shining, metallic. Fracture radiated. Surface of fracture streaked. Fragments splintery or wedge-shaped. In granular distinct concretions. Streak similar. Stains. Soft. Brittle. Rather tough. Specific gravity from 3·7076 to 4·756.

Subsp. 2. *Foliated Grey Ore.*

Colour steel-grey. Found massive, disseminated, and

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* Pott, Miscelan. Berolens. vi. 49. Margraff, Mem. Berlin, 1773, p. 3. La Perouse, Jour. de Phys. xvi. 156, and xv. 67, and xxviii. 68. Sage, Mem. Par. 1785, p. 235.

† Kirwan, ii. 291. Brochant, ii. 414. Haüy, iv. 243. Jameson, iii. 315.

crystallized in longish rhombs. Internal lustre shining, metallic. Fracture foliated. Fragments indeterminate, blunt-edged. Streak black and dull. Stains. Soft. Brittle. Easily frangible. Specific gravity 3·742.

Subsp. 3. *Compact Grey Ore.*

Colour steel-grey. Found massive and disseminated. External lustre dull; internal glistening, metallic. Fracture even; sometimes inclining to flat conchoidal. Fragments indeterminate, not very sharp-edged. Usually unseparated; sometimes in thick lamellar distinct concretions. Specific gravity 4·407. In other respects resembles the preceding.

Subsp. 4. *Earthy Grey Ore.*

Colour dark steel-grey, inclining a little to bluish. Massive. Composed of delicate scaly particles, which have a glimmering metallic lustre. Soils strongly. More or less cohering. Feels fine but meagre. Moderately heavy.

The grey ore of manganese, before the blow-pipe, becomes brownish-black, but does not melt. Tinges borax violet.

Sp. 2. *Black Ore of Manganese.**

This ore is rare, and usually occurs along with grey antimony ore. Colour between brownish and greyish-black. Found massive, or disseminated, or crystallized in octahedrons. Surface of the crystals smooth and shining. Internal lustre glistening. Fracture imperfect foliated. Fragments indeterminate, blunt-edged. In small granular distinct concretions. Streak reddish-brown. Opaque. Semihard. Brittle. Heavy.

The following table exhibits a view of the constituents of these species, according to the analyses hitherto made :

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* Brochant, ii. 424. Jameson, iii. 324.

	Radiated Grey Ore.					Compact Grey Ore.			
	*	*	†	†	†	‡	‡	‡	‡
Ox. of mangan.	92·75	99·25	83·5	82	86	68	67	83·7	72
Oxide of iron..	7	—	2	—	3	18	13·5	—	—
Charcoal	—	—	—	—	1·5	—	—	0·4	—
Lime	—	—	—	8·5	—	7	6	—	7
Barytes	—	—	1·5	2	—	4	5	14·7	9
Silica	—	—	7·5	7	5	3	7	1·2	6
Water.........	—	0·5	—	—	—	—	—	—	—
Loss..........	0·25	0.25	5·5	0·5	4·5	—	1·5	—	6
	100	100	100	100	100	100	100	100	100

Sp. 3.   *Sulphureted Oxide.*§

This mineral has been found in Cornwall, and at Nagyag in Transylvania. Colour, when fresh broken dark steel-grey; but on exposure assumes a brownish-black colour. Massive. Lustre of the fresh fracture splendent; of the tarnished surface shining and metallic. Fracture imperfect foliated, inclining to fine-grained uneven. Opaque. Soft. Sectile. Streak greenish. Specific gravity 3·950. Before the blow-pipe gives out sulphur and tinges borax-violet-blue. Its constituents are as follows:

Oxide of manganese .. 82·0 .. 85
Sulphur .... 11·5 .. 15
Carbonic acid .... 5·0 .. —
Loss .... 1·5 .. —

100·0 ‖ 100**

GENUS II.   SALTS.

Sp. 1.   *Phosphate of Manganese*††—*Pitchy Iron Ore.*
This mineral was discovered by Alluau near Limoges,

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* Klaproth, Beitrage, iii. 303.   The specimen was from Ilefeld in the Hartz.

† Cordier and Beaunier, Jour. de Min. No. lviii. p. 778.   The first specimen yielded 38 per cent. of oxygen, the second 36·5, and the third 42.   The lime in the second specimen was in the state of carbonate.

‡ Cordier and Beaunier, ibid. The first specimen, from St. Micaud, yielded 33 per cent. of oxygen; the second, from Perigueux, 17 per cent. The lime in these was contaminated with some magnesia, iron, and manganese.   The third specimen, from Romaneche, yielded 33·7 per cent. of oxygen; the fourth, from Laveline, 17 per cent. The lime in this last was in the state of carbonate.   § Jameson, iii. 332.

‖ Klaproth, Beitrage, iii. 42.

** Vauquelin, Gehlen's Jour. Second Series, ii. 34.

†† Jour. de Min. No. lxiv. 295. Ann. de Chim. xli. 242. Brochant, ii. 533. Jameson, iii. 333.

and sent to Vauquelin as an ore of tin. It is found massive.
Colour raven-black. Surface earthy, and without lustre: in-
ternal lustre shining, resinous. Fracture flat and pretty per-
fect foliated. Fragments indeterminate, pretty sharp-edged.
Translucent on the edges. When held between the eye and
the light, appears blackish-green on the edges. Scratches
glass. Brittle. Rather tough. Specific gravity 3·956.
Before the blow-pipe it melts into a black enamel.

Its constituents are as follows :

> Phosphoric acid 27
> Oxide of manganese ... 42
> Oxide of iron 31
> ___
> 100 *

Sp. 2. *Silicate of Manganese.†*

This mineral is found at Longbanshytta in Wermeland,
Sweden. Its colour is rose-red. Massive. Fracture foli-
ated, with a threefold cleavage like felspar. Opaque when
in large masses; but the thin splinters are translucent.
Strikes sparks with steel and scratches glass. Specific
gravity 3·5384. Before the blow-pipe it becomes dark-
brown and at last fuses into a reddish-brown bead.

Its constituents, according to the analysis of Berzelius, are
as follows :

> Peroxide of manganese .. 52·60
> Silica .... 39·60
> Oxide of iron .... 4·60
> Lime .... 1·50
> Volatile matter .... 2·75
> ___
> 101·05 ‡

ORDER XI.   ORES OF URANIUM.

The ores of uranium occur in Saxony, Bohemia, Norway,
Cornwall, France, and are found in veins in primitive
mountains. Hitherto it has been observed only in the state
of oxide. The following are the species at present known :

* Vauquelin, Ann. de Chim. xl. 242.
† Hisinger, Afhandlingar, i. 105.
‡ Afhandlingar, i. 110.

I. OXIDES.
  1. Protoxide or pitch ore.
  2. Green mica or hydrate.
  3. Uran ochre or peroxide.

GENUS I. OXIDES.

Sp. 1. *Pitch Ore—Pechblende.**

This ore, which has been found at Johanngeorgenstadt in Saxony, Joachimsthal in Bohemia, and Conigsberg in Norway, is either massive or disseminated.

Colour velvet-black or dark greyish-black. Streak similar. Internal lustre shining, resinous. Fracture imperfect flat conchoidal. Fragments indeterminate, sharp-edged. Occurs in thick curved lamellar, and in coarse angulo-granular distinct concretions. Soft. Very brittle. Specific gravity from 6·3785 † to 7·5, and even higher.‡ Imperfectly soluble in sulphuric and muriatic acids; perfectly in nitric acid and aqua regia. Solution wine-yellow. Infusible with alkalies in a crucible: infusible by the blow-pipe *per se*. With borax and soda forms a grey opaque slag; with microcosmic salt, a green glass. A specimen of this ore from Joachimsthal, analysed by Klaproth, contained

Uranium	86·5
Sulphuret of lead	6·0
Silica	5·0
Oxide of iron	2·5
	100·0 §

Sp. 2. *Hydrate of Uranium—Uran Mica* ‖ *—Green Mica— Chalcolite.*

This substance is found in Cornwall, France, at Johanngeorgenstadt, and near Eibenstock and Rheinbreidenbach.** It is sometimes in membranes, but more commonly crystallized. Its crystals are rectangular four-sided tables, cubes, and octahedrons.

* Kirwan, ii. 305. Jameson, iii. 553.
† Morveau, Jour. de Min. No. xxxii. 610.
‡ Klaproth, Beitrage, ii. 197.   § Beitrage, ii. 221.
‖ Kirwan, ii. 304. Haüy, iv. 283. Brochant, ii. 463. Jameson, iii. 556.   ** Gmelin.

Colour glass-green, passing into emerald-green and into siskin-green. External lustre shining to splendent; internal shining and glistening, pearly. Translucent. Fracture foliated. Soft. Sectile. Easily frangible. Specific gravity from 2·190 to 3·3.* Soluble in nitric acid without effervescence. Infusible by alkalies.

Its constituents, according to the analysis of Mr. Gregor, are as follows :

Oxide of uranium .. 74·4
Oxide of copper ... 8·2
Water .... 15·4
Loss .... 2·0
——————
100·0†

Sp. 3. *Uran Ochre.*‡

This species, which occurs along with the other ores of uranium, is divided into two subspecies.

Subsp. 1. *Friable.*

Colour straw-yellow, passing into lemon-yellow, into yellowish-brown and orange-yellow, and sometimes aurora-red. Usually coats pitch ore. Friable, and composed of dull dusty particles. Soils feebly. Feels meagre. Not particularly heavy.

Subsp. 2. *Indurated.*

Colour as the preceding. Massive and disseminated. Internal lustre dull; sometimes glimmering. Fracture small-grained uneven; sometimes passes into earthy, sometimes into small conchoidal. Fragments indeterminate. Opaque. Soft. Brittle. Soils a very little. Specific gravity 3·15 to 3·2438.§

ORDER XII. ORES OF CERIUM.

This metal has been found hitherto in the state of a salt only. Seven species are known, which are silicates or fluates. These are

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* Gregor.   † Annals of Philosophy, v. 284.
‡ Kirwan, ii. 303. Brochant, ii. 466. Jameson, iii. 559.
§ Lametherie and Haüy.

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1. Silicate of cerium or cerite.
2. Silicate of cerium and iron or allanite.
3. Silicate of yttria, cerium, and iron, or gadolinite.
4. Yttrocerite.
5. Orthite.
6. Fluate of cerium.
7. Subfluate of cerium.

Sp. 1. *Cerite.*[*]

This mineral is found in Bastnas near Riddarhytta in Westmannland. Colour between carmine-red, clove-brown, and reddish-brown. Massive and disseminated. Internal lustre scarce glimmering, resinous. Fracture fine splintery. Fragments indeterminate, not remarkably sharp-edged. Opaque. Streak greyish-white. Powder reddish-grey. Semihard. Brittle. Specific gravity 4·660. Its constituents, according to the analysis of Hisinger, are as follows:

Silica	18
Oxide of cerium	68·59
Oxide of iron	2·00
Lime	1·25
Water and carbonic acid	9·60
Loss	0·56

100·00 [†]

Sp. 2. *Allanite.*[‡]

This mineral was found by Giesecké, in a granite rock in West Greenland, and was described and analysed by me about seven years ago. I have seen a specimen of the same mineral in the museum at the India-house which had been brought from Hindostan. Colour brownish-black. Hitherto it has been found only massive. External lustre dull. Internal shining and resinous. Fracture small conchoidal. Fragments indeterminate angular and sharp-edged. Opaque. Streak greenish-grey. Scratches glass and hornblende. Brittle. Easily frangible. Specific gravity 3·523 to 4·001. Before the blow-pipe froths and melts imperfectly into a black scoria. Its constituents are as follows:

* Klaproth, Gehlen's Jour. ii. 305, and Beitrage, iv. 140.
† Afhandlingar, iii. 283.   ‡ Edinburgh Transactions, vi. 385.

Silica .... 35·4
Oxide of cerium . 33·9
Oxide of iron .. 25·4
Lime .... 9·2
Alumina ...... 4·1
Moisture ...... 4·0
                 ————
                 112·0

Sp. 3. *Gadolinite.**

This mineral was first observed by Captain Arhenius lodged in a white felspar in the quarry of Ytterby in Sweden, and received the name *Gadolinite,* because Gadolin was the chemist who first ascertained its composition. Colour velvet-black, passing sometimes to brown. Massive. Lustre shining, glassy. Fracture conchoidal. Hard. Scratches quartz. Opaque. Brittle. Specific gravity 4·0497. Gelatinizes with hot diluted nitric acid. Before the blow-pipe decrepitates, and assumes a whitish red colour, but does not melt. With borax it melts into a topaz-yellow glass. Its constituents are as follows:

Silica .... 25·80 .... 24·16
Yttria................... 45·00 .... 45·93
Protoxide of cerium .... 16·69 .... 16·90
Protoxide of iron ...... 10·26 .... 11·34
Volatile matter.......... 0·60 .... 0·60
Loss .... 1·65 .... 1·07
                         ———————   ———————
                         100·00†   100·00†

Sp. 4. *Yttrocerite.*

This mineral occurs at Finbo in Sweden, and has been described and analyzed by Berzelius. It is found in amorphous masses, varying in size from a thin crust to half a pound in weight, disseminated through quartz. Its colour is various, violet, greyish-red, white, grey, often all mixed in the same specimen. Fracture foliated. Lustre glistening. Opaque. Scratched by the knife and by quartz. Scratches fluor spar. Specific gravity 3·447. Before the

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* Haüy, iii. 141. Brochant, ii. 512. Klaproth, iii. 52. Jameson, iii. 565.　　　† Berzelius, Afhandlingar, iv. 225.

blow-pipe it loses its colour and becomes white; but does not fuse. When mixed with gypsum it melts readily into a bead. When in fine powder it dissolves completely in muriatic acid and the solution has a yellow colour. Its constituents are

Lime	47·63 to	50·00
Yttria...................	9·11 to	8·10
Oxide of cerium	18·22 to	16·45
Fluoric acid	25·05 to	25·45
	100·01	100·00

Or

Fluate of lime	65·162 to	68·18
Fluate of yttria..........	11·612 to	10·60
Fluate of cerium	23·226 to	21·22
	100·000	100·00*

Sp. 5.   *Orthite.*

This mineral occurs in a granite vein at Finbo in Sweden, and was discovered during the summer of 1816, by Professor Berzelius and Assessor Gahn. It approaches gadolinite considerably in its appearance but differs in its fusibility. Its constituents are

Silica	32·00
Lime	7·84
Alumina	14·80
Protoxide of cerium	19·50
Protoxide of iron	12·44
Protoxide of manganese	3·44
Yttria	3·44
Water	5·36
	98·82†

A variety occurs at Korervet containing 25 per cent. of charcoal, to which Berzelius has given the name of *pyrorthite,* because it takes fire before the blow-pipe.

Sp. 6.   *Fluate of cerium.*

This mineral has been discovered at Finbo along with

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* Afhandlingar, iv. 151.   † Annals of Philosophy, ix. 160.

the preceding species. It is crystallized in regular six-sided prisms. Its constituents are

Protofluate of cerium ...... 30·43
Perfluate of cerium .... 68·00
————
98·43

Sp. 7. *Subfluate of Cerium.*

This mineral occurs along with the preceding. It has a strong resemblance to porcelain jasper. Its colour is yellow, and its form gives marks of crystallization. It consists of fluoric acid combined with twice as much protoxide and peroxide of cerium as in the preceding species.

ORDER XIII. ORES OF TANTALUM.

This metal has been hitherto found only in the state of oxide, constituting two species, which have been distinguished by the names of *tantalite* and *yttrotantalite*.

Sp. 1. *Tantalite—Columbite* of Hatchett.

This mineral occurs in Finland disseminated in granite. It is not quite certain whence the specimen analyzed by Mr. Hatchett originated. It has been long known; but before the analysis of Ekeberg was mistaken for an ore of tin. Found in irregular crystals, which seem to be octahedrons. Colour between bluish-grey and iron-black. Surface smooth and glimmering. Internal lustre shining, metallic. Streak blackish-grey, approaching brown. Very hard. Not magnetic. Specific gravity 7·953. Its constituents according to the analysis of Berzelius are as follows:

Protoxide of tantalum ...... 83·2
Protoxide of iron .... 7·2
Protoxide of manganese .... 7·4
Oxide of tin .... 0·6
Loss .... 1·6
————
100·0*

Sp. 2. *Yttrotantalite.†*

This mineral occurs along with gadolinite in the quarry of Ytterby. Colour dark iron-grey, yellowish-brown, and dark-brown. Occurs massive and crystallized in oblique four and six-sided prisms. Fracture foliated. Lustre glim-

* Afhandlinger, iv. 264. † Berzelius, Afhandlingar, iv. 267.

mering and metallic. Powder grey. Opaque. Scratches glass. Specific gravity from 5·395 to 5·882. Before the blow-pipe with phosphate of soda the black variety melts into a yellowish-red transparent glass, the yellow variety into a rose-red opaque glass, and the dark brown variety into a greenish-grey opaque glass. The constituents of this mineral according to the analysis of Berzelius are as follows:

Oxide of tantalum	57	60·124	51·815
Tungstic acid	8·25	1·044	2·592
Yttria	20·25	29·780	38·515
Lime	6·25	0·500	3·260
Oxide of iron	3·50	1·155	0·555
Oxide of uranium	0·50	6·622	1·111
Loss	4·25	0·775	2·152
	100·00*	100·000*	100·000*

ORDER XIV.   ORES OF COBALT.

Cobalt ores occur both in primitive, transition, and floëtz mountains. They are not very abundant; and for that reason cobalt is more valuable than many of the other metals which have been already treated of. They are commonly accompanied by nickel, bismuth, or iron. They are most abundant in Germany, Sweden, Norway, and Hungary; they have been found also in Britain and France, but not in any great quantity.

Few of the ores of cobalt have been analysed with precision; hence the confusion which still obscures their mineralogical arrangement and description. The following table exhibits what are at present considered as the different species of these ores, arranged according to their supposed composition:

I. ALLOYS.
  1. White cobalt ore.
  2. Glance cobalt.
  3. Grey cobalt ore.
II. SULPHURETS.
  1. Cobalt pyrites.
III. OXIDES.
  1. Black cobalt ochre.
  2. Brown cobalt ochre.
  3. Yellow cobalt ochre.
IV. SALTS.
  1. Arseniate of cobalt.
  2. Sulphate.

* Berzelius, Afhandlingar, iv. 267. The first specimen was black, the second yellow, the third dark-brown.

GENUS I. ALLOYS.

Sp. 1. *White Cobalt Ore*—Weisser Speisskobalt* of the Germans.

This is the most common species of cobalt ore.

Colour tin-white, slightly inclining to reddish; acquires a greyish tarnish. Commonly massive, or in particular shapes; sometimes crystallized in cubes or dodecahedrons. Crystals usually small; faces smooth. External lustre splendent; internal glistening, metallic. Fracture fine grained uneven; sometimes fibrous and radiated. Fragments indeterminate, rather sharp-edged. Usually unseparated; sometimes in granular distinct concretions. Semihard. Brittle. Easily frangible. Specific gravity 7·379. When struck with steel emits an arsenical smell.

Its constituents according to the analysis of Laugier are as follows:

<div align="center">

Arsenic .... 68·5
Iron. .... 9·7
Cobalt. .... 9·6
Sulphur .... 7·0
Silica .... 1·0
Loss .... 4·2
———
100· †

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Sp. 2. *Grey Cobalt Ore.*‡

This ore occurs in various parts of Germany, Cornwall, France, &c. Colour light steel-grey, inclining to white; but when exposed to the air, is soon tarnished greyish-black. Massive, disseminated, tubiform, and specular. Internal lustre glimmering, metallic. Fracture even; sometimes passing into large flat conchoidal, and into fine grained uneven. Fragments indeterminate, pretty sharp-edged. Seldom in lamellar distinct concretions. Streak similar. Semihard. Very brittle. Easily frangible. Specific gravity 5·571.§

Its constituents according to the analyses of Laugier and Stromeyer are as follows:

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* Jameson, iii. 495.   † Ann. de Chim. lxxxv. 34.
‡ Jameson, iii. 497.   § Kirwan.

Arsenic	50	74·2174
Silica	25	——
Iron	12·5	3·4257
Cobalt	12·7	20·3135

—— Copper 0·1586

100·2* Sulphur 0·8860

—————

100·0000†

Does the silica in this ore exist in the state of silicon, or is it a foreign body?

Sp. 2.   Glance Cobalt Ore. ‡

Found in beds in mica slate, at Tunaberg in Sweden, from which most of the crystallized specimens are brought; at Los and at Modum, in Norway; and likewise at Giern, in Silesia.   Colour silver white; sometimes tarnished grey. Massive, in various particular forms, and crystallized in cubes and octahedrons.   Surface of crystals smooth and splendent.   Internal lustre glistening, metallic.   Fracture foliated; cross fracture small conchoidal.   Fragments indeterminate, blunt-edged.   Sometimes in granular distinct concretions.   Semihard.   Brittle.   Easily frangible.   Specific gravity 6·4509.§   Streak grey.

Its constituents are as follows:

	‖	**	††
Cobalt	36·7	44·0	33·1012
Arsenic	49·0	55·5	43·4644
Iron	5·6	—	3·2324
Sulphur	6·5	0·5	20·0840
Loss	2·2	—	0.1180
	100	100	100·0000

GENUS II.   SULPHURETS.

Sp. 1.   Cobalt Pyrites.‡‡

This mineral occurs at New Bastnäs or St. Görans mine at Riddarhyttan, in Sweden, in a bed of gneiss, where it

* Ann. de Chim. lxxxv. 33.
+ Stromeyer, Annals of Philosophy, x. 228.
‡ Jameson, iii. 499.   § Haüy.
‖ Tassaert, Ann. de Chim. xxviii. 100.
** Klaproth, Beitrage, ii. 307.
++ Stromeyer, Annals of Philosophy, x. 228.
‡‡ Hisinger, Afhandlingar, iii. 316.

accompanies actinolite and copper pyrites. It had been repeatedly mentioned by Swedish mineralogical writers, though it was not admitted into modern systems of mineralogy. Colour light steel-grey. Massive and crystallized, but so confusedly that the figure of the crystals cannot be determined. Lustre shining and metallic. Fracture granular uneven. Semihard. Not attracted by the magnet. Before the blow-pipe emits a sulphurous smell and melts into a grey bead, which when pulverized is attracted by the magnet. Colours glass and borax smalt-blue. Its constituents are as follows:

Cobalt	43·20
Copper	14·40
Iron	3·53
Sulphur	38·50
Stony matter	0·33
Loss	0·04
	100·00 *

GENUS III. OXIDES.

Sp. 1. *Black Cobalt Ore.*†

This ore, which occurs in different parts of Germany, is either in the form of a powder or indurated. Hence it is divided into two subspecies.

Subsp. 1. *Earthy.*

Colour bluish-black; sometimes brownish-black. Composed of dull dusty particles, which soil very little; sometimes loose. Lustre of streak shining. Feels meagre. Light, almost swimming. Before the blow-pipe gives a white smoke, which has an arsenical smell, and colours borax blue.

Subsp. 2. *Indurated.*

Colour usually bluish-black. Massive, disseminated, and as a coating. External lustre scarce glimmering; internal dull. Fracture fine earthy. Fragments indeterminate, blunt-edged. Lustre of streak shining, resinous. Very soft. Rather sectile. Very easily frangible. Specific gravity 2·019 to 2·425.‡ Considered as pure oxide of cobalt, but has not been analysed.

* Hisinger, Afhandlingar, iii. 316.
† Kirwan, ii. 275. Brochant, ii. 396. Haüy, iv. 214. Jameson, iii. 503. ‡ Gellert.

Sp. 2. *Brown Cobalt Ochre.**

This ore seems peculiar to the floëtz mountains. It is found in Saxony and Spain. Colour liver-brown; sometimes passing into yellowish-brown, and into black. Massive and disseminated. Lustre dull. Fracture fine earthy. Fragments indeterminate, blunt-edged. Streak similar, but shining. Very soft. Sectile. Easily frangible. Light.

Sp. 3. *Yellow Cobalt Ochre.*†

This ore occurs in the same situation as the preceding, but is rarer. Colour dirty straw-yellow; sometimes passing into yellowish-grey. Massive. Internal lustre dull. Fracture fine earthy. Fragments indeterminate, blunt-edged. Streak shining. Soft, passing into friable. Sectile. Easily frangible. Specific gravity 2·677 after having absorbed water.

GENUS IV. SALTS.

Sp. 1. *Arseniate of Cobalt‡—Red Cobalt Ochre.*

This species, which accompanies several of the other ores of cobalt, has been divided into two subspecies.

Subsp. 1. *Cobalt Crust—Earthy Red Cobalt Ochre.*

Colour peach blossom red. Seldom massive; often in velvety coatings. Lustre glimmering or dull. Fracture fine earthy. Fragments indeterminate, blunt-edged. Scarcely soils. Streak shining. Very soft. Light.

Subsp. 2. *Cobalt Bloom—Radiated Red Cobalt Ochre.*

Colour peach blossom-red; often cochineal and crimson-red, pearl-grey, greenish-grey. Massive, disseminated, reniform, and crystallized in short needles, acute double six-sided pyramids, rectangular four-sided prisms. External lustre shining; internal glistening, pearly. Fracture radiated. Fragments splintery and wedge-shaped; sometimes in thin columnar distinct concretions, collected into coarse granular distinct concretions. Translucent. Streak similar. Soft. Not particularly brittle. Rather sectile. Easily frangible. Light.

Before the blow-pipe becomes grey, and emits a garlic smell, but without smoke. Tinges borax blue.

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* Jameson, iii. 507.   † Ibid. iii. 508.
  ‡ Klaproth, ii. 278. Brochant, ii. 403. Haüy, iv. 216. Jameson, iii. 510.

Its constituents according to the analysis of Bucholz are as follows:

Arsenic acid .... 37·9
Oxide of cobalt .... 39·2
Water .... 22·9
_____
100·0*

Sp. 2. *Sulphate of Cobalt.*†

This mineral has been found at Bieber near Hanau in Germany. For its description and analysis we are indebted to Kopp. Its colour is light flesh-red passing into rose-red. Its form is stalactitical. External lustre dull; sometimes though rarely it has a silky lustre. Fracture earthy. In granular distinct concretions. Opaque. Streak reddish white. Soft. Brittle. Easily frangible. Light. Has a styptic taste and is soluble in water. Its constituents are as follows:

Sulphuric acid .... 19·74
Oxide of cobalt ...... 38·71
Water .... 41·55
_____
100·00

It is obviously a compound of

Sulphuric acid .... 1 atom
Oxide of cobalt....... 2 atoms
Water .... 9 atoms

ORDER XV. ORES OF NICKEL.

Hitherto the ores of nickel have been found only in a small quantity, and always in veins. They occur both in primitive and floëtz mountains, and are usually accompanied by cobalt. Hitherto only three species of nickel ores have been recognised by mineralogists.

GENUS I. ALLOYS.

Sp. 1. *Native Nickel.*‡

This mineral has been hitherto found only in the mine named Adolphus at Johanngeorgenstadt in Saxony, and at Joachimsthal in Bohemia. Colour bronze-yellow; but frequently tarnished various shades of grey. In capillary crystals which are either promiscuous or scopeformly

* Gehlen's Journal, Second Series, ix. 314.
† Kopp, Gehlen's Jour. Second Series, vi. 157.
‡ Jameson, iii. 516.

aggregated. Externally shining or splendent, unless where tarnished. Internally splendent and metallic. Cross fracture even passing into very flat conchoidal. Opaque. Semihard, passing into soft. Intermediate between brittle and sectile. Very easily frangible. More or less elastic flexible.

It consists of nickel alloyed with a little cobalt and arsenic.*

Sp. 2. *Copper Nickel* †—*Kupfer Nickel.*

This, which is the most common ore of nickel, occurs either massive or disseminated, but never crystallized.

Colour copper-red. Internal lustre shining metallic. Fracture imperfect conchoidal; sometimes passing into coarse and small grained uneven. Fragments indeterminate, sharp-edged. Semihard. Brittle. Rather tough. Specific gravity 6·6086 to 6·6481. ‡ Before the blow-pipe exhales an arsenical smoke, and melts into a bead; which darkens by exposure to the air. This ore, when pure, is merely an alloy of nickel and arsenic; but it frequently contains cobalt and iron, and always a portion of pyrites.

GENUS II. OXIDES.

Sp. 1. *Nickel Ochre.*§

This mineral occurs almost always as a thin coating. Seldom massive.

Colour apple-green. Composed of dull dusty particles, which scarcely soil. Loose. Feels meagre. Specific gravity inconsiderable. Stains. Slowly dissolves in acids: solution green. Before the blow-pipe does not melt; but gives a hyacinth-red tinge to borax, and is reduced. Insoluble in nitric acid.

According to the analysis of Lampadius, it is composed of:

Oxide of nickel ...	67·0
Oxide of iron	23·2
Water	1·5
Loss	8·3
	100·0 ‖

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* Klaproth, Ann. de Chim. lxv. 186.

† Kirwan, ii. 286. Brochant, ii. 408. Haüy, iii. 503. Jameson, iii. 518.   ‡ Brisson.

§ Kirwan, ii. 284. Brochant, ii. 411. Haüy, iii. 516. Jameson, iii. 522.   ‖ Handbuch, p. 297.

ORDER XVI.   ORES OF MOLYBDENUM.

GENUS I.   SULPHURETS.

Sp. 1.   *Common Sulphuret* *—*Molybdena.*

This ore, which is the only species of molybdenum ore at present known, is found commonly massive; sometimes, however, it is crystallized in hexahedral tables and prisms. Its primitive form, according to Haüy, is a rhomboidal prism with angles of 60° and 120°.

Colour light lead-grey. Streak similar. Lustre splendent, metallic. Fracture perfect foliated. Lamellæ slightly flexible. Occurs in large and coarse granular distinct concretions. Soft. Easily Frangible. Splits easily. Sectile. Specific gravity 4·569 † to 4·7385.‡ Feels greasy; stains the fingers. Marks bluish-black. A piece of resin rubbed with this mineral becomes positively electric.§ Insoluble in sulphuric and muriatic acids; but in a boiling heat colours them green. Effervesces with warm nitric acid, leaving a grey oxide undissolved. Before the blow-pipe, on a silver spoon, emits a white smoke, which condenses into a white powder, which becomes blue in the internal, and loses its colour in the external flame. Scarcely affected by borax or microcosmic salt. Effervesces with soda, and gives it a reddish-pearl colour.

Composed of about 60 molybdenum
                    40 sulphur
                    ——————
                    100 ‖

ORDER XVII.   ORES OF TIN.

Tin ores are by no means numerous; but where they do occur they are usually abundant. In Europe only three tin districts are known: the first is in Germany, between Saxony and Bohemia; the second in Spain, in that part of Gallicia which borders on Portugal; and the third in Cornwall. In Asia, it abounds in Siam and the island of

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* Kirwan, ii. 322. Scheele's Works, i. 236. French Translation. Pelletier, Jour. de Phys. xxvii. 434. Ilsemann, ibid. xxxiii. 292. Sage, ibid. 389. Klaproth and Modeer, Ann. de Chim. iii. 120. Brochant, ii. 432. Haüy, iv. 289. Jameson, ii. 465.

† Karsten.   ‡ Brisson.
§ Haüy, Jour. de Min. xix. 70.
‖ Klaproth. This result agrees exactly with the analysis of this ore by Bucholz. See Gehlen's Jour. iv. 603.

Barka: it is said likewise to have been discovered in Chili. The ores are confined to the primitive mountains, or they occur in alluvial land, and have obviously been washed from primitive mountains. Few metals exhibit a smaller variety of states; since it has hitherto been found only in three, as may be seen from the following table:

I. SULPHURETS.
    1. Sulphuret of tin and copper.
II. OXIDES.
    1. Tin-stone.
    2. Wood-tin.

GENUS I.   SULPHURETS.

Sp. 1. *Tin Pyrites.**

Hitherto this ore has only been found in Cornwall. There is a vein of it in that county, in the parish of St. Agnes, nine feet wide and twenty yards beneath the surface.†

Colour between steel-grey and brass-yellow. Massive and disseminated. Internal lustre shining, metallic. Fracture usually uneven; sometimes conchoidal and imperfect foliated. Fragments blunt-edged. Easily frangible. Yields easily to the knife. Brittle. Specific gravity 4·35.‡ Before the blow-pipe it melts easily, with a sulphureous smell, into a black bead, and deposites a bluish oxide on the charcoal. The composition of this ore, as Klaproth informs us, was first discovered by Mr. Raspe. According to Klaproth's analysis, it is composed of

Consti-
tuents.

Tin	26·5
Copper	30
Sulphur	30·5
Iron	12
Loss	1

100·0§

GENUS II.   OXIDES.

Sp. 1. *Tin-stone.* ‖

This ore, which may be considered as almost the only ore of tin, occurs in masses, in rounded pieces, and crys-

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* Kirwan, ii. 200. Brochant, ii. 332. Haüy, iv. 154. Jameson, iii. 437. Ann de Chim. liii. 266.

† Klaproth's Cornwall, p. 21.   ‡ Klaproth.   § Beitrage, v. 230.

‖ Kirwan, ii. 197. Brochant, ii. 354. Haüy, iv. 137. Jameson, ii. 384.

tallized. These crystals are very irregular. Haüy supposes that their primitive form is a cube;* but Romé de Lisle, with more probability, makes it an octahedron;† and in this opinion Mr. Day agrees with him.‡ The octahedron is composed of two-four-sided pyramids applied base to base. The sides of the pyramids are isosceles triangles; the angle at the vertex of which is 70°, and each of the other angles 55°. The sides of the two pyramids are inclined to each other at an angle of. 90°.§ This primitive form, however, never occurs; but crystals of tin-stone are sometimes found, in which the two pyramids are separated by a prism. For a complete description of the varieties of the crystals of tin-stone, the reader may consult Romé de Lisle, Mr. Day,‖ and above all Mr. Phillips.**

Colour blackish-brown; sometimes passing into velvet-black and reddish-brown, yellowish-grey, green, yellowish and greenish-white. Streak greyish-white. Internal lustre shining, between resinous and adamantine. Fracture uneven, inclining to imperfect conchoidal. Very seldom foliated. Fragments blunt-edged; often in granular distinct concretions. Translucent and also opaque. Hard. Easily frangible. Brittle. Specific gravity 6·3 to 6·97. Before the blow-pipe it decrepitates, and on charcoal is partly reduced. Tinges borax white.

Sp. 2. *Wood Tin.* ††

This mineral has hitherto been found only in Cornwall and in Mexico. It occurs always in fragments, which are generally rounded. Colour hair-brown; passing into wood brown, yellowish-grey, reddish-brown. Streak yellowish-brown. Internal lustre shining, resinous. Opaque. Fracture fibrous. Fragments wedge-shaped and splintery. In granular distinct concretions. Specific gravity 6·450‡‡ to 6·738.§§ Hard. Before the blow-pipe becomes brownish-red; decrepitates when red-hot, but is not reduced. Dr.

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* Jour. de Min. xxxii. 576.   † Crystallog, iii. 413.
‡ Phil. Mag. iv. 152.   § Romé de Lisle, Phil. Mag. iv. 152.
‖ Romé de Lisle, Phil. Mag. iv. 152.
** Geological Transactions, vol. i.
†† Kirwan, ii. 198. Brochant, ii. 340. Haüy, iv. 147. Jameson, iii. 446.
‡‡ Klaproth.   §§ Humboldt.

Clarke fused it by means of the oxygen and hydrogen blow-pipe. It then acquires a decided metallic lustre; but is not reduced.

The following table exhibits the constituents of the preceding species, according to the result of the most accurate analyses hitherto made:

	Tin-stone.					Wood-tin.
	*	*	†	‡	§	‖
Oxide of tin	99	99·5	84	95	93·6	91
Oxide of tantalum ..	—	—	—	—	2·4	—
Oxide of iron	0·25	0·5	9	5	1·4	9
Oxide of manganese.	—	—	—	—	0·8	—
Silica	0·75	—	7	—	—	—
Loss	—	—	—	—	1·8	—
	100	100	100	100	100·0	100

ORDER XVIII.   ORES OF TITANIUM.

Hitherto titanium has been found almost exclusively in the primitive mountains, the Capracks,** the Alps,†† and the Pyrenees,‡‡ in Brittany,§§ and in Cornwall; or in alluvial sand. The following are the ores of this metal hitherto observed:

I. OXIDES.
  1. Pure.
    a. Ruthile.
    b. Anatase.
  2. Oxides of titanium and iron.

    a. Menachanite.
    b. Iserine.
    c. Nigrine.
II. SALTS.
  1. Silicate or Sphene.

* Klaproth, Beitrage, ii. 256.   + Lampadius, Handbuch, p. 280.
‡ Collet Descotils, Ann. de Chim. liii. 268.
§ Berzelius, Afhandlingar, iv. 164. The specimen occurs in grains in the rock at Finbo. Its colour is black and its specific gravity 6·55. the tantalites in that district contain tin, and the grains of tin-stone contain tantalum.
‖ Vauquelin, Gehlen's Jour. v. 251.
** Jour. de Min. No. xii. 51.
†† Dolomieu, ibid. No. xlii. 431, and Saussure, Voyages, No. 1894.
‡‡ Jour. de Min. No. xxxii. 614.   §§ Ibid.

GENUS I. OXIDES.

Sp. 1. *Rutile*—Red Schorl—Titanite* of Kirwan—*Sage-nite* of Saussure—*Nadelstein.*

This ore has been found in Hungary, the Pyrenees, the Alps, in Brittany, in France, and in Scotland. It is generally crystallized. The primitive form of its crystals, according to the observations of Haüy, is a rectangular prism, whose base is a square; and the form of its molecules is a triangular prism, whose base is a right-angled isosceles triangle; and the height is to any of the sides of the base about the right angle as $\sqrt{12}$ to $\sqrt{5}$, or nearly as 3 : 2.† Sometimes the crystals are six-sided, and sometimes four-sided prisms, and often they are implicated together. Sometimes acicular.

Colour dark blood-red, passing into light hyacinth and brownish-red. Crystals longitudinally streaked. External lustre shining; of principal fracture splendent; of cross fracture shining, adamantine. Principal fracture foliated; cross fracture imperfect small conchoidal. Fragments cubical. Translucent. Sometimes shows slender columnar distinct concretions. Hard. Brittle. Streak pale-yellow or orange yellow. Easily frangible. Specific gravity from 4·18‡ to 4·2499. § Not affected by the mineral acids. When fused with carbonate of potash, and diluted with water, a white powder precipitates, heavier than the one employed. Before the blow-pipe it does not melt, but becomes opaque and brown. With microcosmic salt it forms a globule of glass, which appears black; but its fragments are violet. With borax it forms a deep yellow glass with a tint of brown; with soda it divides and mixes, but does not form a transparent glass.

According to Klaproth it is pure oxide of titanium.‖ Vauquelin found in it traces of iron, manganese, and silica.**

Sp. 2. *Anatase* ††*—Octahedrite.*

This mineral has been hitherto found only in Dauphiny.

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* Brochant, ii. 470. Haüy, iv. 29. Kirw. ii. 329. Jameon, iii. 351.
† Jour. de Min. No. xv. 28, and xxxii. 615.   ‡ Klaproth.
§ Vauquelin and Hecht.   ‖ Beitrage, i. 233, and ii. 222.
** Jour. de Phys. lxvi. 345.
†† Haüy, iii. 129. Brochant, ii. 548. Jameson, iii. 355.

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Book III. It is always crystallized. The primitive form is an elongated octahedron, whose base is a square: the inclination of the two pyramids is 137°. The summits are sometimes complete and sometimes truncated. Colour from indigo-blue passes to reddish and yellowish-brown. Faces of the crystals transversely striated. Lustre splendent, adamantine. Fracture foliated. Translucent. Scratches glass. Brittle, easily broken. Specific gravity 3·8571.

By the analysis of Vauquelin it is pure oxide of titanium. The different crystalline figures of these two species, and the other differences in their external characters have not yet been accounted for by mineralogists. Probably they constitute two different oxides of titanium.

Sp. 3.   *Menachanite.**

This substance was found in the valley of Menachan in Cornwall; and hence was called *menachanite* by Mr. Gregor, the discoverer of it. It has been since observed in the Island Providence, in Botany Bay, and in the Mica-slate mountains, near Genoa.† It is in small grains like gun-powder of no determinate shape, and mixed with a fine grey sand. Colour greyish-black. Easily pulverised. Powder attracted by the magnet. Surface rough and glimmering. Internal lustre shining, adamantine; passing into semimetallic. Fracture imperfect foliated. Fragments indeterminate, sharp-edged. Opaque. Soft. Brittle. Streak similar. Specific gravity 4·427. With two parts of fixed alkali it melts into an olive-coloured mass, from which nitric acid precipitates a white powder. The mineral acids only extract from it a little iron. Diluted sulphuric acid mixed with the powder in such a proportion that the mass is not too liquid, and then evaporated to dryness, produces a blue-coloured mass. Before the blow-pipe does not decrepitate nor melt. It tinges microcosmic salt green; but the colour becomes brown on cooling; yet microcosmic salt does not dissolve it. Soluble in borax, and alters

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* Kirwan, ii. 326. Gregor, Jour. de Phys. xxxix. 72 and 152. Schmeisser, Crell's Annals, Eng. Trans. iii. 252. Brochant, ii. 468. Jameson, iii. 338.

† Viviani, Nicholson's Jour. xxvi. 94.

its nature in the same manner. Its constituents are as
follows:

	Menachanite.			
	*	†	‡	§
Oxide of titanium ..	45 ..	45·25 ..	43·5 ..	40
Oxide of iron	46 ..	51 ..	50·4 ..	49
Oxide of manganese	— ..	0·25 ..	0·9 ..	—
Silica	— ..	3·50 ..	3·3 ..	11
Alumina	— ..	— ..	1·4 ..	—
Loss	9 ..	— ..	0·5 ..	—
	100	100	100	100

Sp. 4. *Iserine.* ||

This mineral has been found in the sand of a small river
in Bohemia called *Iser*, and in the sand of the Don in
Aberdeenshire. It is in the state of small angular grains
and rolled pieces. Colour iron-black, bordering on brown.
Internal lustre glistening, semimetallic. Fracture con-
choidal. Opaque. Hard. Brittle. Streak similar. Spe-
cific gravity 4·5. Its constituents are as follows:

	**	††
Oxide of titanium ..	41·1	28
Oxide of iron	39·4	72
Silica	16·8	—
Alumina..........	3·2	—
Uranium oxide	3·4	—
	103·9	100

Sp. 5. *Nigrine.* ‡‡

This species, like menachanite, is found in the alluvial

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* Gregor, Jour. de Phys. xxxix. 73 and 152. Under the loss a
little silica and manganese are included.

† Klaproth, Beitrage, ii. 231. ‡ Lampadius, Handbuch, p. 322.

§ Chenevix, Nicholson's Quarto Jour. v. 132.

|| Brochant, ii. 478. Jameson, iii. 340.

** By my analysis, Trans. Edin. vi. 260. The specimen was from the
river Don, Aberdeenshire, and was not quite free from quartz and fel-
spar, and probably contained also a portion of iron-sand. For it was
originally mixed with iron-sand, which was separated by the magnet.

†† Klaproth, Beitrage, v. 208. ‡‡ Jameson, iii. 342.

formation. It occurs in Transylvania, Siberia, Ceylon, &c. Colour dark brownish-black, passing into velvet-black. In larger and smaller angular grains and rolled pieces. Lustre shining, adamantine. Principal fracture imperfect straight foliated; cross fracture flat imperfect conchoidal. Fragments indeterminate, sharp-edged. Opaque. Semihard. Brittle. Streak yellowish-brown. Specific gravity 4·445 to 4·673.* Not attracted by the magnet. Infusible before the blow-pipe. With borax melts into a hyacinth-red bead. Its constituents are as follows:

	†	‡	§	‖
Oxide of titanium	84	53	63	87
Oxide of iron	14	47	35	9
Oxide of mangan	2	—	2	3
	100	100	100	99

GENUS II. SALTS.

Sp. 1. *Silicate—Sphene---Sphene Ore***—Titanite---Rutilite ---Brown-Ore.*

This ore has hitherto been found only near Passau in Bavaria, and at Arendal in Norway, and near St. Gothard. It was discovered by Professor Hunger. It is sometimes disseminated, but more commonly crystallized in four-sided prisms, not longer than one-fourth of an inch. Primitive form a rhomboidal prism.

Colour reddish, yellowish, or blackish-brown. Streak and powder-grey. Lustre of crystals shining, of cross fracture glimmering, of longitudinal fracture glistening. Fracture scopi-form radiated; sometimes straight foliated. Cross fracture flat conchoidal. Fragments indeterminate; sometimes inclining to rhomboidal. Usually in coarse and longish granular distinct concretions. Translucent on the edges, or opaque. Hard. Brittle. Easily frangible.

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* Klaproth and Lowitz.   † Klaproth, Beitrage, i. 233, and ii. 222.
‡ Lowitz, Crell's Annals, 1799, i. 183.
§ Vauquelin and Hecht, Jour. de Min. No. xix. 57.
‖ Lampadius, Jameson, ii. 501.
** Kirwan, ii. 331. Brochant, ii. 474. Haüy, iv. 307. Jameson, iii. 345.

Specific gravity 3·510. Muriatic acid, by repeated digestion, dissolves one-third of it. Ammonia precipitates from this solution a clammy yellowish substance. Infusible by the blow-pipe, and also in a clay crucible; but in charcoal is converted into a black opaque porous slag. Its constituents are as follows:

	*	†	‡
Oxide of titanium ..	33 ..	58 ..	46
Silica	35 ..	22 ..	36
Lime	33 ..	20 ..	16
Water.............	— ..	— ..	1
Loss	— ..	— ..	1
	101	100	100

ORDER XIX. ORES OF ZINC.

Though the ores of zinc are very few in number, they are by no means scarce. Blende, the most abundant of them, occurs most frequently in transition rocks, though sometimes also it is found in primitive and floetz rocks, and is almost always accompanied by Galena. Calamine, the other principal ore of zinc, seems to be nearly confined to floetz rocks; and it occurs most frequently in beds in a particular lime-stone.

The following table exhibits the different states in which this metal has hitherto occurred:

I. Sulphurets.
  1. Blende.
II. Oxides.
  1. Red zinc-ore.
III. Salts.
  1. Silicate.
  2. Anhydrous carbonate.
  3. Hydrous carbonate.
  4. Sulphate.

GENUS I. SULPHURETS.

Sp. 1. *Blende §—Black Jack.*

This ore is common. It occurs both in amorphous masses and crystallized. The primitive form of its crystals

* Klaproth, Beitrage, i. 251.   † Abelgaard, Haüy, iv. 308.
‡ Klaproth, Beitrage, v. 244.
§ Kirwan, ii. 238. Berg. ii. 429. Brochant, ii. 350. Haüy, iv. 167. Jameson, iii. 426.

is the rhomboidal dodecahedron. The figure of its integrant particles is the tetrahedron.*

The principal varieties of its crystals are the tetrahedron; the octahedron; the octahedron with its edges wanting; a 24-sided crystal, 12 of whose faces are trapezoids, and 12 elongated triangles; and, lastly, a 28-sided figure, which is the last variety, augmented by four equilateral triangles.† It is divided into three subspecies, which characterize different formations. The yellow is the oldest, the black newest, and the brown intermediate.

Subsp. 1. *Yellow Blende.*

Colour dark wax-yellow and sulphur-yellow, passing into asparagus and olive-green, and into hyacinth, aurora, and brownish-red. All the colours incline somewhat to green. Massive and crystallized in four-sided prisms. Surface smooth. Lustre shining, adamantine. Fracture straight foliated, cleavage sixfold; cross fracture conchoidal. Fragments dodecahedral; but seldom perfect. In granular distinct concretions. Translucent. Refraction single. Streak yellowish-grey. Semihard. Brittle. Very easily frangible. Specific gravity 4·044 to 4·067. Often phosphoresces when scraped or rubbed.‡

Subsp. 2. *Brown Blende.*

Of this there are two varieties; the *foliated* and the *fibrous.*

Foliated. Colour reddish and yellowish-brown; passes into hyacinth-red, and into blackish-brown. Massive; and crystallized in tetrahedrons, octahedrons, rhomboidal dodecahedrons, and octahedrons with an intermediate four-sided prism. External lustre shining; internal from splendent to glimmering, between resinous and adamantine. Fracture foliated; cleavage six-fold. In granular distinct concretions. Translucent. Streak yellowish-grey and yellowish-brown. Semihard. Brittle. Easily frangible. Specific gravity from 3·77 to 4·049.§

* Haüy, Jour. de Min. No. xxxiii. 669.
† See Haüy, ibid. and Romé de Lisle, iii. 65.   ‡ Bergman.
§ The specimen with this last specific gravity was from Huel Anne, in Cornwall. It was it that I analysed.

Fibrous. Hitherto found only at Geroldseck in the Breisgau. Colour reddish-brown. Massive and reniform. Lustre glistening. Fracture fibrous. In granular distinct concretions, intersected by curved lamellar distinct concretions. Opaque. In other respects agrees with the preceding.

Subsp. 3. *Black Blende.*

Colour between greyish and velvet-black, sometimes brownish-black; when held between the eye and the light, appears blood-red if transparent. Massive and crystallized. Internal lustre shining, metallic. Fracture foliated; cleavage six-fold, but very indistinct. Fragments indeterminate, pretty sharp-edged. In granular distinct concretions. Mostly opaque. Streak between yellowish-grey and light yellowish-brown. Semihard. Brittle. Easily frangible. Specific gravity 3·967 to 4·166.

Blende is essentially a sulphuret of zinc. The yellow subspecies I conceive to be pure; the brown and black subspecies contain more or less oxide of iron. I analysed a specimen of brown blende from Cornwall with great care. The following table exhibits the result:

$$\begin{aligned}
&\text{Zinc} \ldots \ldots \ 59\text{·}09\\
&\text{Sulphur} \ldots \ 28\text{·}86\\
&\text{Iron} \ldots \ldots \ 12\text{·}05\\
&\overline{\hphantom{\text{Sulphur}} 100\text{·}00 \ *}
\end{aligned}$$

GENUS II. OXIDES.

Sp. 1. *Red Zinc Ore.* †

This mineral occurs in abundance in some of the iron mines in Sussex county, New Jersey. It was first discovered and described by Dr. Bruce. Colours blood-red, and aurora-red. Massive and disseminated. Fresh fracture shining; but becomes dull by exposure to the air. Principal fracture foliated, cross fracture conchoidal. Translucent on the edges or opaque. Easily scratched by the knife. Brittle. Streak brownish-yellow. Specific gravity 6·220. Soluble in mineral acids. Does not fuse

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* Annals of Philosophy, iv. 94.　　　† Jameson, iii. 416.

Book III. before the blow-pipe. Its constituents according to Dr. Bruce are:

Zinc 76
Oxygen 16
Oxides of manganese and iron 8
————
100

GENUS III. SALTS.

Sp. 1. *Silicate—Electric Calamine.*

This species, first properly distinguished by Mr. Smithson, occurs in different British mines along with ores of lead. Colour bluish, greyish, and yellowish-white. Massive, and crystallized.   The primitive form of its crytals appears, from the mechanical division of one of them by Mr. Haüy, to be an octahedron composed of two four-sided pyramids, whose sides are equilateral triangles.*   But the crystals are minute, and their figure not very distinct.   They are either four or six-sided tables with bevelled edges, six-sided prisms, or three-sided pyramids.   Colour usually greyish-white. Fracture radiated or foliated. Lustre vitreous. Specific gravity 3·434. Before the blow-pipe decrepitates and shines with a green-light. Gelatinizes in acids.   Becomes electric when heated.   A specimen of this mineral, from Regbania in Hungary, yielded Mr. Smithson

Oxide of zinc 68·3
Silica ...... 25·0
Water   .... 4·4
————
97·7

Another specimen, analysed by Klaproth, contained

Oxide of zinc 66
Silica 33
——
99

From Mr. Smithson's analysis it appears to be a compound of 1 atom silica, and 1 atom oxide of zinc.

Sp. 2. *Anhydrous Carbonate—Calamine.*

Bergman first announced that many calamines are car-

* Jour. de Min. No. xxxii. 596.

bonates of zinc. The experiments of that chemist and of Dr. Watson * demonstrate, that most of the calamines of this country are in that state; and this has been confirmed by the late experiments of Mr. Smithson.

The carbonate of zinc occurs both massive and in crystals; but their form has not yet been ascertained with precision, though they seem to be rhomboids. Colour brownish or yellowish-white. Internal lustre shining, pearly. Fracture foliated or radiated. Semi-transparent and opaque. Easily scratched by the knife. Specific gravity, as determined by Smithson, 4·334. Soluble in sulphuric acid with effervescence. Does not gelatinize with acids. Mr. Smithson found a specimen from Somersetshire of a mamellated form, composed of

<div align="center">

Oxide of zinc   64·8
Carbonic acid   35·2
———
100·0

</div>

And a specimen in small crystals from Derbyshire contained

<div align="center">

Oxide of zinc   65·2
Carbonic acid 34·8
———
100·0

</div>

Sp. 3.   *Hydrous Carbonate—Earthy Calamine.*

This species is distinguished from the last by its low specific gravity, in which it nearly agrees with silicated oxide of zinc. Opaque. Yields to the nail. Adheres to the tongue. The specimen examined by Mr. Smithson was from Bleyberg in Saxony. Its colour was white, and its form stalactitical. Specific gravity 3·584. Before the blowpipe it became yellow; and when exposed to the heat of the blue flame was gradually dissipated. Dissolved with effervescence in sulphuric acid; and when heated lost about ¼th of its weight.   It yielded

<div align="center">

Oxide of zinc .... 71·4
Carbonic acid . .. 13·5
Water .... 15·1
———
100 †

</div>

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* Chemical Essays, iv. 10.   † See Phil. Trans. 1803.

<div align="center">5</div>

Sp. 4. *Sulphate of Zinc.*

This salt is usually in a state of solution, and therefore belongs properly to mineral waters. Its properties have been described in the first part of this work.

ORDER XX.   ORES OF BISMUTH.

Bismuth occurs usually in veins in primitive rocks. It is said also to have been observed disseminated in wacka. It is usually accompanied by the ores of cobalt. Its ores are not abundant. They exist in much greater quantity in Saxony than in any other country; but they are found likewise in Sweden, France, and Cornwall. The following table will serve to show how little diversified are the ores of this metal.

I. ALLOYS.
    1. Native bismuth.

II. SULPHURETS.
    1. Common.
    2. Plumbo-cupriferous sulphuret.
    3. Cupriferous sulphuret.

III. OXIDES.
    1. Bismuth ochre.

Bismuth, like gold, platinum, and silver, occurs most commonly in the state of metal.

GENUS I.   ALLOYS.

Sp. 1. *Native Bismuth.*

This mineral, which is found at Schneeberg, Johangeorgenstadt, &c. in Germany, has commonly the form of small plates lying above one another. Sometimes it is crystallized in four-sided tables, indistinct cubes, and truncated tetrahedrons. Its primitive form is the regular octahedron.

Colour silver white, inclining to red; surface often tarnished red, yellow, or purple. Internal lustre splendent, metallic. Fracture perfect foliated. Fragments, indeterminate, bluntedged. In granular distinct concretions. Soft. Sectile. Opaque. Easily frangible. Specific gravity 9·022 † to

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* Kirwan, ii. 264. Brochant, ii. 343. Haüy, iv. 184. Jameson, iii. 449.   † Brisson.

3·57. * Exceedingly fusible. Before the blow-pipe gives a silvery-white bead, and at last evaporates in a yellowish-white smoke, which is deposited on the charcoal.

GENUS II. SULPHURETS.

Sp. 1. *Common Sulphuret.* †

This ore, which is found in Sweden, Saxony, and Bohemia, occurs sometimes in amorphous masses, and sometimes in needle-form crystals.

Colour light lead-grey. Powder black and shining. Internal lustre of the foliated splendent; of the radiated shining, metallic. Streak obscurely metallic. Fracture foliated; sometimes radiated. The foliated in granular distinct concretions. Soils. Soft. Brittle. Easily frangible. Specific gravity 6·131 ‡ to 6·4672. When held to the flame of a candle, it melts with a blue flame and sulphureous smell. Before the blow-pipe emits a reddish-yellow smoke, which adheres to the charcoal. This powder becomes white when it cools, and resumes its former colour when the flame is directed upon it. ‖

Its constituents according to the analysis of Sage are as follows:

Bismuth 60
Sulphur 40
———
100

Sp. 2. *Needle Ore.* **

This mineral occurs in the mines of Pyschminskoi and Klintzefskoi, near Beresof, in the district of Catherinenburg in Siberia, and was first described and analized by Karsten and John. Colour steel-grey, with a pale copper-red tarnish. Massive and crystalized in oblique four or six-sided prisms, in which the lateral faces are deep longitudinally streaked. The crystals are long and frequently acicular. Principal fracture foliated; cross fracture small

* Kirwan.
† Kirwan, ii. 266. Sage, Mem. Par. 1782, p. 307. Brochant, ii. 346. Haüy, iv. 190. Jameson, iii. 452.
‡ Kirwan. § Brisson.
‖ Gillet, Jour. de Min. No. xxxii. 585.
** Karsten and John, Gehlen's Journal, Second Series, v. 227.

grained uneven. Foliated fracture splendent; cross fracture shining. Opaque. Easily scratched by the knife. Specific gravity 6·125. Its constituents, according to the analysis of John, are as follows:

Bismuth	43·20
Lead	24·32
Copper	12·10
Nickel?	1·58
Tellurium?	1·32
Sulphur	11·58
Loss	5·90
	100·00

Sp. 3. *Cupreous Sulphuret.**

This ore was discovered by Selb in a cobalt mine in Furstenberg, where it composes a vein about a yard wide. Colour lead-grey, but by exposure to the air it acquires a reddish or bluish tarnish. Massive. Lustre shining metallic. Fracture small-grained uneven. Gives a dull blackish streak. Soft. Sectile. Heavy.

Its constituents are as follows:

Bismuth	47·24
Sulphur	12·58
Copper	34·66
Loss	5·52
	100·00†

GENUS III. OXIDES.

Sp. 1. *Bismuth Ochre.‡*

This ore is extremely rare. It has been observed at Schneeberg and in Bohemia. It is usually disseminated, or at the surface of other minerals. Colour straw-yellow; sometimes passing into light yellowish-grey and ash-grey. Fracture fine-grained uneven; passing into foliated, and into earthy. Lustre of the fine-grained uneven; glimmering; of the foliated shining; of the earthy dull, adamantine.

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* Klaproth, Gehlen's Jour. ii. 187, and Beitrage, iv. 91.
† Klaproth, Gehlen's Jour. ii. 191.
‡ Kirwan, ii. 265. Brochant, ii. 348. Jameson, iii. 458.

Opaque. Soft; verging on friable. Not very brittle. Easily frangible. Specific gravity 4·3711. Easily reduced and volatilized by the blow-pipe on charcoal. Dissolves in acids with effervescence. Its constituents, according to the analysis of Lampadius, are as follows:

Oxide of bismuth .. 86·3
Oxide of iron .... 5·2
Carbonic acid .... 4·1
Water.......... 3·4
—————
99·0 *

ORDER XXI.   ORES OF LEAD.

Ores of lead occur in great abundance in almost every part of the world. They are generally in veins, but sometimes in beds; and they occur both in the primitive, transition, and floetz formations.

The following table exhibits a view of the different states in which this mineral has hitherto been observed:

I. SULPHURETS.
   1. Galena.
   2. Blue lead ore.
   3. Antimonial sulphuret.
II. OXIDES.
   1. Yellow oxide.
   2. Native minium.
III. SALTS.
   1. Carbonate.
      a White lead ore.
      b Earthy lead ore.
      c Black lead ore.
   2. Muriocarbonate.
   3. Phosphate.
   4. Arsenio-phophate.
   5. Chromate.
   6. Sulphate.
   7. Molybdate.
   8. Arseniate.

Of these the first species is by far the most common. From it indeed almost the whole of the lead of commerce is extracted. More lead is smelted in Northumberland, Cumberland, Durham, and Yorkshire, than in all the rest of Europe.

GENUS I.   SULPHURETS.

Sp. 1.   *Galena.*†

This ore is divided into two subspecies.

* Handbuch, p. 287.
† Kirwan, ii. 216. Brochant, ii. 295. Haüy, iii. 456. Jameson, ii. 346.

Subsp. 1. *Common Galena.*

This ore, which is very common, is found both in masses and crystallized. The primitive form of its crystals is a cube. The most common varieties are the cube, sometimes with its angles wanting, and the octahedron, composed of two four-sided pyramids applied base to base. The summits of these pyramids ars sometimes cuneiform, and sometimes their solid angles are wanting.* It occurs also in four and six-sided prisms terminated by four-sided pyramids, and in three-sided tables.

Colour lead-grey. Streak similar, but brighter. External lustre splendent; internal splendent to glistening, metallic. Fracture foliated; cleavage threefold and rectangular. Fragments cubic. The massive varieties are in granular distinct concretions. Soft. Sectile. Very easily frangible. Specific gravity 7·22 to 7·786.† Before the blow-pipe decrepitates, and melts with a sulphureous smell; part sinks into the charcoal. It generally contains some silver.

Subsp. 2. *Compact Galena.*

Found massive; sometimes in specular plates. Colour lead-grey. Internal lustre glimmering, metallic. Fracture even. Never in distinct concretions. Softer than common galena. Streak brighter. Fragments indeterminate. In other respects agrees with the preceding.

Pure galena is a sulphuret of lead quite free from every other substance. The easiest mode of analysis is to convert it into sulphate of lead by means of nitric acid.

Sp. 2. *Blue Lead Ore.*‡

This ore has hitherto been observed only at Zschoppau, in Saxony, and Huelgöet, in France. Occurs massive, and crystallized in small six-sided prisms. Colour between indigo-blue and lead-grey. Internal lustre glimmering, metallic. Streak brighter. Fracture even. Fragments indeterminate. Soft. Sectile. Easily frangible. Specific gravity 5·461.§ Before the blow-pipe melts with a low

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* Romé de Lisle, iii. 364. Haüy, iii. 458.
† Watson. I found a specimen of the specific gravity 7·602.
‡ Kirwan, ii. 220. Brochant, ii. 503. Jameson, iii. 370.
§ Gellert.

blue flame and a sulphureous smell, and is easily reduced. It has not been analysed. Its crystals resemble those of phosphate of lead; but its component parts seem to be the same as those of galena.

Sp. 3. *Antimonial Sulphuret* *—*Bournonite.*

This rare ore was first obtained from Cornwall, and was neglected by mineralogists, till accurately described and analysed by Bournon and Hatchett, in 1804. Various specimens have been since analysed by Klaproth.

Colour dark lead-grey, inclining to black. Massive, and crystallized in four-sided rectangular prisms, variously truncated. All the varieties have been described and figured by Bournon with his usual precision. Crystals large; surface splendent. Internal lustre glistening, resinous. Fracture coarse-grained uneven. Scratches calcareous spar, but not fluor spar. Sectile. Easily frangible. Leaves a black trace upon paper, but not so readily as lead or sulphuret of antimony. Specific gravity 5·765. When thrown in powder on a hot iron, emits a phosphorescent light of a bluish-white colour, but without any smell. When suddenly heated by the blow-pipe, it crackles and splits; but when gradually heated it melts, and on cooling assumes a metallic-grey colour.

The following table exhibits a view of the constituents of the preceding species, according to the most recent analyses:

* Bournon and Hatchett, Phil. Trans. 1804. Klaproth, Gehlen's Jour. v. 31. Jameson, iii. 372.

	Galena							Antimonial Sulphuret			
	*	*	*	*	*	†	‡	§	‖	**	††
Lead	54	69	69	68	64	83·00	85·13	42·62	42·5	34·5	39
Antimony	—	—	—	—	—	—	—	24·23	19·75	16	28·5
Copper	—	—	—	—	—	—	—	12·8	11·75	16·25	13·5
Silver	—	—	—	—	—	0·08	0·5	—	—	2·25	—
Iron	—	—	—	—	—	—	—	1·2	5	13·75	1
Sulphur	8	16	18	16	18	16·41	13·02	17	18	13·5	16
Lime and silica	38	15	13	16	18	—	—	2·15	3	2·5	—
Loss	—	—	—	—	—	0·51	1·35	—	—	1·25	2
	100	100	100	100	100	100	100	100	100	100	100

* Vauquelin, Jour. de Min. No. ix. p. 69.   † Westrumb, Jameson's Min. ii. 35.   ‡ By my analysis.
§ Hatchett, Phil. Trans. 1804.   ‖ Klaproth, Gehlen's Jour. v. 34.   The specimen from Alten Segen in Clausthal.
** From St. Andreasberg, Klaproth, Beitrage, iv. 86.
†† From Nanslo in Cornwall, ibid. p. 87.

GENUS II.   OXIDES.

Sp. 1.   *Yellow Oxide.*‡‡

This very rare mineral was described and analysed by Dr. John, from a specimen with which he was presented,

‡‡ John, Schweigger's Jour. iv. 222.

though he could not learn the place where it had been found. Colour intermediate between sulphur and lemon-yellow. Massive. Fracture in one direction earthy, in another foliated, with a three-fold cleavage. External lustre dull; internal semimetallic. Opaque. Semihard. Brittle. Easily frangible. Does not soil. Streak lighter coloured. Specific gravity 8·000. Melts easily before the blow-pipe. Its constituents, according to the analysis of John, are

Lead	82·6923
Oxygen	10·5768
Carbonic acid	3·8462
Oxide of iron and lime . .	0·4808
Copper	Trace
Ferruginous silica	2·4039
	100·0000

Sp. 2. *Native Minium.**

This ore was discovered by Mr. Smithson in Germany, disseminated in small quantity in a compact carbonate of zinc. It has been observed also in England. In general it was in a pulverulent state, but in places showed to a lens a flaky and crystalline texture. Its colour is the same as that of factitious minium, a vivid red mixed with yellow. It possesses the chemical characters of red oxide of lead, and must of course be considered as the same substance.

According to Mr. Smithson, it is produced by the decay of a galena, which he suspects to be itself a secondary production, from the metallization of white carbonate of lead by sulphureted hydrogen gas.

GENUS III. SALTS.

Sp. 1. *Carbonate of Lead†—White Lead Ore.*

This is the most generally diffused lead ore after galena, though it seldom occurs in any considerable quantity together. Colour snow, greyish, and yellowish-white; yellowish-grey; cream-yellow; clove-brown. Massive and

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* Smithson, Phil. Trans. 1806.

† Kirwan, ii. 203. Klaproth, iii. 167. Haüy, iii. 475. Brochant, ii. 309. Jameson, iii. 376.

disseminated, but most commonly crystallized. Primitive form the rectangular octahedron: But it occurs most frequently crystallized in six-sided prisms, terminated by six or four-sided summits; in four-sided prisms; and four and six-sided tables, often variously bevelled. Crystals usually small. Lustre splendent to glistening, adamantine. Fracture commonly small conchoidal; sometimes passes into fine-grained uneven. Fragments indeterminate. Transparent and translucent. Refracts doubly very strongly. Soft. Brittle. Easily frangible. Specific gravity 7·2357.* Before the blow-pipe decrepitates; becomes red, then yellow, and at last is reduced to a globule of lead.

Sp. 2.   *Earthy Lead Ore.*†

Of this ore there are two subspecies, the *indurated* and *friable*.

Subsp. 1.   *Indurated.*

Most frequent colour yellowish-grey; passes into straw-yellow, greenish-grey, sisken and apple green, and into yellowish-brown. Massive. Internal lustre glistening, resinous. Fracture fine-grained uneven; passing into splintery and earthy. Opaque. Streak brown. Soft. Inclining to sectile. Easily frangible. Specific gravity 5·579.

Subsp. 2.   *Friable.*

Colour yellowish-grey and straw-yellow. Friable; sometimes massive, and as a coating. Composed of dull dusty particles. Meagre and rough. Heavy.

Sp. 3.   *Black Lead Ore.*‡

This ore often accompanies white lead ore and galena. Colour greyish-black. Massive, and crystallized in six-sided prisms. External lustre shining; internal glistening, adamantine. Fracture small grained uneven. Translucent and opaque. Streak greyish white. Rather brittle. Easily frangible. Heavy.

The constituents of these three species are as follows:

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* Bournon, Nicholson's Jour. iv. 220.
† Kirwan, ii. 205. Brochant, ii. 327. Jameson, iii. 382.
‡ Kirwan, ii. 221. Brochant, ii. 307. Jameson, iii. 390.

	Carbonate.			Earthy Lead Ore.	Black Lead Ore.
	*	*	†	‡	§
Oxide of lead	81·2	80·25	82	66·00	78·5
Carbonic acid	16	16	16	12·00	18
Oxide of iron	0·3	0·18	—	2·25	—
Silica..............	—	—	—	10·50	—
Alumina	—	0·75	—	4·75	—
Lime	0·9	0·5	—	—	—
Charcoal	—	—	—	—	1·5
Water	—	—	—	2·25	2
Loss	1·6	2·32	2	2·25	—
	100	100	100	100·00	100

Sp. 4. *Murio-carbonate of Lead.*

For the first description of this ore which has hitherto been observed in Derbyshire, in Germany, and in America, we are indebted to the Count de Bournon. The primitive form of its crystals is the cube, often lengthened, and the edges or the angles not unfrequently truncated, and replaced by small planes. Colour usually a light straw-yellow ; sometimes a clear transparent white, with a lustre far surpassing common carbonate of lead. Internal lustre splendent, adamantine. Principal fracture foliated; cross fracture conchoidal. Semitransparent. Streak snow-white and dull. Sectile. Scratched by carbonate of lead. Specific gravity 6·0651. ‖

Its constituents are as follows:

	**	††
Oxide of lead	85	85·5
Carbonic acid	6	6
Muriatic acid	8	8·5
Loss	1	—
	100	100

* Westrumb.   † Klaproth, Beitrage, iii. 167.
‡ John, Chem. Unter. ii. 299.
§ Lampadius, Handbuch, p. 275.
‖ Bournon, Nicholson's Jour. iv. 220.
** Chenevix, Nicholson's Jour. iv. 220.
†† Klaproth, Beitrage, iii. 141.

Sp. 5.   *Phosphate of Lead.* *

There are two varieties of this ore, distinguished chiefly
by their colour; namely, the *brown* and *green lead ore.*
We may consider them as subspecies.   The primitive form
of its crystals is a dodecahedron, consisting of two six-sided
pyramids, the sides of which are isosceles triangles. †   The
crystals are usually six-sided prisms, sometimes terminated
by six-sided summits.   The summits are sometimes trun-
cated, as are also the edges of the prism.

Subsp. 1.   *Brown Phosphate—Brown Lead Ore.*

Colour hair-brown of different degrees of intensity.
Massive, and crystallized in six-sided prisms.   Internal
lustre glistening, resinous.   Fracture small and fine grained
uneven.   Fragments indeterminate.   Crystallized varieties
show a tendency to thin columnar distinct concretions.
Translucent.   Soft.   Brittle.   Easily frangible.   Specific
gravity from 6·600 to 6·909. ‡

Subsp. 2.   *Green Phosphate—Green Lead Ore.*

Colour grass-green, which passes to sulphur-yellow and
to greenish-white.   Seldom massive; usually crystallized in
six-sided prisms, often variously truncated.   Crystals small.
Externally smooth and shining.   Internal lustre glistening,
resinous.   In other respects it agrees with the preceding.

Before the blow-pipe this ore melts without being re-
duced, and on cooling assumes a polygonal form.   The
yellow varieties become green when heated.

Its constituents are as follows :

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* Kirwan, ii. 207.   Klaproth, iii. 146.   Haüy, iii. 490.   Brochant,
ii. 314.   Jameson, iii. 394.

† Romé de Lisle, iii. 391.   See also Haüy's remarks on the same sub-
ject, in Jour. de Min. No. xxxi. 506, and Min. iii. 491.

‡ Klaproth and Haüy.

	Phosphate.				
	*	*	*	*	†
Oxide of lead ..	78·58	78·4	77·1	80	79
Muriatic acid ..	1·65	1·7	1·54	1·62	—
Phosphoric	19·73	18·37	19	18	18
Oxide of iron ..	—	0·1	0·1	Trace	1
Water	—	—	—	—	2
Loss	04	1·43	2·26	0·38	—
	100	100	100	100	100

Sp. 6. *Arsenio-phosphate of Lead.* ‡

This mineral has been found in Auvergne, Brittany, Germany, and Spain. Colour reddish-brown or pistachio-green, with a yellowish-grey crust. Occurs in botryoidal pieces. External lustre dull, internal from glimmering to shining, pearly or adamantine. Fracture passes from fibrous to radiated. In concentric lamellar distinct concretions. Opaque. Streak lighter. Soft. Rather sectile. Specific gravity 6·5. Its constituents are as follows:

Phosphoric acid .. 13
Arsenic acid 7
Muriatic acid .... 1·75
Oxide of lead .... 76·00
Water .... 1·75
Loss 50

100·00 §

Sp. 7. *Chromate of Lead* ||—*Red Lead Ore of Siberia.*

This mineral which has now become scarce, is found in the gold mines of Beresof near Ekaterinbourg in Siberia,

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* Klaproth, Beitrage, iii. 146. † Fourcroy.
‡ Jameson, iii. 401. § Klaproth, Beitrage, v. 204.
|| Kirwan, ii. 214. Brochant, ii. 318. Haüy, iii. 467. Jameson, iii. 410.

crystallized in four-sided prisms, sometimes terminated by four-sided pyramids, sometimes not.

Colour hyacinth-red. Streak and powder lemon-yellow. Lustre splendent, between adamantine and resinous. Fracture foliated. Fragments indeterminate, blunt-edged. Transparent to translucent. Soft. Specific gravity 6·0269 * to 5·75. † Does not effervesce with acids. Before the blow-pipe decrepitates; some lead is reduced, and the mineral is converted to a black slag, which tinges borax green.

A brown ore of lead from Zimapan in Mexico, brought to Europe by Humboldt, was found by Descotils to be a compound of chromic acid and oxide of lead; but the proportion of acid was considerably smaller than in the red lead ore. This ore seems to constitute a species apart, but no description of it has been published. ‡

The constituents of these minerals are as follows:

	Chromate.		Brown Chromate.
	§	‖	**
Oxide of lead ..	65·12	64	74·2
Muriatic acid ..	—	—	1·5
Chromic	34·88	36	16
Oxide of iron ..	—	—	3·5
Loss	—	—	4·8
	100	100	100

Sp. 8.   *Sulphate of Lead.* ††

This ore, which is found in Anglesey, in the Leadhills in Scotland, in Andalusia, and in Germany, is generally crystallized. The primitive form of its crystals is a rectangular octahedron, with obtuse pyramids. The pyramids are often variously truncated. Colour yellowish-grey and yellowish-white; sometimes passes into smoke and ash grey. External lustre shining; internal splendent, adamantine. Frac-

* Brisson.   † Bindheim.   ‡ Ann. de Chim. lviii. 268.
§ Vauquelin, Jour. de Min. No. xxxiv. p. 760.   ‖ Thenard.
** Collet Descotils, Ann. de Chim. liii. 271.
†† Kirwan, Min. ii. 211.   Klaproth, iii. 162.   Haüy, iii. 513.   Brochant, ii. 325.   Jameson, iii. 403.   Schweigger's Jour. viii. 49.

ture compact. Transparent and translucent. Scratched by the nail. Brittle. Specific gravity 6·3. Immediately reduced before the blow-pipe. Its constituents are as follows:

Sulphuric acid	24·8	25·75	26·0191	25
Oxide of lead	71·0	70·50	72·9146	69·5
Oxide of iron.	1·	—	0·1151	—
Oxide of manganese	—	—	0·1654	—
Silica and alumina .	—	—	Trace	—
Water............	2·	2·25	0.1242	1·5
Loss.............	1·2	1·50	·0·6616	4
	100 *	100·00 *	100 †	100 ‡

Sp. 9. *Molybdate of Lead.*§

This ore, which is found in Carinthia, was first mentioned in 1781 by Mr. Jacquin. || It occurs sometimes massive, but usually crystallized in cubic, or rhomboidal, or octahedral plates. The primitive form of its crystals is an octahedron with isosceles triangular faces; the incidence of a face of one pyramid on that of another 76° 40′. **

Its colour is wax-yellow. External lustre shining; internal glistening, resinous. Fracture small grained uneven, passes into imperfect small conchoidal. Fragments sharp-edged. Translucent. Between brittle and sectile. Easily frangible. Soft. Specific gravity 5·486; †† when purified from its gangue by nitric acid, 5·706. ‡‡ Soluble in fixed alkalies and in nitric acid. Communicates a blue colour to hot sulphuric acid. Soluble in muriatic acid, and decomposed by it. Before the blow-pipe decrepitates, melts into a yellowish-grey mass, and globules of lead are reduced. §§

Its constituents are as follows:

* Klaproth, Beitrage, iii. 162.
† Stromeyer, as quoted by Jameson, iii. 406.
‡ Jordan, Schweigger's Jour. viii. 52.
§ Kirwan, ii. 212. Klaproth, Ann de Chim. viii. 103. Hatchett, Phil. Trans. 1796, p. 285. Haüy, iii. 498. Brochant, ii. 322. Jameson, iii. 407. || In his Miscellanea Austriaca, ii. 139.
** Haüy. †† Macquart. ‡‡ Hatchett. §§ Macquart.

	*	†
Oxide of lead	64·42	58.4
Molybdic acid	34·25	38
Oxide of iron	—	3·08
Silica	—	0·28
Loss	1·33	1·24
	100	100

Sp. 10.   *Arseniate of Lead.* ‡

This ore, which was first found at Johann-Georgenstadt, was at first confounded with the preceding, till the analysis of Rose showed that it contained no molybdic acid.

Beautiful specimens of it have been found in Huel Unity Mine, about two miles east of Redruth in Cornwall, where it occurs in large six-sided prisms and in capillary crystals. It is said to occur sometimes in double six-sided pyramids applied base to base. Colour wax-yellow. External lustre splendent, adamantine; internal shining, resinous. Principal fracture of the crystals foliated, cross fracture fibrous. Translucent. Soft. Sectile. Specific gravity 7·2612. Its constituents are as follows :

Oxide of lead	69·76
Arsenic acid	26·40
Muriatic acid	1·58
Loss	2·26
	100·00 §

ORDER XXII.   ORES OF ANTIMONY.

The ores of antimony occur almost always in veins, and affect the primitive and transition mountains. By far the most abundant, and the only ore wrought for metallurgic purposes, is the sulphuret. Antimony ores occur in considerable quantities in different parts of Sweden, Norway, Germany, France, Britain, &c. The following table exhibits the different states in which this metal has hitherto been found in nature:

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* Klaproth, Beitrage, ii. 275.   † Hatchett, Phil. Trans. lxxxvi. 323.
‡ Karsten, Gehlen's Jour. iii. 60.   Jameson, iii. 404.
§ Gregor, Phil. Trans. 1809. p. 205.

I. ALLOYS.
 Native.

II. SULPHURETS.
 1. Grey ore of antimony.
 2. Nickeliferous sulphu-
  ret.

3. Black ore of antim.

III. OXIDES.
 1. White oxide.
 2. Red ore of antimony.
 3. Antimony ochre.

GENUS I. ALLOYS.

Sp. 1. *Native Antimony.* *

This mineral was first discovered by Swab at Sala, in Sweden, in 1748. It has been since observed in two other places, at Allemont in France, and at Andreasberg in the Hartz. It occurs massive and in kidney-form lumps. Colour tin-white. Lustre splendent, metallic. Fracture perfect foliated with a fourfold cleavage. Fragments sometimes rhomboidal, usually indeterminate, blunt-edged. In granular, and sometimes in lamellar distinct concretions. Rather sectile. Very easily frangible. Soft. Specific gravity 6·720.† Before the blow-pipe melts and evaporates, depositing a white oxide of antimony. A specimen from Andreasberg, analysed by Klaproth, consisted of

<div align="center">

Antimony. .. 98·00
Silver. ...... 1·00
Iron .... 0·25
———
99·25 ‡

</div>

GENUS II. SULPHURETS.

Sp. 1. *Grey Ore of Antimony.*§

This ore, which is the most common, and indeed almost the only ore of antimony, occurs both massive, disseminated, and crystallized. Its crystals are four-sided prisms, somewhat flattened, whose sides are nearly rectangles, terminated by short four-sided pyramids whose sides are trapeziums. || Sometimes two of the edges are wanting, which renders the prism six-sided. ** The primitive form of its crystals is an octahedron slightly rhomboidal with scalene

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* Kirwan, ii. 245. Brochant, ii. 367. Haüy, iv. 252. Jameson, iii. 471.   † Klaproth, iii. 170.   ‡ Beitrage, iii. 172.
§ Kirwan, ii. 247. Brochant, ii. 371. Haüy, iv. 264. Jameson, iii. 473. || Romé de Lisle, iii. 49.
** Ibid. See also Haüy, Jour. de Min. No. xxxii. 606.

triangular faces, in which the angle formed by two of the faces meeting at the base is 87° 52′, and the incidences of the adjacent faces on one another are 109° 24′, 107° 27′, and 110° 58′. *

It is divided into four subspecies.

Subsp. 1. *Compact.*

Colour light lead-grey, surface often tarnished, and then it is blue or purplish. Massive and disseminated. Internal lustre shining metallic. Fracture fine-grained uneven. Fragments indeterminate, blunt-edged. Seldom in small granular distinct concretions. Soft. Easily frangible. Soils. Streak more shining. Specific gravity 4·368. The most uncommon of the subspecies.

Subsp. 2. *Foliated.*

Colour as the preceding. Massive and disseminated. Internal lustre shining metallic. Fracture foliated; sometimes passing into broad radiated. Cleavage single. Fragments indeterminate. In granular distinct concretions; coarse and fine, and usually longish. Soft. Not particularly brittle. Easily frangible. Specific gravity 4·368.

Subsp. 3. *Radiated.*

Colour light lead-grey, often tarnished. Massive, disseminated, and crystallized in six and four-sided prisms. Surface of crystals streaked longitudinally, and usually shining. Internal lustre splendent to glistening metallic. Fracture radiated. Fragments indeterminate; sometimes splintery. In thin imperfect columnar, and longish granular distinct concretions. Soft. Not particularly brittle. Easily frangible. Specific gravity 4·2 to 4·5.

Subsp. 4. *Plumose.*

Colour between blackish lead-grey and steel-grey. Massive, but usually in thin capillary crystals. External lustre shining; internal glimmering, metallic. Fracture delicate promiscuous fibrous. Fragments indeterminate, blunt-edged. Opaque. Very soft. Not particularly brittle. Easily frangible. Heavy.

A specimen of the radiated variety of this species analysed by me was composed of

* Haüy, Lucas Tableau, ii. 465.

$$\begin{array}{ll} \text{Antimony} \dots & 73\cdot77 \\ \text{Sulphur} \dots & 26\cdot23 \\ \hline & 100\cdot00 \ * \end{array}$$

Sp. 2. *Nickeliferous Sulphuret of Antimony.* †

This mineral occurs in veins near Freussberg, in the county of Sayn-Altenkirchen, in the principality of Nassau. It was described and analysed by Klaproth in 1812, and in 1814 by Dr. John. Colour steel-grey, passing into lead-grey and violet. Massive. Principal fracture foliated with a two-fold cleavage, cross fracture granular uneven. Lustre shining; cross fracture glistening. Fragments usually indeterminate, sometimes inclining to cubic. Streak dark grey. Brittle. Easily frangible. Specific gravity 5·65. Before the blow-pipe melts emitting a white vapour having the smell of arsenic, part of which remains attached to the charcoal giving it a yellow colour. Its constituents are as follows :

$$\begin{array}{lll} \text{Antimony.} \dots & 47\cdot75 & \therefore \ 61\cdot68 \\ \text{Nickel} \dots & 25\cdot25 & \dots \ 23\cdot33 \\ \text{Arsenic.} \dots & 11\cdot75 & \dots \ \text{---} \\ \text{Sulphur.} \dots & 15\cdot25 & \dots \ 14\cdot16 \\ \text{Unknown body.} & \text{---} & \dots \ 0\cdot83 \\ \hline & 100\cdot00 \ \ddagger & 100\cdot00 \ \S \end{array}$$

GENUS III. OXIDES.

Sp. 1. *White Ore of Antimony.* ‖

This ore, which has been found in Bohemia and Dauphiny, is sometimes in quadrangular tables and cubes; sometimes in acicular crystals grouped like zeolites, and sometimes in prisms. Colour passes from snow-white to yellowish-white. Internal lustre shining, between pearly and adamantine. Fracture foliated. Single cleavage;

* Annals of Philosophy, iv. 97.

† Ann. de Chim. lxxxiii. 229; lxxxv. 65. Schweigger's Jour. xii. 238. Jameson, iii. 482.

‡ Klaproth, Ann de Chim. lxxxv. 71.

§ John, Schweigger's Jour. xii. 242. He includes the arsenic under the antimony not having been able to separate them.

‖ Kirwan, ii. 251. Brochant, ii. 381. Haüy, iv. 273. Jameson, iii. 487.

Book III. sometimes radiated. Fragments indeterminate. In granular and columnar distinct concretions. Translucent. Soft. Rather sectile. Heavy. Melts easily by the flame of a candle, and emits a white vapour. * Before the blow-pipe decrepitates; when powdered and just ready to melt, it evaporates and leaves a white powder around. Between two pieces of coal it is reducible to a metallic state. This ore had been taken for a muriate of antimony; but Klaproth has lately ascertained it to be pure white oxide of that metal. †

Sp. 2.   Ochre of Antimony. ‡

This mineral is uncommon. It has been found at Braunsdorf near Freyberg, and in Hungary. Sometimes massive, sometimes covering grey ore of antimony. Colour straw-yellow. Lustre dull. Fracture earthy. Soft. Not particularly brittle, nor heavy. Infusible before the blow-pipe; but emits a white smoke, and is volatilized. With borax it froths, and is partly reduced to the metallic state.

Sp. 3.   Red Ore of Antimony. §

This ore occurs at Braunsdorf in Saxony, and Kremnitz in Hungary, and at Allemont in France. It is usually in the state of capillary crystals grouped together. Colour cherry-red. Lustre glistening, adamantine. Fracture fibrous. Fragments wedge-shaped and splintery. In coarse and small longish granular distinct concretions. Opaque. Streak similar. Very soft. Not very brittle. Easibly frangible. Specific gravity 3·75 ‖ to 4·09. ** Before the blow-pipe melts, emits a slight smell of sulphur, and is volatilized. When heated in muriatic acid it emits sulphureted hydrogen gas, holding hydrosulphuret of antimony in solution. When heated to redness a little carbonic acid is emitted, some glass of antimony is formed, and the greatest part assumes the form of oxide of antimony. It yields 67½ per cent. of antimony.

The following table exhibits a view of the constituents of such of the preceding species as have been analysed:

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* Haüy, Jour. de Min. No. xxxii. 609.   † Klaproth, iii. 183.

‡ Kirwan, ii. 252.   Brochant, ii. 383.   Jameson, iii. 489.

§ Kirwan. ii. 250.   Brochant, ii. 379.   Haüy, iv. 276.   Jameson, iii. 483.   ‖ Lametherie.   ** Klaproth iii. 179.

	White Ore.			Red Ore.
	*	†		‡
Oxide of antimony	100	.. 89	..	78·3
Sulphur.	—	.. —	..	19·7
Silica................	—	.. 8	..	—
Loss	—	.. 3	..	2·0
	100	100		100

ORDER XXIII. ORES OF ARSENIC.

Arsenic is scattered in great abundance over the mineral kingdom, accompanying almost every other metal, and forming also sometimes peculiar veins of its own. These veins occur most commonly in primitive mountains, though they are found also, at least some of the species, in floetz rocks.

The following table exhibits a view of the different ores in which this metal occurs,

I. ALLOYS.
　　Native arsenic.
II. SULPHURETS.
　　1. Arsenical pyrites.
　　2. Orpiment.
III. OXIDES.
　　Native oxide.

GENUS I. ALLOYS.

Sp. 1. *Native Arsenic.*§

This mineral is found in different parts of Germany, &c. It occurs generally in masses of various shapes, kidney-form, botryoidal, &c. Colour light lead-grey. Its surface quickly becomes tarnished by exposure to the air, and becomes greyish-black. Lustre metallic (when fresh) shining. Streak bluish-grey, metallic and bright. Powder dull and black. Fracture small-grained uneven; sometimes imperfect foliated. In thin curved lamellar distinct concretions. Semi-hard. Very easily frangible. Sectile.

* Klaproth, Beitrage, iii. 183.
† Vauquelin, Haüy, iv. 274. Under the oxide of antimony a little iron is included. 　　　‡ Klaproth, Beitrage, iii. 132.
§ Kirwan, ii. 255. Brochant, ii. 435. Haüy, iv. 220. Jameson, iii. 524.

Specific gravity 5·67 * to 5·7249.† Gives an arsenical smell when struck. Before the blow-pipe emits a white smoke, diffuses a garlic smell, burns with a blue flame, gradually evaporates, depositing a white powder. It is always alloyed with some iron, ‡ and often contains silver, and sometimes gold.

GENUS II. SULPHURETS.

Sp. 1. *Arsenical Pyrites.*§

This mineral is common in different parts of Germany, &c. It occurs massive and disseminated, and very often crystallized. The primitive form of its crystals is a rhomboidal prism, the angles of whose base are 103° 20′ and 76° 40′. It occurs in this form. Sometimes the prism is terminated by four-sided summits; sometimes its lateral faces are cylindrical. It occurs also in lenticular crystals.‖ This species is divided into two subspecies.

Subsp. 1. *Common.*

Colour of the fresh fracture silver-white; by exposure it acquires a yellowish tarnish. Massive; disseminated; and crystallized in oblique four-sided prisms, very acute double four-sided pyramids, irregular cubes, and needles. Lateral faces smooth; those formed by truncation usually streaked. Their lustre is splendent. Internal lustre shining, metallic. Fracture coarse and small grained uneven. Fragments indeterminate, blunt-edged. Usually unseparated; sometimes in columnar distinct concretions. Hard. Brittle. Rather tough. Specific gravity 5·405 to 6·522. When rubbed emits an arsenical smell.

Subsp. 2. *Argentiferous.*

Colour silver-white, surface tarnished yellowish. Massive, disseminated, and in small acicular four-sided prisms. External lustre shining; internal glistening, metallic. Fracture fine-grained uneven. Fragments indeterminate. Has

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* Kirwan.   † Brisson.   ‡ De Born, Catal. of Raab, iii. 194.
§ Kirwan, ii. 256. Brochant, ii. 438. Haüy, iv. 57. Jameson, ii. 469.
‖ A description of the different forms in which arsenical pyrites occurs, with figures of each, is given by Bernhardi in Gehlen's Jour. Second Series, iii. 80.

sometimes a tendency to fine granular distinct concretions. In other respects agrees with the preceding. The constituents of arsenical pyrites are as follows :

Arsenic .... 48·1	.... 43·4	.... 42·88
Iron .... 36·5	.... 34·9	.... 36·04
Sulphur .... 15·4	.... 20·1	.... 21·08
Loss .... —	.... 1·6	.... —
───	───	───
100 *	100 †	100 ‡

Sp. 2. *Orpiment.*

This species is divided into two subspecies; namely, *red orpiment* and *yellow orpiment*.

Subsp. 1. *Red Orpiment—Realgar.*§

This mineral is found in Sicily, about Mount Vesuvius, in Hungary, Transylvania, and various parts of Germany, &c. It is either massive or crystallized. The primitive form of the crystals is an octahedron with scalene triangles, which seem to be the same with the primitive form of sulphur; and it commonly appears in 4, 6, 8, 10, or 12 sided prisms, terminated by four-sided summits.||

Colour aurora-red. Streak lemon or orange-yellow. Lustre shining, between pearly and adamantine. Translucent. Very soft. Brittle. Easily frangible. Specific gravity 3·3384.** It is an electric *per se*, and becomes negatively electric by friction.†† Nitric acid deprives it of its colour. Before the blow-pipe it melts easily, burns with a blue flame and garlic smell, and soon evaporates.

Subsp. 2. *Yellow Orpiment.* ‡‡

This ore, which is found in Hungary, Wallachia, Georgia, and Turkey in Asia, is either massive or crystallized. The crystals are confused, and their figure cannot

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* By my analysis.   † Chevreul.
‡ Stromeyer, Schweigger's Journ. x. 404.
§ Kirwan, ii. 261. Bergman, ii. 297. Brochant, ii. 447. Haüy, iv. 228. Jameson, iii. 533. || Romé de Lisle, iii. 34. Haüy, iv. 229.
** Brisson.   †† Haüy, Jour. de Min. No. xxxii. 612.
‡‡ Kirwan, ii. 260. Alberti de Auripigmento. Scopoli in anno 5to Hist. Nat. p. 59. Bergman, ii. 297. Brochant, ii. 444. Haüy, iv. 234, Jameson, ii. 481.

be easily determined; some of them appear octahedrons, and others minute four-sided prisms. Colour lemon-yellow. Streak similar. Internal lustre splendent, between adamantine and semi-metallic. Fracture curve-foliated. Plates flexible, but not elastic. Occurs in large and small granular distinct concretions. Translucent to transparent. Soft. Sectile. Specific gravity from 3·048 * to 3·521.† Effervesces with hot nitric acid. Burns with a bluish-white flame. Before the blow-pipe melts, smokes, and evaporates, leaving only a little earth and some traces of iron. Becomes electrified minus when rubbed.

These two subspecies, though they differ in colour, appear to be composed of the same constituents. The following is their composition, according to the analysis of Klaproth :

	Realgar.	Orpiment.
Arsenic	69	62
Sulphur	31	38
	100‡	100‡

According to Laugier, realgar consists of sulphuret of arsenic mixed with a variable quantity of metallic arsenic, while orpiment is the sulphuret of arsenic in the state of purity.

GENUS III. OXIDES.

Sp. 1. *Native Oxide.*§

This ore is found in various parts of Germany, Hungary, &c. either in powder, or massive, or crystallized in prismatic needles. It is very uncommon. Colour white or grey, often with a tint of red, yellow, green, or black. Lustre common, glimmering. Opaque or translucent on the edges; when crystallized, translucent. Texture earthy. Soft. Brittle. Specific gravity 3·7.‖ Soluble in hot diluted nitric acid without effervescence. Soluble at 60° Fahrenheit in 80 times its weight of water. Before the blow-pipe sublimes, but does not inflame. Tinges borax yellow.

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* Kirwan. † Gellert. ‡ Beitrage, v. 238.
§ Kirwan, ii. 258. Bergman, ii. 285. Brochant, ii. 450. Haüy, iv. 225. Jameson, iii. 540. ‖ Kirwan.

CHAP. III.

OF COMPOUND MINERALS.

THE minerals described in the last chapter hardly ever
occur insulated. They are usually united together in various
groups, consituting the rocks and the soil of which the
globe of the earth is composed. These groups are termed
COMPOUND MINERALS. The study of them constitutes
geology or geognosy; one of the most important branches
of philosophy. It teaches us the structure of the globe, the Geognosy.
relative situation of the different minerals, their connexion
with each other, and the changes which they are under-
going, or have undergone. It is by numerous and skilful
observations alone that any progress can be made in this
difficult investigation. In Germany, mining has been long
an object of greater attention than in any other country;
men of science have been long employed to superintend the
mines, and exact records have been kept of every thing that
occurred. It is in that country, accordingly, that the
greatest number of observations have been made, and the
materials collected, for raising geology to the rank of a
science. The difficult task was undertaken by Werner, Generaliz-
the celebrated Professor of Mineralogy in Freyberg, who ed by Wer-
generalized his own observations, and those of his pre- ner.
decessors, with the most exquisite skill, and constructed a
theory which has excited universal attention. To the
branch of science which he has thus created he has given
the name of *geognosy.* Hitherto Werner's theory has been
detailed only in his lectures. No intelligible account of it,
so far as I know, has been published on the continent. But,
in this country, we are indebted to Professor Jameson for a
very full and excellent treatise on the subject, under the title
of *Elements of Geognosy.* It was published in 1808, and
constitutes the third volume of his *Mineralogy.* *

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* To that important work I earnestly recommend the attention of
every mineralogist. It contains (independent of the *theory* of Werner)
a vast mass of information of the utmost consequence, with which every
mineralogist ought to be acquainted. The sketch in the text, though
only a very short abridgement, is as detailed as is consistent with the na-

1

Respecting the structure of the internal parts of the earth, we have no direct means of information; but towards the superficies, this structure is laid open to our view by ravines, rivers, mines, &c. Observations on these afford the only means of learning the structure of the earth. They constitute the foundations of geognosy, the ground work from which all the conclusions of that science are deduced. The stony masses of which the earth, as far as we know it, is composed, are sometimes *simple*, or composed of some one of the minerals described in the preceding chapter; as, for example, *lime-stone, serpentine, quartz:* But more frequently they are compound, or composed of two or more simple minerals variously mixed and united together; as *granite*, which is composed of *quartz, felspar,* and *mica*.

Rocks.

Follow a particular order.

These stony masses, or *rocks*, are numerous, and they are found in the earth laid one above another; so that a rock of one kind of stone is covered by another species of rock, and this by a third, and so on. Now in this superposition of rocks it has been observed, that their situation is not arbitrary; every one occupies a determinate place, so that they follow each other in regular order from the deepest part of the earth's crust, which has been examined, to the very surface. Thus there are two things respecting rocks which claim our attention; namely, their composition, and their relative situation. But besides the rocks which constitute almost the whole of the earth's crust, there are masses which must also be considered. These traverse the rocks

ture of the present work. I was indebted to Professor Jameson for the whole of the materials out of which it was formed.

There is another geological theory, in some measure the opposite of that of Werner, contrived with much ingenuity and sagacity, by a man of undoubted genius, which is well known in this country under the name of the *Huttonian Theory*. It may seem at first sight singular, that I have taken no notice of this theory in the text, especially after the numerous experiments of Sir James Hall, equally unexpected and important, and the great mass of *Proofs and Illustrations* brought forward in support of it with such exquisite art and eloquence by Professor Playfair. But any examination of this theory would have been foreign to the present chapter, as it refers not so much to the situation of the compound minerals, as of their *original formation;* a subject which must of necessity be hypothetical, and upon which therefore I do not touch.

in a different direction, and are known by the name of *veins*, as if the rocks had split asunder in different places from top to bottom, and the chasm had been afterwards filled up with the matter which constitutes the vein.

Thus it appears, that when we consider compound minerals, or rocks, the subject naturally divides itself into three parts; namely, 1. The structure of rocks; 2. The situation of rocks; 3. Veins. These shall form the subject of the three following sections.

SECT. I.

OF THE STRUCTURE OF ROCKS.

Rocks may be divided into two classes; viz.

I. Simple, or composed of one mineral substance.

II. Compound, or composed of more than one mineral substance.

Compound rocks are of two kinds; namely,

    I. Cemented; composed of grains agglutinated by a cement, as *sand-stone*.

    II. Aggregated; composed of parts connected together without a cement, as *granite*.

The aggregated rocks are likewise of two kinds; namely,

    I. Indeterminate.

Only one instance of this kind of aggregation has hitherto occurred; namely, in the *older serpentine*, where lime-stone and serpentine are so conjoined, that it is difficult to say which predominates.

    II. Determinate.

The determinate are either, I. Single aggregated; or, II. Double aggregated.

    There are four kinds of single aggregated rocks; namely,

    1. Granular; composed of grains whose length, breadth, and thickness are nearly alike, and which are of contemporaneous formation. As *granite, sienite*.

    2. Slaty; composed of plates laid above each other; as *mica slate*.

    3. Porphyritic; composed of a compact ground, containing in it crystals which appear to have been

deposited at the time the rock was formed; as *common porphyry*.

4. Amygdaloidal; composed of a compact ground, containing in it vesicles which appear to have been afterwards filled up; as *amygdaloid*.

There are five kinds of double aggregated rocks; namely,

1. Granular slaty; composed of slaty masses laid on each other. Every individual slate is composed of grains cohering together; or it is slaty in the great, and granular in the small; as *gneiss*.

2. Slaty granular; composed of large granular masses cohering together; each grain is composed of plates; or the rock is granular in the great, and slaty in the small; as *topaz rock*.

3. Granular porphyritic; granular in the small, and porphyritic in the great; as *granite, green-stone* frequently.

4. Slaty porphyritic: slaty in the small, porphyritic in the great; as *mica slate* frequently.

5. Porphyritic and amygdaloidal; a mass porphyritic and amygdaloidal at the same time; as *amygdaloid* and *basalt* frequently.

Such are the different kinds of structures of rocks hitherto observed and described. The following table will give the reader a synoptical view of these different kinds of structure:

I. Simple rocks.

II. Compound rocks.

    A. Cemented.

    B. Aggregated.

      a. Indeterminate.

      b. Determinate.

        I. Single.

          1. Granular.

          2. Slaty.

          3. Porphyritic.

          4. Amygdaloidal.

        II. Double.

          1. Granular slaty.

          2. Slaty granular.

          3. Granular porphyritic.

          4. Slaty porphyritic.

          5. Porphyritic and amygdaloidal.

SECT. II.

OF THE RELATIVE SITUATION OF ROCKS.

THE rocky masses, or rocks, hitherto observed, amount to about sixty. Of these rocks, variously placed over each other, the whole crust of the earth is composed, to the greatest depth that the industry of man has been able to penetrate. Now these rocks, with respect to each other, occupy a determinate situation, which holds invariably in every part of the earth. Thus lime-stone is nowhere found *under* granite, but always *above* it. Were we to suppose every particular rock, or *layer*, which constitutes a part of the earth's surface to be extended round the whole earth, and to be wrapped round the central nucleus, like the coat of an onion, in that case every rock would occupy a determinate place; one species would be always lowest or nearest the centre; another species would uniformly rest upon this first; a third upon the second, and so on. Now though the rocks do not in reality extend round the earth in this uninterrupted manner; though partly from the inequality of the nucleus on which they rest, partly from their own inequality of thickness in different places, and partly from other causes, the continuity is often interrupted; yet still we can trace enough of it to convince us that the rocks which constitute the earth's crust, considered in a great scale, are every where the same, and that they invariably occupy the same situation with respect to each other. Werner has therefore chosen this relative situation as the basis of his classification of rocks. He divides them into five classes. The first class consists of those rocks which, if we were to suppose each layer to be extended over the whole earth, would in that case lie *lowest*, or nearest the centre of all the rocks which we know, and be covered by all the other rocks. The second class consists of those rocks which in that case would be immediately above the first class, and cover them. The third class would cover the second in the same manner; the fourth the third; and the fifth would be uppermost of all, and constitute the immediate surface of the earth. The first class of rocks are covered by all the rest, but never themselves lie over any other. The others lie in order over each other. These

grand classes of rocks he has denominated *formations*, and distinguished them by the following specific names:

<div style="margin-left:2em">

I. Primitive formations.
II. Transition formations.
III. Floëtz formations.
IV. Alluvial formations.
V. Volcanic.

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Classes of rocks.

The primitive formations are of course the lowest of all, and the alluvial constitute the very surface of the earth; for the volcanic, as is obvious, are confined to particular points. Not that the primitive are always at a great depth under the surface, very often they are at the surface, or even constitute mountains. In such cases the other classes of formations are wanting altogether. In like manner the transition, and other formations, may each in its turn occupy the surface, or constitute the mass of a mountain. In such cases, all the subsequent formations which ought to cover them are wanting in that particular spot.

Each of these grand classes of formations consists of a greater or smaller number of rocks, which occupy a determinate position with respect to each other, and which, like the great formations themselves, may often be wanting in particular places. Let us take a view of the rocks which compose all these different formations.

CLASS I. PRIMITIVE FORMATIONS.

The rocks which constitute the primitive formations are very numerous. They have been divided therefore into seven sets; which constitute as many primitive formations, and are distinguished each by the name of that particular rock which constitutes the greatest proportion of the formation. These seven sets of primitive formations are the following:

Principal formations.

1. Granite.	5. Newest primitive porphyry.
2. Gneiss.	6. Sienite.
3. Mica-slate.	7. Newer serpentine.
4. Clay-slate.	

Subordinate.

The granite is the undermost, and the sienite the uppermost of the primitive formations. Granite is scarcely mixed with any other rock; but in gneiss, mica-slate, and clay-

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slate, there occur *beds* * of *old porphyry, primitive trap, primitive lime-stone, old serpentine, quartz rock.* For that reason, these rocks are said to constitute formations *subordinate* to gneiss, mica-slate, and clay-slate. Gypsum occurs in beds in mica-slate, and old flinty-slate occurs in the same way in clay-slate. Hence they constitute formations subordinate to mica and clay-slate. Thus, besides the seven principal primitive formations, there occur seven subordinate formations, interspersed through the second, third, and fourth formations; and *topaz rock*, which lies over gneiss and under clay-slate, must be added to the list: so that the primitive formations altogether amount to fifteen.

If we suppose the nucleus of the earth to have been first formed, and the formations to have been afterwards deposited in succession upon this nucleus, it will follow that the lowest formation is the oldest, and that the formations are newer and newer according as they approach the surface. This supposition accounts for some of the names given to the primitive formations. That porphyry, for example, is considered as the oldest which lies lowest down in the series of formations, and those formations of porphyry which lie nearer the surface are considered as newer. Granite, of course, according to this way of speaking, is the oldest formation of all, while the alluvial are the newest of all. The following table exhibits a synoptical view of the primitive formations :

Principal.	Subordinate.	
1. Granite.		Table of formations.
2. Gneiss.	6. Older porphyry.	
3. Mica-slate.	7. Primitive trap.	
4. Topaz rock.	8. Primitive lime-stone.	
5. Clay-slate.	9. Older serpentine.	
	10. Quartz.	
	11. Gypsum.	
	12. Older flinty-slate.	
13. Newer porphyry.		
14. Sienite.		
15. Newer serpentine.		

* When a mountain is composed of *layers* of the same kind of stone, it is said to be *stratified* ; but when the layers are of *different* kinds of stone, it is said to be composed of *beds.*

Let us consider each of them in the order of the forma-
tions.

1. *Granite.*

Granite * is the lowest of all the formations, and the basis
upon which the others rest. It is composed of *felspar,
quartz,* and *mica ;* each in a crystallized state, and cohering
together without any cement. The felspar is usually the
most abundant ingredient, and the mica the smallest in
quantity. The colour of the quartz and mica is usually
grey ; but the felspar has a considerable variety of colours,
occurring in different shades of white, grey, red, and green.
The size of the constituents of granite varies considerably.
Sometimes the grains are very large, and sometimes they
are so small that the granite has the appearance of a sand-
stone. Sometimes it is *porphyritic,* large crystals of felspar
occurring in a basis of fine-grained granite. Sometimes
this rock is distinctly stratified, but in other cases no strati-
fication can be perceived. The unstratified or *massive* gra-
nite is frequently composed of large globular masses, each
of which is composed of concentric lamellar distinct con-
cretions. The intervals between these balls consist of a
softer granite, subject to crumble down when exposed to
the action of the weather.

Besides the three constituents of which granite essentially
consists, other crystallized minerals occasionally occur in
it, though only in small quantities. These crystals are
chiefly of *schorl ;* sometimes *garnet* and *tin-stone.*

Granite very seldom contains among its strata beds of
any foreign rock. Beds of felspar alone have occasionally
been observed in it. It is not so rich in ores as some of the

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* Professor Jameson informs us, on the authority of Werner, that
the word *granite* was first used by Tournforte in his Voyage to the
Levant, published in 1699. I stated, in a former edition of this work,
that the word occurs in the register of the Royal Society as far back as
1662 ; where it is mentioned that Mr. Winthrop exhibited a piece of a
rock of granite. But on consulting the register of the Royal Society, I
find that Dr. Birch from whom I got my information (Birch's Hist. of
the R. Soc. i. 80) has altered the spelling. In the Register it is *a piece
of a rock of granate.* Now I find that Dr. Brown in his travels uses
granate to signify what we now call *garnet.* Probably therefore the spe-
cimen exhibited to the Royal Society was of *garnet,* not *granite.* So
that my objection does not hold good.

other formations. Tin and iron are the metals which are most abundant in it. Hitherto molybdena has been found chiefly in granite. It contains also silver, copper, lead, bismuth, arsenic, cobalt, tungsten, and titanium.

Besides the great granite formation which has been just described, Werner recognizes a second; which is supposed to occur nearly in the same geognostic situation as porphyry and sienite. The granite veins which traverse gneiss, mica-slate, and clay-slate, belong to this formation. There are several particularities by which this newer granite may be distinguished from the other. It usually occurs in a lower level; it has commonly a deep red colour; contains garnets; and is not porphyritic. *(Newer granite.)*

When granite is not covered by any other formation, it forms high insulated cliffs and steep rugged rocks.

Granite occurs likewise in transition and even in floëtz formations.

2. Gneiss.

Gneiss * is the formation which lies immediately over granite, and into which indeed it gradually passes. Gneiss consists of the same constituents as granite; namely, felspar, quartz, and mica: but it differs in its structure, being disposed into slates from the prevalence of the mica. The texture of the individual slates is granular. Hence the structure of gneiss is *granular slaty*. Gneiss is always distinctly stratified. It sometimes contains crystals of schorl; but they are smaller and much more uncommon than in granite. Tourmaline is more common, and so likewise is garnet. It contains in it many foreign beds, which is not the case with granite. Beds of three of the first six subordinate formations are found in it. It is, perhaps, richer in metallic ores than any other formation. Almost every metal occurs in it, either in beds or veins. *(Composition. Foreign minerals.)*

When gneiss is not covered by any other formation, it forms round-backed mountains, and likewise crags; but less steep and insulated than those composed of granite.

* The word *gneiss* is of Saxon origin, and was applied by the miners to the decomposed stone which forms the walls of veins. Werner first gave it the meaning which it now bears. See Jameson's Geognosy, p. 113.

3. *Mica-slate.*

The formation which lies immediately over gneiss, and into which it insensibly passes, is *mica-slate.* This rock, like the preceding, is compound, and composed essentially of quartz and mica. Like gneiss it is slaty, but it differs from that rock in containing no felspar. It is always stratified. It very frequently contains garnet crystals in considerable quantity, so as to give it a porphyritic appearance. Its structure is then slaty porphyritic. It sometimes also contains crystals of tourmaline, cyanite, and granatite. Felspar likewise occurs in it occasionally; not, however, as a constituent, but in kidney-form and irregular masses. Like gneiss, it contains many foreign bodies (older porphyry, primitive trap, primitive lime-stone, older serpentine, and gypsum, occur in it.) It is rich in ores; containing beds of magnetic iron-stone, pyrites, galena, copper pyrites (containing gold), blende, cinnabar, cobalt glance, magnetic pyrites, and sometimes even native gold. It abounds also in metalliferous veins.

Foreign minerals.

4. *Clay-slate.*

Mica-slate gradually passes into clay-slate, the formation immediately over it. Clay-slate consists essentially of the mineral described in the preceding chapter under that name. This rock is always slaty and always stratified. When it approaches mica-slate, grains of quartz, and also of mica, may be distinguished in it. Occasionally also it contains crystals of felspar, schorl, tourmaline, garnet, and hornblende.

Comprehends a variety of slates.

Under the name of *clay-slate formation* is included not only clay-slate, strictly so called, but likewise *chlorite-slate, talc-slate, whet-slate, drawing-slate,* and *alum-slate;* all of which occur along with pure clay-slate, are similarly stratified, and gradually pass into it and into each other, and therefore are considered as only constituting a part of the same formation : but these substances affect a particular order. The following table exhibits that order, beginning with the lowest or oldest, as it is called, and terminating with the uppermost or newest :

Their relative position.

1. Light yellowish-grey clay-slate.
2. Dark-grey clay-slate.

3. Green clay-slate.
4. Chlorite slate and potstone.
5. Talc-slate.
6. Whet-slate.
7. Bluish-grey clay-slate.
8. Red clay-slate.
9. Drawing slate.
10. Alum-slate.

Besides these different beds, which are considered as Foreign constituting the clay-slate formation, it contains also beds minerals. of all the eight subordinate formations. It contains also a considerable number of metallic ores in beds; as iron pyrites, copper pyrites, arsenic pyrites, cobalt, galena, &c. It contains also a variety of mineral veins.

Clay slate occurs likewise in transition formations.

Having now described the four first primitive formations, let us proceed to the subordinate formations; taking topaz rock along with them, on account of its rarity. These are the older porphyry, primitive trap, primitive lime-stone, older serpentine, quartz, topaz rock, gypsum, and primitive flinty-slate.

5. *Older Porphyry.*

By porphyry, as defined by Werner, is to be understood a rock consisting of a basis or ground of some compact mineral, and in this ground are interspersed crystals of some other mineral. The ground or basis varies in different porphyries. Sometimes it is clay-stone, sometimes pitch-stone, &c.; and the porphyry is named from this basis. The following are the species of porphyry that have Species. been described:

1. Clay porphyry.
2. Horn-stone porphyry.
3. Felspar porphyry.
4. Pitch-stone porphyry.
5. Sienite porphyry.
6. Obsidian porphyry.
7. Pearl-stone porphyry.

The crystals interspersed through the different bases are commonly felspar, sometimes quartz, and sometimes hornblende and mica; but the two last are uncommon, especially the mica.

There are two very different formations of porphyry: Two forthe first is found in beds in gneiss, mica-slate, and clay-mations of slate; whereas the second always lies over all these forma- porphyry.

tions. Hence the first is distinguished by the name of *older*, and the second is called *newer porphyry*. It is the first of these that we are to consider at present.

Older. The basis of the older porphyry is usually a species of horn-stone, and sometimes felspar; and the crystals which occur in it are felspar and quartz. Hence the older porphyry consists chiefly of *horn-stone porphyry*, and *felspar porphyry*. When not covered by other formations it sometimes forms single rocks, but never large mountains.

6. *Primitive Trap.*

Definition. The word *trap* is Swedish, and signifies a *stair*. It was applied by the Swedish mineralogists to certain rocks, whose strata when exposed, from the one jutting out under the other, gave an appearance somewhat like a stair. The term was adopted by other nations, and was applied indiscriminately to a great variety of rocks, which bore a certain resemblance to each other. This generalization introduced much confusion into the subject, which was first cleared up by Werner and his disciples. Under the term *traps* Werner comprehends certain series of rocks, distinguished chiefly by the hornblende, which they all contain. In the most ancient, the hornblende is almost pure: this purity gradually diminishes, and in the most recent traps the Three for- hornblende degenerates to a kind of indurated clay. There mations. are, then, three formations of trap: 1. Primitive trap; 2. Transition trap; 3. Floetz trap. The first only occupies our attention at present.

Primitive. The primitive trap formation contains a considerable number of rocks; which, occurring in different parts of the earth in similar situations, and as it were substituted for each other, are considered altogether as constituting only Rocks be- one formation. The following table exhibits a list of the longing to rocks belonging to this formation:

  I. Hornblende.
    1. Granular or common hornblende.
    2. Hornblende slate.
  II. Hornblende and felspar united.
    i. Granular.
      1. Common green-stone.
      2. Porphyritic green-stone.

3. Green-stone porphyry.
4. Green porphyry.
 ii. Slaty.
  1. Green-stone slate.
 III. Hornblende and mica united.
  1. Porphyritic trap.

The first two of these rocks consist essentially of the minerals described in the last chapter under the names of common *hornblende* and *hornblende slate*. The latter sometimes passes into fine slaty gneiss and into chlorite slate.

Common green-stone is composed of hornblende and felspar, both in the state of grains or small crystals, and the hornblende usually constitutes by far the greatest proportion of the mass. The felspar is almost always tinged green from the hornblende. This rock sometimes contains a little mica; sometimes it is intersected by small veins of quartz and actinolite; and sometimes also, though less frequently, of felspar and calcareous spar.

Porphyritic green-stone, like the preceding rock, is a compound of granular hornblende and felspar; but it contains likewise large crystals of felspar and quartz, interspersed through the green-stone ground.

Green-stone porphyry (*black porphyry* of the antiquary) is a rock consisting of granular green-stone, so small-grained that at first sight it has the appearance of being a simple stone; containing in it large crystals of felspar, coloured green from hornblende.

Green porphyry (the *verde antico serpentine*) is a rock which has for its ground a mixture of hornblende and felspar, so intimate that the two ingredients cannot be distinguished by the naked eye, and having a blackish-green or pistachio-green colour. This trap contains greenish-coloured felspar crystals, often cruciform.

Green-stone slate is a rock composed of hornblende and felspar, and sometimes a little mica, and having a slaty texture. It is very hard; but, like the other species of green-stone, soon withers when exposed to the air.

Porphyritic trap is a rock composed of an intimate mixture of hornblende and felspar, containing in it large plates of mica, which give it a porphyritic appearance.

All the rocks of the primitive trap formation are characterized by containing a mixture of iron pyrites. Their

stratification is indistinct ; and, indeed, if we except green-stone slate and hornblende slate, usually not perceptible. When primitive trap is not covered by any other formation, it constitutes considerable hills and cliffs. It abounds in ores, especially green-stone slate.

7. *Primitive Lime-stone.*

Lime-stone occurs in all the four grand classes of formations, but it assumes a peculiar and characteristic appearance in each. In the primitive it is distinctly crystalline and transparent. The crystalline texture gradually becomes less and less distinct, as the formations advance, till at last the lime-stone assumes the appearance of an earthy deposite.

Primitive lime-stone occurs usually in beds, and seldom forms entire mountains. Its colour is usually white, sometimes it is grey, but very seldom assumes any other colour. It is the species of lime-stone described in the preceding chapter under the name of *granular foliated.* It sometimes *Foreign* contains in it quartz, mica, hornblende, actinolite, garnet, *minerals.* tremolite, talc, clay-slate, serpentine, asbestus, blende, galena, common and magnetic pyrites, and magnetic iron-stone. The ores are usually found at the lower part of the beds of lime-stone. It is sometimes stratified, and sometimes not. When not covered by any other formation, it forms steep bare rocks; and when it occurs in considerable quantities, often contains caverns.

8. *Older Serpentine.*

The serpentine formation consists essentially of the mineral described under that name in the preceding chapter. Two subspecies were there described ; namely, the *common* and *precious serpentine.* The latter (a tleast chiefly) constitutes the formation at present to be described. It occurs, like the other subordinate primitive formations, in beds in gneiss, mica, and clay-slate, and alternates with lime-stone. It is seldom stratified. It contains in it galena, and auriferous arsenic pyrites.

9. *Quartz.*

Quartz occurs in beds, and in no great quantity. It is usually granular and of a white colour; sometimes it con-

tains a mixture of mica, which gives it a slaty texture. It
is very often unstratified ; but as it abounds in rents, these
have often been mistaken for strata.

10. *Topaz Rock.*

The rock which constitutes this formation is very rare,
having been observed only in Saxony, where it constitutes
a mountain. There it rests on gneiss, and is covered by
clay-slate. It is composed of three ingredients ; namely,
fine granular quartz, *schorl*, in thin prismatic distinct con-
cretions, and *topaz* almost massive. These are arranged
in thin layers, and these again into roundish and granular
distinct concretions, so that the rock is *slaty granular*. The
intervals between these concretions are filled up with a
yellowish or greenish-coloured lithomarge.

11. *Gypsum.*

Gypsum was formerly believed to be peculiar to the floetz
formations; but an immense bed of it has lately been dis-
covered in Switzerland in mica-slate. This primitive gyp-
sum is characterized by containing mica and clay-slate.*

12. *Primitive Flinty-slate.*

This rock consists essentially of the mineral described in
the last chapter, under the name of *flinty-slate*. It is
often traversed by veins of quartz. There are two forma-
tions of it; namely, the *primitive*, which occurs in beds in
clay-slate, and another which belongs to the transition
formations.

Having now described the eight formations which are
subordinate to gneiss, mica, and clay-slates, let us proceed
to the remaining primitive formations, which always cover
clay-slate, and are therefore considered as newer than it.
These are the newer primitive porphyry, sienite, and the
newer serpentine.

13. *Newer Porphyry.*

To this formation belong the following species of por-

* It was first observed by Freisleben at the bottom of St. Gothard.
D'Aubuisson observed a bed of it in mica-slate in a mountain between
the valley of Cogne and Fenis in the High Alps. Jour. de Phys. lxv.
402.

phyry; namely, *clay porphyry, pitch-stone porphyry, obsidian phorphyry, pearl-stone phorphyry*, and sometimes *felspar porphyry*. Clay porphyry is by far the most common. To this formation also belongs *clay-stone*, a mineral described in the preceding chapter. It constitutes the basis of clay porphyry, and frequently occurs without any crystals of felspar or quartz. To it we must also refer a kind of breccia porphyry, composed chiefly of fragments of hornstone porphyry and felspar porphyry.

In the rocks belonging to this formation, it is common to find round masses of a harder and more flinty stone than the mass of the rock itself. Thus in clay porphyry we find masses of horn-stone porphyry, containing in their centre a kernel of calcedony; in pitch-stone porphyry we find masses of conchoidal hornstone, with a quartz kernel in the centre. Agate, calcedony, heliotrope, amethyst, and quartz, often occur either in plates, thin beds, veins, or irregular masses; sometimes also the precious opal is found in this formation occupying clefts. It contains also a variety of ores, as of gold, silver, lead, iron, tin, manganese, &c.; but hitherto they have been discovered only in veins, and never in beds.

This formation lies over all the preceding, and consists of beds more irregular, and more interrupted. It extends very widely. Hitherto it has scarcely been discovered stratified. When it composes hills, they are often split into columns like those of basalt.

14. *Sienite.*

This rock occurs usually along with porphyry; and when they are both together, the sienite generally forms the uppermost part of the hill.

Sienite is a rock composed essentially of felspar and hornblende, the same constituents which form green-stone; but in sienite the felspar is the prevailing ingredient, whereas in green-stone it is the hornblende. In sienite the felspar is usually red, and very seldom has a tinge of green, whereas in green-stone the felspar is never red, but almost always greenish-white. The structure of sienite is granular, and the grains vary greatly in size: sometimes small-grained sienite contains in it large crystals of felspar; it is then called *porphyritic sienite*. When the two ingredients

that constitute sienite are so small, and so intimately mixed, that they cannot be distinguished by the naked eye, and when such a rock contains crystals of felspar and quartz, it is denominated *sienite porphyry.*

Sienite, like porphyry, contains few foreign beds; but it is rich in ores, containing gold, silver, iron, tin, copper, lead, &c. always however in veins.

The rocks of sienite are often divided into columns. Like the newer porphyry it often occurs in round masses.

15. *Newer Serpentine.*

This formation consists of the rock composed essentially of the mineral called common serpentine. It bears a striking resemblance to the newer porphyry formation, and occurs in similar situations; but whether it covers it, is covered by it, or comes in place of it, has not hitherto been ascertained in a satisfactory manner. It sometimes contains steatite, asbestus, talc, meerschaum, native magnesia, pyrop, and schillerstone. It is seldom or never stratified, and except magnetic iron-stone contains scarcely any ore.

Such is a sketch of the rocks constituting the primitive formations. It deserves attention, 1. That the rocks constituting them are all chemical combinations, and generally crystallized; the crystallized appearance being most striking in the oldest, and gradually becoming less perfect in the newer formations: 2. That they contain no petrifactions: 3. That the oldest formations contain no carbonaceous matter, and that it occurs only very sparingly in the primitive formations. Slaty glance coal and graphite occur in them. 4. That when we compare together the height of the different formations, where each individual is not covered by any succeeding one, we find that *granite* stands *highest* of all; that the level of the *gneiss* is a little *lower;* that of the *mica-slate* still *lower;* and that of the *clay-slate lowest* of all. So that there is a regular sinking of the level from granite to clay-slate; but the newer porphyry and sienite are laid over the tops of the preceding, as if these two formations had been deposited long after the formation of the rest. Nay, there is often interposed between the porphyry and these formations, a bed of breccia, composed of fragments of the anterior formation. 5. That almost

all the rocks which contain magnesia are confined to the clay-slate formation.

CLASS II. TRANSITION FORMATIONS.

Having described the primitive formations, let us now proceed to the second great class, the *transition*, which lie immediately over them. These are by no means so numerous, since they consist of the following sets; namely,

1. Granite.
2. Greywacka.
3. Transition lime-stone.
4. Transition trap.
5. Transition flinty-slate.
6. Dialage rock.
7. Gypsum.

They all alternate with each other, sometimes one, sometimes another being undermost, except one bed of transition lime-stone, which seems always to rest upon the primitive formations, and may therefore be considered as the oldest of the transition formations.

It is in the transition rocks that petrifactions first make their appearance; and it deserves particular attention that they usually consist of species of corals and zoophites, which do not at present exist, and which therefore we must suppose extinct. The vegetable petrifactions are likewise the lowest in that kingdom, such as ferns, &c. This remarkable circumstance has induced Werner to conclude, that the transition rocks were formed after the earth contained organic beings. Hence the name *transition*, which he has imposed, as if they had been formed when the earth was passing from an uninhabited to an inhabited state. The date of their formation is conceived to be very remote, since the petrifactions which they contain are the remains of animal and vegetable species now extinct. It is in the transition rocks, too, that carbonaceous matter makes its first appearance in any notable quantity.

Why called transition.

1. *Granite.*

Granite has been discovered in different places, lying over rocks that contain petrifactions. And as these rocks belong to the transition class, we are entitled to infer that the granite lying over them is likewise transition. I found the granite of St. Michael's Mount, in Cornwall, alternating with beds of clay-slate. This clay-slate may be traced

from Plymouth to St. Michael's. Now at Plymouth it alternates with transition lime-stone containing petrifactions. Therefore the St. Michael's granite must be transition. Von Buch found granite covering lime-stone containing petrifactions near Christiania in Norway.

2. *Greywacka.*

This formation consists of two different rocks, which usually alternate with each other, and pass into each other. These are *greywacka*, and *greywacka-slate*. The first characterizes the formation.

Greywacka is a rock composed of pieces of quartz, flinty-slate, felspar, and clay-slate, cemented together by a basis of clay-slate. The pieces are sometimes as large as a hen's egg; sometimes so small that they cannot be perceived by the naked eye. The clay-slate basis likewise varies in quantity considerably. It often contains soft plates of mica, and quartz veins are very common in it; sometimes it is so hard that it appears indurated by some siliceous cement. The texture of greywacka becomes gradually finer and finer grained, till at last it can no longer be perceived, and a slaty structure succeeds. It then passes into greywacka-slate.

Greywacka-slate is nothing else than a variety of *clay-slate*; but it may be distinguished from primitive slate by different circumstances. Its colour is usually ash or smoke-grey, seldom showing that greenish or light yellowish-grey colour which is so common in primitive slate. It does not show the silvery uninterrupted lustre of primitive slate, but is rather glimmering, from interspersed scales of mica. It contains no beds of quartz, but very often veins of that mineral. It contains no crystals of felspar, schorl, tourmaline, garnet, or hornblende; nor beds of garnet, chlorite-slate, talc, or magnetic iron-stone. It contains petrifactions.

The greywacka rocks are stratified. When not covered by any other formation, they form round-backed hills, usually insulated at top and intersected by deep valleys. It contains immense beds of transition lime-stone, trap, and flinty-slate. It is rich in ores both in beds and veins, and the veins are often of an uncommonly large size.

3. *Transition Lime-stone.*

This, like primitive lime-stone, is a simple rock; but it approaches more to compact, and is less transparent than the primitive. It contains often veins of calcareous spar, and exhibits a variety of colours, which gives it a *marbled* appearance. It contains marine petrifactions of corals and zoophites, which no longer exist, and which do not occur in the subsequent lime-stone formations. These petrifactions increase in quantity as the beds of transition limestone advance farther and farther in their position from the primitive formations. It is often mixed with greywackaslate, which gives it a slaty texture. It occurs in beds of greater and smaller size, and often forms whole mountains. It contains no foreign beds except of transition trap. It is scarcely stratified. It is rich in ores. The species of lime-stone called lucullite usually characterizes the transition formations.

4. *Transition Traps.*

This formation, as the name imports, consists of rocks distinguished by the great proportion of hornblende which they contain. It comprehends four species of rocks; namely,

Rocks in-included.

1. Triansition green-stone.
2. Amygdaloid.
3. Porphyritic transition trap.
4. Globular trap (kugel fels).

Transition green-stone is a rock composed of fine granular hornblende and felspar intimately mixed together, and not so distinctly crystallized as in primitive green-stone. Sometimes the mixture is so intimate, that the two minerals cannot be distinguished. In that state it often becomes loose in its texture, and approaches *wacka* and *basalt*. In this last case it often contains vesicles. When these are filled up with other minerals, the rock passes into *amygdaloid*.

Amygdaloid is nothing more than this last state of greenstone. The vesicles are filled up with calcareous spar, calcedony, quartz, jasper-agate, green-earth, amethyst, &c. either completely or partially.

Sometimes the transition green-stone, in this softened

state, contains crystals of felspar coloured green by the hornblende. It then constitutes *phorphyritic transition trap*.

Globular trap is a fine granular hornblende rock of a loose texture, and tending very strongly to clay; of a liver-brown colour, and containing in it globular masses composed of concentric lamellar concretions, and containing a hard kernel.

The transition trap rocks are only doubtfully stratified. They alternate with the other transition formations in beds, and sometimes compose whole mountains. Common and lenticular clay-iron-stone occurs in it in beds.

5. *Transition Flinty-slate.*

This formation consists essentially of common flinty-slate and Lydian-stone, which pass into each other. It is a simple stone, but is characterised by containing many veins of quartz. It is not stratified. When it constitutes rocks they are usually steep, and appear very much lacerated and worn down by the weather. This is occasioned by the numerous rents which this species of rock contains.

To this formation seems to belong ribbon jasper, which sometimes constitutes whole rocks. It may possibly occur also in some of the subsequent formations.

6. *Diallage Rock.*

This beautiful rock consists essentially of masses or crystals of diallage and saussurite mixed together, like granite. Pieces of serpentine often occur in it also, which adds greatly to the beauty of the rock. It was observed long ago in the Alps and in Italy, where it is known by the name of *gabbro*. Von Buch found it near Christiania; and I observed it in the peninsula of the Lizzard in Cornwall, where it is associated with transition green-stone, and serpentine.

7. *Gypsum.*

Von Buch observed a bed of gypsum in greywacka at Leogang in Salzburg. Brochant has examined the different gypsum beds in the Alps, and has satisfied himself that they all lie in transition formations. Indeed it seems at present doubtful, whether any real primitive gypsum has yet occurred.

CLASS III. FLOETZ FORMATIONS.

The next grand class of formations have received the name of *floetz*, because they lie usually in beds much more nearly horizontal than the preceding. When not covered by a succeeding formation, they form hills which do not rise to the same height as the primitive or transition. They contain abundance of petrifactions; and these much more various in their nature than those which occur in the transition formations, consisting of shells, fish, plants, &c. indicating that they were formed at a period when organized beings abounded.

The floetz formations lie immediately over the transition. They comprehend a great number of individual formations, each of which affects a particular situation. The following table exhibits a view of these different formations in the order of their position, as far as is known :

Table of the formations.

1. Old red sand-stone and floetz trap.
2. Independent coal.
3. First floetz lime-stone.
4. First floetz gypsum with rock salt.
5. Varigated sand-stone.
6. Second floetz gypsum.
7. Second floetz or shell lime-stone.
8. Third sand-stone or free-stone.
9. Chalk.
10. Newest floetz trap.

The last formation, the newest floetz trap, lies over the rest, pretty much as the newer porphyry and sienite do over the older primitive formations.

1. *Old Red Sand-stone.*

This formation lies immediately over the transition, or, where they are wanting, over the primitive rocks. Hence it is considered as the oldest of the floetz formations.

Sand-stone is composed of grains of quartz, or some other siliceous stone, cemented together by some basis, and can only be considered as a mechanical mixture. The cement is sometimes clay, sometimes quartz, lime, marl, &c. and the sand-stone is named, in consequence, argillaceous, siliceous, calcareous, marly, &c. This cement

varies much in quantity, but never predominates; sometimes it is too small in quantity to be perceived. The size of the grains is no less subject to variation; when they are large the rock is sometimes called *pudding-stone*.

The old red sand-stone has usually a red colour. Its grains are large. They consist of quartz, flinty-slate, &c. cemented by iron-shot clay. It is distinctly stratified, and contains few ores. Cobalt, however, occurs in it; and it is often impregnated with copper, from the formation which lies over it.

2. *Independent Coal Formation.*

In Great Britain, where coal occurs in greater quantity than in any other country, it seems very generally to lie over the old red sand-stone. This at least is the case in the north of England and in Scotland. It is deposited in detached patches, usually in valleys over the red sand-stone, or over the transition formation when the red sand-stone is wanting. These patches, in general, have no connexion with each other. Hence the epithet *independent*, by which the formation is distinguished: but they are found in considerable quantities in the most distant parts of the earth, Europe, America, New Holland, and always similarly situated with respect to the other formations. Coal occurs in it in great abundance; though in the preceding formations it is very scarce, and indeed is only found in thin individual beds. Hence it is considered as characteristic of this formation. The rocks of which (not reckoning the coal) this formation is composed are the following:

Sand-stone.	Lime-stone.
Coarse conglomerate.	Marl.
Slate-clay.	Clay iron-stone.
Bituminous shale.	Porphyritic-stone.
Indurated clay.	Green-stone.

Rocks belonging to it.

Layers of these rocks alternate a great many times with each other, and in them the coal occurs in numerous beds, varying extremely in thickness. The subspecies of coal which occur in this formation are *coarse coal, foliated coal, cannel coal, slate coal,* and a little *pitch coal.* Professor Jameson has likewise discovered glance-coal in this formation.

All the different rocks of which this formation is com- Includes se-

posed seldom or never occur together. Hence it is presumed, that there are several subordinate formations belonging to the independent coal, which occupy determinate situations with respect to each other. Three such formations have been characterized. The oldest or lowest is composed of beds of *indurated clay, lime-stone, marl, porphyritic stone, slate-clay, bituminous shale, green-stone,* and *soft sand-stone,* and is characterized by containing in it some metallic ores. These are ores of *copper, iron, lead,* and perhaps also *mercury.* The second is composed of beds of *indurated clay, marl, lime-stone,* and *porphyritic stone.* It contains some pyrites, but no other ore. The third, or newest, is composed of *soft sand-stone, conglomerate,* and *slate-clay,* and contains no ore.

The *sand-stone* of this formation consists usually of grains of quartz, differing in size, and cemented by a calcareous or argillaceous, and sometimes even a siliceous basis. Its colour is various, though most commonly grey, and it often contains very thin seams of coal interspersed through it. It is often employed in building.

The *conglomerate* consists of fragments of lime-stone, quartz, greywacka, &c. cemented together by a basis of clay.

The *slate-clay, bituminous shale,* and *indurated clay,* are the minerals described in the last chapter under these names.

The *lime-stone* belongs to the *compact* subspecies, has a splintery fracture, and is scarcely translucent on the edges.

The *marl* and *clay iron-stone* are the minerals described in the preceding chapter under these names. The *green-stone,* which was first discovered in this formation by Professor Jameson, belongs to the species which occurs in the floetz trap rocks, to be described immediately. The *porphyritic stone,* I presume, consists of a clay basis, containing crystals of felspar.

The rocks belonging to this formation are very distinctly stratified. Abundance of petrifactions occur in it, especially in the sand-stone and bituminous shale. They are chiefly of vegetables; ferns, reeds, &c. are the most common. Those in the sand-stone are usually rather casts of vegetables than real petrifactions. They seem often to resemble palms, &c.; but none of them have been distinctly referred to any vegetable species at present existing.

3. *First Floetz Lime-stone.*

Floetz lime-stone is usually of a grey colour; its fracture is compact; it has no lustre, and is only translucent on the edges. Sometimes, indeed, thin beds of granular foliated lime-stone occur in it; but they contain petrifactions, which distinguish them from primitive lime-stone. Floetz lime-stone is well characterized by the masses of horn-stone and flint which it contains.

The first floetz lime-stone formation lies over the old red sand-stone, and is well characterized by a bed of bituminous marl-slate, containing copper, which is peculiar to it. This bed is always situated lowest, and therefore immediately contiguous to the sand-stone. It contains but few petrifactions; and when they occur they are in the undermost strata, and in the bituminous marl bed. They consist chiefly of fish. Various beds of marl occur in this formation, and likewise a species of vesicular lime-stone, known in Germany by the name of *rauch wacke.*

Foreign minerals.

4. *First Floetz Gypsum.*

Gypsum, in general, may be considered as a simple rock; sometimes, however, it contains crystals of boracite, arragonite, and quartz. Sulphur is likewise found in it, both disseminated and in compact masses. There are two formations of it.

The first floetz gypsum lies immediately over the first floetz lime-stone. It consists chiefly of foliated and compact gypsum, together with a good deal of selenite. It is in this formation that swine-stone occurs, either in beds or mixed with the gypsum. Rock salt also belongs to it, and appears to lie over it in short thick beds, being usually mixed with a species of saline clay. Hence the saline springs, which obviously originate from rock salt, are likewise peculiar to this formation.

Rock salt and salt springs.

5. *Variegated Sand-stone.*

This formation lies immediately over the preceding. The rock which composes it consists of a fine granular argillaceous sand-stone, usually of a green, brown, red, and white colour. Several of these colours alternate in stripes, which gives the stone a variegated appearance. Hence the name.

It often contains masses of a fat clay, of a greenish, reddish, or yellowish colour.

This formation is characterized by two species of rocks, which occur in it in beds. These are, 1. The subspecies of lime-stone described in the last chapter under the name of *roe-stone;* and 2. *Sand-stone slate.* The first is almost peculiar to this formation; but the second is found also, though in small quantity, in the *old red sand-stone.* It consists chiefly of fine micaceous scales, forming a slaty texture, and having generally thin layers of fine granular sand-stone interposed between them.

6. *Second Floetz Gypsum.*

This formation lies over the preceding in beds, and is sometimes, to a certain degree, mixed with it. It contains foliated gypsum, but scarcely any selenite, and no swine-stone; and is characterized by the fibrous gypsum, of which it is in a great measure composed. It is of no great extent; and, like the first floetz gypsum, is destitute of petrifactions.

7. *Second Floetz Lime-stone,* or *Shell Lime-stone.*

This formation is separated from the first floetz lime-stone by the beds of older gypsum, of variegated sand-stone, and of second gypsum; which constitute the third, fourth, and fifth formations. It is characterized by the vast number of shells which it contains in the state of petrifactions. It contains little marl; and only individual beds or seams of coal occur in it, so small as not to be worth working. In many places flint and horn-stone are found in it; sometimes in small beds, sometimes in plates, and sometimes massive or in roundish pieces. Particles of galena are likewise found scattered through it.

8. *Third Sand-stone,* or *Free-stone.*

Though the relative position of this formation has not been well ascertained, yet it is known to cover all the preceding, and therefore to be much newer than either the first or second sand-stone formations. It consists mostly of a sand-stone of a white colour, well adapted for building. It contains traces of coal, but no sand-stone slate, nor roe-stone; and gypsum never occurs either immediately over

or under it. It is usually stratified, and contains natural rents or seams, which cross each other at right angles; the one parallel to the stratification, the other perpendicular to it, so that it can be easily quarried into large square blocks. This indeed is a character that in some measure applies to all the sand-stones. When not covered by any other formation, it forms beautiful hills and romantic valleys.

9. *Chalk.*

Chalk occurs in great abundance in England and the northern parts of France. In England there occur about ten beds between the *lias lime-stone* and the chalk. These consist of marl, clay, sand, and lime-stone. Immediately under the chalk there is usually a bed of green-coloured sand, of no great thickness.

Chalk contains numerous beds of nodular flint, often full of vesicles. Various petrifactions of echinites, belemnites, &c. occur in it. It is indistinctly stratified, and forms beautiful round knols and hills of very small height. Pyrites is sometimes found in it, but scarcely any other metallic ore.

10. *Newest Floetz Trap.*

Beds of floetz trap occur in the old red sand-stone, and perhaps also in other situations. But those called *newest floetz trap* cover the other floetz rocks, precisely as the newer porphyry and sienite do the primitive. The level of the uncovered floetz formations becomes gradually lower, in the order in which they have been described; but that of the floetz trap is high, as it covers them all, and often forms the summit of hills whose lower part consists of older formations. The rocks belonging to the floetz trap formations are of two kinds; namely, those which are peculiar to it, and those which occur also in other formations. The following are the rocks peculiar to this formation:

Wacka.	Porphyry slate.	Rocks peculiar to this formation.
Iron-clay.	Grey-stone.	
Basalt.	Amygdaloid.	
Pitch-stone.	Trap tuff.	
Green-stone.		

Basalt claims the first place, as it characterizes the floetz

formation. It consists essentially of the mineral described in the last chapter, under the name of *basalt*, for a basis, containing crystals of basaltic hornblende, augite, olivine, and iron-sand, which give it a porphyritic structure. It contains also vesicles, which are filled with zeolite, calcareous spar, lithomarge, &c. The vesicles are sometimes filled with water. Sometimes it passes into wacka; sometimes into grey-stone; and sometimes, though rarely, into porphyry slate.

Wacka is sometimes the simple mineral described under that name in the preceding chapter. Sometimes it contains basaltic hornblende and mica, which give it a porphyritic appearance; sometimes it is spotted, from crystals which it contains. It passes sometimes into clay; sometimes into basalt. The *iron-clay* likewise has been described in the preceding chapter.

Pitch-stone was first observed in this formation by Professor Jameson. It is distinguished from that which occurs in the older rocks by the following circumstances. Its colours are usually black or green; it is composed of lamellar distinct concretions, and it contains crystals of glassy felspar, or *meionite* as it is called.

Porphyry-slate is much less common than basalt; but where it does occur it usually forms considerable hills. This rock is slaty in the large, compact and splintery in the small. The basis of it consists of clink-stone; the crystals which it contains are of felspar and hornblende. It contains also zeolite, iron-sand, and some minerals not yet described.

Grey-stone is still less common than porphyry slate. It appears to consist of an intimate mixture of much white felspar and a little black hornblende. This basis contains augite and olivine.

Floetz green-stone is an intimate mixture of grains of felspar and hornblende. It is distinguished from primitive and transition green-stone by the more intimate mixture and less crystallized appearance of the constituents. It passes into basalt.

Amygdaloid has for its basis sometimes *wacka*; sometimes a fine granular green-stone, frequently already somewhat decomposed. The vesicles which it contains are filled with green earth, lithomarge, steatite, &c. Sometimes they remain empty; sometimes this basis contains crystals of horn-

blende, &c. which gives the rock both a porphyritic and amygdaloidal structure.

Trap-tuff consists of fragments of floetz trap and other rocks, cemented by a basis of alluvial clay.

The minerals which this formation contains, in common with others, are not so numerous as the preceding. They are the following:

Sand.	Lime-stone.
Quartzy sand-stone.	Coal.
Clay.	

The grains of sand are of all degrees of magnitude. The clay sometimes contains *schaum earth*. The coal consists chiefly of the following subspecies: *common brown coal, bituminous wood,* and *pitch coal.* Sometimes, though seldom, *glance coal* and *columnar coal* occur in this formation.

The lowest bed of the floetz trap formation consits of sand, which becomes gradually finer and finer as we approach the upper part of the bed; at last it becomes clayey, and gradually passes into indurated clay. Over this lies a bed of wacka, into which the clay gradually passes. The wacka, in its turn, passes into basalt; and the basalt into green-stone, grey-stone, or porphyry slate, which constitute the uppermost part of the formation: so that the lowest part of this formation consists entirely of a mechanical deposite, while the uppermost part has the appearance of a chemical compound. Instead of the sand, we sometimes find the quartzy sand-stone, as if the sand had been united together by siliceous cement.

When coal occurs in this formation it commonly lies under the basalt. In these cases, beds of sand, clay, wacka, basalt, &c. are found in several repeated series.

All the rocks of this formation seldom or never occur together; sometimes one, sometimes more, are wanting. They are commonly horizontally stratified, and form conical, insulated rocks, often flat at the top. This formation extends over the whole earth, but the beds are broken and interrupted, so as to cap detached mountains, or fill up hollows, but all similarly situated with regard to each other. It is the newest of the floetz formations, as it covers not only the older, but likewise even the newest floetz formations.

Besides these formations, there appear to be several others

not yet described.   How far these are universal or limited to particular spots has not yet been decided.   Thus in the environs of Paris, the lowest rock known consists of chalk in very thick beds.   Over the chalk lie about 11 beds of various substances, nearly in the same order and thickness in all the hills in the neighbourhood.   These beds are obviously newer than the chalk ; and they differ in their nature from all the floetz formations above described.   An excellent account of these beds has been published by different mineralogists in Paris, especially De la Metherie, and Cuvier and Brogniart.   The following are these beds arranged according to their position, beginning with the lowest in the order, and terminating with that at the surface of the earth.

1. Clay.
2. Lime-stone.
3. Plaster, or a mixture of gypsum and limestone.
4. Marl and adhesive slate.
5. Plaster.
6. Marl and adhesive slate.
7. Plaster.
8. Marl and adhesive slate.
9. Clay containing sulphate of strontian in nodules.
10. Marl.
11. Sand.

1. The bed of clay is about 30 feet thick; but it varies in thickness in different places.   It contains very thin beds of sand, and a kind of bituminous matter is found in it which burns when heated, and emits a smell like coal.

2. The lime-stone differs in its appearance, but the greatest part of it is a species of roe-stone full of small shells. It is the stone employed for building in Paris.   At first it is very soft, but it hardens by exposure to the air.   It is subject to moulder down, and hence the decay observable in several of the public buildings of that capital.   A stone nearly similar occurs in the neighbourhood of Bath, and is there employed as a building stone.   It is not improbable, from this circumstance, that formations similar to those at Paris occur near Bath.

3. Over the lime-stone lies a bed of plaster about 16 feet thick, called by the workmen the *low mass*.   It is mixed

here and there with marl and adhesive slate. It contains also thin beds of selenite.

4. Over the *low mass* lies a bed of marl and adhesive slate, about 16 feet thick.

5. Over this lies the second bed of plaster, about 15 feet thick, called the *middle mass*, and divided into several layers; some of these consist of ordinary plaster, others of *selenite*, called *grignards* by the workmen, and rejected by them.

6. Over the *middle mass* lies a bed of adhesive slate and marl, about 20 feet thick. This bed in Montmartre contains a thin bed of variegated clay, a kind of fuller's earth. Instead of this, *menilite* occurs in Meneil Montant. It contains rifts, often filled with lenticular selenite.

7. Over the preceding lies a bed of plaster about 50 feet thick, called by the workmen the *high mass*. It is divided into a number of layers. This bed at Meneil Montant is divided into irregular columns, similar to those so common in basaltic and green stone mountains. It contains a number of siliceous nodules like agates, often hollow within and filled with plaster.

8. Over the *high mass* lies a bed of marl and adhesive slate, about 70 feet thick, and very distinctly stratified. It contains vegetable petrifactions.

9. Over this lies a bed of greenish-coloured clay about 18 feet thick. It contains very impure sulphate of strontian in irregular nodules, which form thin beds like flint in chalk. It contains also regular crystals of selenite.

10. Over this lies a bed of marl about 18 feet thick, regularly stratified, and in the lower part of which occurs a great variety of common oyster shells.

11. The uppermost bed of all, which crowns the hills in the neighbourhood of Paris, consists of fine sand, containing in it abundance of sea shells. Sometimes this sand is agglutinated, constituting a kind of sand-stone. Sometimes it becomes hard enough to be used as a mill-stone. Sometimes it contains masses of a kind of clay iron-stone. It contains abundance of mica. It is about 55 feet thick.

It is chiefly in the beds of plaster that the great number of fossil bones of land animals have been found, for the description of which we are chiefly indebted to Cuvier.*

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* See Jour. de Phys. lxvi. 309.

CLASS IV.   ALLUVIAL FORMATIONS.

The alluvial formations constitute the great mass of the earth's surface.   They have been formed by the gradual action of rain and river water upon the other formations, and may be considered as very recent formations, or rather as deposites, the formation of which is still constantly going on.   They may be divided into two kinds; namely, those deposited in the valleys of mountainous districts, or upon the elevated plains which often occur in mountains; and those deposited upon flat land.

Of two
kinds.

The first kind consists of sand, gravel, &c. which constituted the more solid parts of the neighbouring mountains, and which remained when the less solid parts were washed away.   They sometimes contain ores (particularly gold and tin) which existed in the neighbouring mountains.   Sometimes the alluvial soil is washed, in order to separate these ores.   On mountain plains there occur also beds of loam.

The second kind of alluvial deposite, or that which occupies the flat land, consists of loam, clay, sand, turf, and calctuff.   Here also occur earth and brown coal (in this mineral amber is found), wood coal, bituminous wood, and bog iron ore.   The sand contains some metals, among others gold.   The calctuff is a chemical deposite and extends widely.   It contains plants, roots, moss, bones, &c. which it has encrusted.   The clay and sand often contain petrified wood, and likewise skeletons of quadrupeds.

CLASS V.   VOLCANIC FORMATIONS.

The volcanic formations are of two kinds; namely, the *pseudo-volcanic* and the *true volcanic.*

Pseudo-vol-
canic.

The pseudo-volcanic consist of minerals altered in consequence of the burning of beds of coal situated in their neighbourhood.   *Porcelain jasper, earth slag, burnt clay, columnar clay iron-stone,* and perhaps also *polishing slate,* are the minerals which have been thus altered.

Volcanic.

The real volcanic minerals are those which have been thrown out of the crater of a volcano.   They are of three kinds; 1. Those substances which, having been thrown out from time to time, have formed the crater of the mountain: 2. Those which have been thrown out of the crater in a stream, and rolled down the mountain; they constitute

lavas: 3. The water which is occasionally thrown out of volcanoes, containing ashes and other light substances, gradually evaporating, leaves the earthy matter behind it; this substance constitutes *volcanic tuff.*

In America it would appear that all elevations higher than Mount Blanc are entirely composed of volcanic matter.

SECT. III.

OF VEINS.

VEINS are mineral repositories which cut through the strata or beds of which a mountain is composed, and which are filled with substances more or less different from the rocks through which they pass. We shall have a very distinct notion of veins, if we suppose that the mountains in which they occur were split by some means or other, and that the rifts thus formed were filled up by the matter which constitutes veins. They are distinguished from *beds* by their direction, which is either perpendicular to the stratifications, or at least forms an angle with it.

Sometimes the strata through which veins pass are merely separated from each other; so that if we cut through the vein we find the same strata of the rock on both sides of it: but sometimes also the corresponding strata on one side are lower than on the other, as if the portion of the rock on one side of the vein had sunk a little, while the portion on the other side kept its original position. In such cases, the side of the rock against which the vein leans, or the *floor* of the vein, has always its strata highest up; while the strata of the portion of rock which leans over the vein, or the *roof* of the vein, are always lowest. So that this is the portion which appears to have sunk. Such a change of position in the strata is known in this country by the name of a *shift.*

In considering veins, there are two circumstances which claim our attention: namely, 1. The shape of veins; and, 2. The substances with which they are filled.

1. All those mineralogists who have had the best opportunity of examining the shape of veins with correctness agree in representing them as widest above, and as gra-

Nature of veins.

Their shape.

1

dually diminishing in size as they deepen, till at last they terminate in a point, exactly as if they had been originally fissures. This is the account of Oppel, of Werner, and indeed of all those writers who have been professionally engaged in superintending mines. Sometimes, indeed, veins widen in different parts of their course, and afterwards contract again to their former size; but more commonly they continue diminishing gradually to their extremity.

2. Sometimes these veins are either partially or entirely empty. In that case they are denominated *fissures;* but most commonly they are filled with a matter more or less different from the rock through which they pass. Sometimes the vein is filled up with one species of mineral. Thus we have veins of *calcareous spar, of quartz,* &c.; but when it is of any size, we frequently find a variety of substances: these are disposed in regular layers always parallel to the sides of the vein, and they follow in their position a very regular order. One species of mineral constitutes the centre of the vein : on each side of this central bed the very same *layers* occur in the same order from the centre to the side of the vein. To give an example; the vein *Gregorius,* at Freyberg, is composed of nine layers or beds. The middle of the vein consists of a layer of *calcareous spar;* on each side of this is a layer consisting of various ores of *silver* mixed together; on each side of this a layer of *brown spar;* on each side of this a layer of *galena;* on each side of this, again, and contiguous to the side of the vein, is a layer of *quartz.* The following sketch will give the reader some notion of the relative position of these layers :

Gneiss rock.	Quartz.	Galena.	Brown spar.	Silver ore.	Calcareous spar.	Silver ore.	Brown spar.	Galena.	Quartz.	Gneiss rock.

Sometimes the number of layers of which a vein is composed greatly exceeds this. Werner describes one in the district of Freyberg, in which the middle layer is calcareous

spar, having on each side of it no less than thirteen layers arranged in the very same order.*

Almost every mineral substance which occurs in the mass of rocks has been found in veins. We sometimes find them filled with different well-known stony bodies. Thus veins of granite, porphyry, lime-stone, basalt, wacka, green-stone, &c. are not uncommon; † veins of quartz, clay, felspar, &c. are equally common.

Pit-coal and common salt, and almost all the metals, likewise occur in veins. Some veins are filled with water-worn pebbles, as one observed by Werner at Joachimstahl.‡ Some are filled with loam.§ Nay, they even sometimes contain petrifactions. Thus Baron de Born describes a petrified porpites which he saw in a compact cinnabar vein in Hungary; and Mr. de Schlottheim communicated an account of a still more remarkable appearance of the same kind to Werner. In a calcareous mountain in Thuringia, there occur veins of marl five or six inches thick, containing petrifactions differing altogether from those which are found in the lime-stone. The petrifactions found in the marl are, cornua ammonis, terebrates, and turbinites; while those that occur in the lime-stone rock are trochites. Beds of the marl occur in the neighbourhood; and these beds contain the same petrifactions that are found in the veins.‖

3. It is very common to find veins crossing each other in the same rock. When that happens, one of the veins may be traced passing through the other without any interruption, and cutting it in two, while the other always separates, and disappears at the point of crossing.

4. Such is a short sketch of the most remarkable pheno- mena respecting veins. Werner supposes that they were originally fissures formed in the rocks, and that they were all gradually filled by minerals deposited slowly from above, while the rocks in which they occur were covered by water, and that they were filled at the same time that the different formations were deposited. This theory he has supported in his book on Veins, by a very complete enumeration of all the circumstances respecting their structure and appear-

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* Nouvelle Theorie de la Formation des Filons, p. 100.
† Werner, Nouvelle Theorie, p. 93.
‡ Ibid. p. 81. § Ibid. p. 82. ‖ Ibid. p. 88.

ances. He has shown that they resemble fissures very exactly in their shape and direction; and that as they contain petrifactions and minerals altered by the action of water, they must of necessity have been filled from above.

Veins of course, according to this theory, are newer than the rocks in which they occur; and when two veins cross, that is obviously the newest which traverses the other without interruption, as the fissures constituting the second vein must have been formed after the first vein was filled up. When different veins contain the same minerals arranged in the same order, he conceives that they were filled at the same time, and says that such veins belong to the *same* formation. When they differ in these respects, they belong to different formations. From the position of the respective veins with respect to each other, he deduces their relative age; and from this draws inferences respecting the relative age of the different mineral substances that occur in veins, similar to the inferences drawn respecting the age of the rocks which constitute the grand classes of formations described in the preceding chapter. But for these curious and important consequences which he deduces from his theory, I must refer the reader to Werner's treatise, an English translation of which has been lately published by Dr. Anderson.

I shall conclude this short sketch of Werner's geognosy with two tables, exhibiting the different formations in which the most important stony bodies and ores occur, without distinguishing whether they are found in beds or in veins.

Table of Stones.

FORMATIONS.	Diamond.	Zircon.	Hyacinth.	Chrysolite.	Olivine.	Coccolite.	Augite.	Vesuvian.	Leucite.	Melanine.	Garnet.	Granatite.	Spinell.	Sapphire.	Emery.	Corundum.	Topaz.	Emerald.	Beryl.	Schorl.
1. Primitive							X	?						?			X			
2. Granite											X	X							X	X
3. Gneiss											X	X					X			X
4. Mica-slate											X	X					X	X		X
5. Clay-slate											X	X		X				X		X
6. Primitive Trap						X														
7. Porphyry and Sienite		?									?					?				
8. Greywacka																	X			
9. Trans. Lime-stone																				
10. Transition Trap																				
11. Transition Flint-slate																				
12. Old Red Sand-stone																				
13. First Floetz Lime-stone																				
14. First Floetz Gypsum																				
15. Variegat. Sand-stone																				
16. Second Floetz Gypsum																				
17. Shell Lime-stone																				
18. Third Lime-stone																				
19. Chalk																				
20. Independent Coal																				
21. Floetz Trap	X	X	X		X		X		X	X			X	X						
22. Alluvial													X	X					X	X

Table of Stones continued.

FORMATIONS.	Epidote.	Schorl.	Beryl	Axinite	Quartz	Iron-flint	Horn-stone.	Flint.	Calcedony.	Opal.	Jasper.	Chrysoprase.	Obsidian.	Pitch-stone.	Pearl-stone.	Pumice.	Prehnite.	Zeolite.	Felspar.	Porcel. Earth.	Clay.
1. Primitive																	X	X			
2. Granite					X				?	X	X			X	X				X	X	
3. Gneiss	X	?	X	X	X	X	X	X	X	X	X			X					X	X	
4. Mica-Slate		X			X		X	X	X	X	X			X					X		
5. Clay-Slate	X				X		X	X	X	X	X								X		
6. Primitive Trap	X		X	X													?	X	X		
7. Porphyry and Sienite					X		X		X	X	X	X	X	X	X	X			X		
8. Greywacka					X						X							X			
9. Trans. Lime-stone																					
10. Transition Trap					X				X	X	X								X		
11. Transition Flint-slate					X																
12. Floetz																					
13. Old Red Sand-stone					X																
14. First floetz Lime-stone							X														
15. First Floetz Gypsum					X																
16. Variegat. Sand-stone					X																
17. Second Floetz Gypsum																					
18. Shell Lime-stone							X	X													
19. Third Lime-stone							X	X													
20. Chalk							X	X													
21. Independent Coal					X									X					X		
22. Floetz Trap	X				X		X	X	X	X	X		X	X	X	X	X	X	X		X
23. Alluvial					X		X	X	X		X								X	X	X

Table of Stones continued.

	Clay-stone.	Adhes. Slate.	Polish Slate.	Mica.	Pot-stone.	Chlorite.	Hornblende.	Clink-stone.	Green Earth.	Lithomage.	Ful. Earth.	Steatite.	Nephrite.	Serpentine.	Talc.	Asebestus.	Actiuolite.	Tremolite.	Cyanite.	Arragonite.	Brown Spar.	Dolomite.	Rhomb Spar.	Swine-stone.	Marl.
1																						X			
2				X		X		X				X	X								X				
3				X		X	X			X		X	X	X	X	X	X	X		X	X				
4				X		X	X							X	?	X	X	X			X				
5				X	X	X	X						X	X	X	X	X	X	X		X		X		
6						X	X				X										X				
7	X			X			X		X	X		X		X	X	X					X				
8				X								X				X				X	X				
9																				X					
10				X			X		X								X								
11																									
12		X									X														
13																					X				
14																									
15																									
16																									
17																			?						
18																								X	
19																									
20																									
21	X			X		X	X	X	X											X	X			X	
22			X			X	X	X	X		X						X			X	X				?
23		X	X	X							X														

2 P 2

Table of Stones continued.

FORMATIONS.	Apatite.	Asparag. Stone.	Phosphorite.	Fluor Spar.	Cube Spar.	Carb. of Bar.	Sulph. of Bar.	Carb. of Stron.	Sulph. of Stron.	Boracite.	Honey-stone.	Chriolite.	Carb. of Soda.	Common Salt.	Sulphur.	Amber.	Mineral Pitch.	Brown Coal.	Black Coal.	Glance Coal.	Graphite.
1. Primitive												X									
2. Granite	X		X	X			X	X									X				
3. Gneiss			X	X			X													X	X
4. Mica-slate				X			X								X					X	X
5. Clay-slate		X		X			X													X	X
6. Primitive Trap	?	X					X														
7. Porphyry and Sienite				X			X								X						
8. Greywacka				X			X										X			X	?
9. Trans. Lime-stone																					
10. Transition Trap							X										X				
11. Transition Flint-slate							X														
12. Floetz		X							X												
13. Old Red Sand-stone							X														
14. First Floetz Lime-stone			X				X										X	X			
15. First Floetz Gypsum					X					X				X	X						
16. Variegat. Sand-stone																					
17. Second Floetz Gypsum				X																	
18. Shell Lime-stone																					
19. Third Lime-stone																					
20. Chalk.																					
21. Independent Coal				X		X	X												X	X	X
22. Floetz Trap				X			X								X		X	X	X	X	
23. Alluvial											X				X	X	X	X			

Table of Metals.

FORMATIONS.	Gold.	Platinum.	Silver.	Mercury.	Palladium.	Rhodium.	Osmium.	Iridium.	Copper.	Iron.	Nickel.	Tin.	Lead.
1. Primitive													
2. Granite	X		X						X	X	X	X	X
3. Gneiss	X		X						X	X	X	X	X
4. Mica-slate	X		X						X	X	X	X	X
5. Clay-slate	X		X	X					X	X	X	X	X
5. Porphyry	X		X						X	X		X	X
7. Greywacka	X		X						X	X			X
8. Trans. Lime-stone	X									X			X
9. Transition Trap			X						X	X			
10. Flint-slate													
11. Old Red Sand-stone	X		X						X	X			
12. First Floetz Lime			X	X					X	X			
13. First Floetz Gypsum										X			
14. Variegat. Sand-stone										X			
15. Second Floetz Gypsum										X			
16. Second Floetz Lime										X			
17. Third Floetz Lime													
18. Chalk										X			
19. Independent Coal	X		X	X					X	X			X
20. Floetz Trap									X	X			
21. Alluvial	X	X			X	X	X	X	X	X		X	

Table of Metals continued.

FORMATIONS.	Zinc.	Bismuth.	Antimony.	Tellurium.	Arsenic.	Cobalt.	Manganese.	Chromium.	Molybdenum.	Uranium.	Tungsten.	Titanium.	Columbium.	Cerium.
1. Primitive														X
2. Granite	X	X			X	X	X		X	X	X	X		
3. Gneiss	X	X	X		X				X	X	X			
4. Mica-Slate	X	X	X		X	X			X	X	X	X		
5. Clay-Slate		X	X		X				X	X	X	X		
6. Porphyry		X		X	X		X				X			
7. Greywacka	X		X	X		X	X							
8. Trans. Lime-stone	X			X			X							
9. Transition Trap														
10. Flint-slate														
11. Old Red Sand-stone														
12. First Floetz Lime						X								
13. First Floetz Gypsum					X									
14. Variegat. Sand-stone														
15. Second Floetz Gypsum														
16. Second Floetz Lime														
17. Third Floetz Lime														
18. Chalk														
19. Independent Coal	X													
20. Floetz Trap												?		
21. Alluvial												X		

CHAP. IV.

OF THE ANALYSIS OF MINERALS.

THE progress which the art of analysing minerals has made within these last thirty years is truly astonishing. To separate five or six substances intimately combined together, to exhibit each of them separately, to ascertain the precise quantity of each, and even to detect the presence and the weight of substances which do not approach $\frac{1}{500}$th part of the compound, would, at no very remote period, have been considered as a hopeless, if not an impossible, task; yet this can now be done with tolerable accuracy.

Analysis of minerals.

The first person who undertook the analysis of minerals was Margraff of Berlin. His attempts were indeed rude; but their importance was soon perceived by other chemists, particularly by Bergman and Scheele, whose industry and address brought the art to a considerable degree of perfection.

Begun by Margraff;

But their methods, though they had very considerable merit, and, considering the state of the science, are wonderful proofs of the genius of the inventors, were often tedious and uncertain, and could not in all cases be applied with confidence. These defects were perceived by Klaproth, who applied himself to the analysis of minerals with a persevering industry which nothing could fatigue, and an ingenuity and accuracy which nothing could perplex. He corrected what was wrong, and supplied what was wanting, in the analytical method; invented new processes; discovered new instruments; and it is to his labours, more than to those of any other chemist, that the degree of perfection, to which the analysis of minerals has attained, is to be ascribed. Many improvements, however, were introduced by other chemists, especially by Vauquelin, whose analyses, both in point of accuracy and ingenuity, and in number, rival those of Klaproth himself. And by Berzelius who has lately distinguished himself very much as an analyst.

Improved by Klaproth.

And others.

I shall, in the following sections, sketch out the methods of analysis at present practised. But it will be proper, in the first place, to premise the following observations.

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Before a mineral is submitted to analysis, it ought to be reduced to an impalpable powder. When the stone is extremely hard, it may be heated to redness, and then thrown into cold water. This makes it crack and break into pieces. If these pieces are not small enough, the operation may be repeated. These fragments are then to be beaten to small pieces in a polished steel mortar ; the cavity of which should be cylindrical, and the steel pestle should fit it exactly, in order to prevent any of the stone from escaping during the act of pounding.

When the stone has been thus pounded, a certain quantity, whose weight is known exactly, 100 grains for instance, ought to be taken and reduced to as fine a powder as possible. This is best done by pounding small quantities of it at once, not exceeding five grains. The mortar employed is usually of agate. It may be about four inches in diameter, and rather more than an inch deep. The pestle is composed of the same ingredients. The powder is as fine as possible when it feels soft, adheres together, and as it were forms a cake under the pestle. It ought then to be weighed exactly. It will almost always be found heavier after being pounded than it was before; owing to a certain quantity of the substance of the mortar which has been rubbed off during the grinding, and mixed with the powder. This additional weight must be carefully noted ; and after the analysis, a portion of the ingredients of the mortar, corresponding to it, must be substracted. When the mortar is of agate or flint, the abstracted portion may be considered as pure silica.

It is necessary to have a crucible of pure silver, or of platinum, capable of holding rather more than seven cubic inches of water, and provided with a cover of the same metal.

The dishes in which the solutions, evaporations, &c. are performed, ought to be of glass or porcelain. Those of porcelain are cheaper, because they are not so apt to break. Those which Mr. Vauquelin uses are of porcelain; they are sections of spheres, and are glazed both within and without, except that part of the bottom which is immediately exposed to the fire. In this country we commonly use Wedgewood's glazed evaporating dishes. The glaze

is thin, and not so apt to crack as the glaze of the French porcelain; but perhaps it does not resist quite so well the action of strong reagents.

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SECT. I.

ANALYSIS OF EARTHS AND STONES.*

THE only substances which enter into the composition of Ingredients the simple stones, as far at least as analysis has discovered, of stones. are the six earths, silica, alumina, zirconia, glucina, lime, and magnesia; and the oxides of iron, manganese, nickel, chromium, and copper.† Seldom more than four or five of these substances are found combined together in the same stone: we shall suppose, however, in order to prevent unnecessary repetitions, that they are all contained in the mineral which we are going to analyse.

Let 100 or 200 grains of the stone to be analyzed, pre- Method of viously reduced to a fine powder, be mixed with three decompos- ing stones. times its weight of pure potash and a little water, and ex- posed in a silver crucible to heat. The heat should at first be applied slowly, and the matter should be constantly stirred, to prevent the potash from swelling and throwing any part out of the crucible. When the whole water is evaporated, the mixture should be kept for half an hour in a red heat.

If the matter in the crucible melts completely, and ap- pears as liquid as water, we may be certain that the stone which we are analysing consists chiefly of silica; if it re- mains opaque, and of the consistence of paste, the other earths are most abundant; if it remains in the form of a powder, alumina is the prevalent earth.‡ If the matter in

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* See Vauquelin's Treatise on the Analysis of Stones, Ann. de Chim. xxx. 66.

† Barytes has also been discovered in one single stone, the staurolite: but its presence in stones is so uncommon, that it can scarcely be looked for. The method of detecting it shall be noticed afterwards.

‡ Mr. Chenevix has suggested an ingenious method of analysing stones that do not fuse with potash. He put it in practice in analysing the dif- ferent varieties of corundum. This mineral is composed almost entirely

the crucible be of a dark or brownish-red colour, it contains oxide of iron; if it be grass-green, manganese is present; if it is yellowish-green, it contains chromium.

When the crucible has been taken from the fire and wiped on the outside, it is to be placed in a capsule of porcelain, and filled with water. This water is to be renewed, from time to time, till all the matter is detached from the crucible. The water dissolves a part of the combination of the alkali with the silica and alumina of the stone; and if a sufficient quantity were used, it would dissolve the whole of that combination.

Muriatic acid is now to be poured in till the whole of the matter is dissolved.* At first a flaky precipitate appears, because the acid combines with the alkali which kept it in solution. Then an effervescence takes place, owing to the decomposition of some carbonate of potash formed during the fusion. At the same time the flaky precipitate is redissolved; as is also that part of the matter which, not having been dissolved in the water, had remained at the bottom of the dish in the form of a powder. This powder, if it consists only of silica and alumina, dissolves without effervescence; but if it contains lime, an effervescence takes place.

If this solution in muriatic acid be colourless, we may conclude that it contains no metallic oxide, or only a very small portion; if its colour be purplish-red, it contains

of alumina, and is extremely hard. Potash acts upon it very feebly; so that, in the common way of analysis, the process is very tedious, and the quantity of potash necessary very great. Mr. Chenevix substituted borax in place of potash, which acts upon aluminous stones very readily. He mixed 100 grains of sapphire in powder with 250 grains of calcined borax, and exposed the mixture to a violent heat in a platinum crucible for two hours. The mass, when cold, had the appearance of a greenish-blue glass, which adhered strongly to the crucible. The whole was boiled in muriatic acid for some hours, by which a complete solution was obtained. The whole of the earthy matter was then precipitated by means of ammonia not entirely saturated with carbonic acid; and the precipitate, after being well washed, was redissolved in muriatic acid. By this means the borax was got rid of. The analysis was then conducted nearly in the manner described in the text, excepting only that muriate of ammonia was employed to separate the alumina from potash. Phil. Trans. 1802, p. 331.

* Muriatic acid does not dissolve the mass completely if the stone consists chiefly of silica.

manganese; orange-red indicates the presence of iron; and golden-yellow the presence of chromium.

This solution is to be poured into a capsule of porcelain, covered with paper, and evaporated to dryness on a sand bath. When the evaporation is drawing towards its completion, the liquor assumes the form of jelly. It must then be stirred constantly with a silver or porcelain rod, to facilitate the disengagement of the acid and water, and to prevent one part of the matter from being too much, and another not sufficiently dried. Without this precaution, the silica and alumina would not be completely separated from each other.

When the matter is reduced almost to a dry powder, a large quantity of pure water is to be poured on it; and, after exposure to a slight heat, the whole is to be poured on a filter. The powder which remains upon the filter is to be washed repeatedly, till the water with which it has been washed ceases to precipitate silver from its solutions. This powder is the *silica* which the stone that we are analysing contained. It must first be dried between folds of blotting paper, then heated red hot in a platinum or silver crucible, and weighed as soon as cold. It ought to be a fine powder, of a white colour, not adhering to the fingers, and entirely insoluble in acids. If it be coloured, it is contaminated with some metallic oxide; and shows that the evaporation to dryness has been performed at too high a temperature. To separate this oxide, the silica must be boiled with an acid, and then washed and dried as before. The acid solution must be added to the water which passed through the filter, and which we shall denominate A.

The watery solution A is to be evaporated till its quantity does not exceed an English pint. A solution of carbonate of potash is then to be poured into it till no more matter precipitates. It ought to be boiled a few moments to enable all the precipitate to fall to the bottom. When the whole of the precipitate has collected at the bottom, the supernatant liquid is to be decanted off; and water being substituted in its place, the precipitate and water are to be thrown upon a filter. When the water has run off, the filter, with the precipitate upon it, is to be placed between the folds of blotting paper. When the precipitate has acquired some consistence, it is to be carefully collected

Book III. by an ivory knife, mixed with a solution of pure potash, and boiled in a porcelain capsule. If any alumina or glucina be present, they will be dissolved in the potash; while the other substances remain untouched in the form of a powder, which we shall call B.

Alumina,   Into the solution of potash as much acid must be poured as will not only saturate the potash, but also completely redissolve any precipitate which may have at first appeared. Carbonate of ammonia is now to be added in such quantity that the liquid shall taste of it. By this addition the whole of the alumina will be precipitated in white flakes, and the glucina will remain dissolved, provided the quantity of carbonate of ammonia used be not too small. The liquid is now to be filtered; and the alumina which will remain on the filter is to be washed, dried, heated red-hot, and then weighed. To see if it be really alumina, dissolve it in sulphuric acid, and add a sufficient quantity of sulphate or acetate of potash; if it be alumina, the whole of it will be converted into crystals of alum.

Glucina,   Let the liquid which has passed through the filter be boiled for some time; and the glucina, if it contains any, will be precipitated in a light powder, which may be dried and weighed. When pure, it is a fine, soft, very light, tasteless powder, which does not concrete when heated, as alumina does.

Lime,   The residuum B may contain lime, magnesia, and one or more metallic oxides.* Let it be dissolved in weak sulphuric acid, and the solution evaporated to dryness. Pour a small quantity of water on it. The water will dissolve the sulphate of magnesia and the metallic sulphates; but the sulphate of lime will remain undissolved, or, if any portion dissolve, it may be thrown down by the addition of a little weak alcohol. Let it be heated red-hot in a crucible, and weighed. The lime amounts to 0·42 of the weight.

Let the solution containing the remaining sulphates be diluted with a large quantity of water; let a small excess of acid be added; and then let a saturated carbonate of potash be poured in. The oxides of chromium, iron, and

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* If yttria be suspected, let the residuum be treated with carbonate of ammonia, which will dissolve the yttria and leave the other bodies. Then proceed as above.

nickel will be precipitated, and the magnesia and oxide of manganese will remain dissolved. The precipitate we shall call C.

Into the solution let a solution of hydrosulphuret of potash be poured, and the magnanese will be precipitated in the state of a hydrosulphuret. Let it be calcined in contact with air, and weighed. The magnesia may then be precipitated by pure potash, washed, exposed to a red heat, and then weighed.

Let the residuum C be boiled repeatedly with nitric acid, then mixed with pure potash; and after being heated, let the liquid be decanted off. Let the precipitate, which consists of the oxides of iron and nickel, be washed with pure water; and let this water be added to the solution of the nitric acid and potash. That solution contains the chromium converted into an acid. Add to this solution an excess of muriatic acid, and evaporate till the liquid assumes a green colour; then add a pure alkali: the chromium precipitates in the state of an oxide, and may be dried and weighed.

Let the precipitate, consisting of the oxides of iron and nickel, be dissolved in muriatic acid; add an excess of ammonia: the oxide of iron precipitates. Let it be washed, dried, and weighed.

Evaporate the solution, and the oxide of nickel will also precipitate, or the whole may be precipitated by adding hydrosulphuret of ammonia; and its weight may be ascertained in the same manner as the other ingredients.

The weight of all the ingredients obtained are now to be added together, and their sum total compared with the weight of the matter submitted to analysis. If the two are equal, or if they differ only by ·03 or ·04 parts, we may conclude that the analysis has been properly performed: but if the loss of weight be considerable, something or other has been lost. The analysis must therefore be repeated with all possible care. If there is still the same loss of weight, we may conclude that the stone contains some substance, which has either evaporated by the heat, or is soluble in water.

A fresh portion of the stone must therefore be broken into small pieces, and exposed in a porcelain crucible to a strong heat. If it contains water, or any other volatile

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substance, it will come over into the receiver; and its nature and weight may be ascertained.

If nothing comes over into the receiver, or if what comes over is not equal to the weight wanting, we may conclude that the stone contains some ingredient which is soluble in water.

To discover whether it contains a *fixed alkali*, which is very frequently found in simple stones, three methods of analysis have been followed.

Methods of separating fixed alkalies.
1. The stone, reduced to an impalpable powder, is cautiously heated repeatedly with sulphuric acid, and the mass digested in water. This solution, properly concentrated, is set aside for some days. If crystals of alum make their appearance, we are sure that the mineral contained potash. The *potash* may be reckoned to amount to 0·104 of the weight of these crystals. If no crystals appear, the solution is to be evaporated to dryness, and the residue exposed to a moderate red heat. It is then to be digested in water, and the solution mixed with carbonate of ammonia, and filtered. It must be again evaporated to dryness, the residue exposed to a heat of 700°, and redissolved. The solution, by proper concentration, will yield crystals, either of sulphate of soda, or of potash, according to circumstances, and these are easily distinguished. Indeed the presence or absence of potash may be recognized by mixing the solution of the salt, obtained with a somewhat concentrated solution of nitro-muriate of platinum. If potash be present, the usual yellow precipitate of muriate of platinum-and-potash is obtained.

2. The method described in the last paragraph may be considered as a short abstract of the plans of analysis at first pursued by Vauquelin and Kennedy, to detect and distinguish fixed alkalies contained in minerals. The following method, invented by Rose, is much easier. He fused one part of the mineral under examination with four parts of nitrate of barytes, in a porcelain crucible. A spongy mass was obtained, which was of a light blue colour, and dissolved completely in diluted muriatic acid. The yellow-coloured solution was mixed with a sufficient quantity of sulphuric acid, not only to precipitate the barytes, but to expel the muriatic acid, and the liquid was evaporated

to dryness. The mass was digested in water, and then thrown upon a filter. The sulphate of barytes and silica remained behind. The solution, which was limpid, was saturated with carbonate of ammonia, and filtered a second time. All the earthy and metallic bodies were now separated, and the solution contained only the sulphates of fixed alkali and ammonia. It was evaporated to dryness, and the salt put into a porcelain crucible, and exposed to a heat sufficient to expel the sulphate of ammonia. The residuum was dissolved in water, and crystallized. Pure fixed alkaline sulphate was obtained. It was dissolved in water, and decomposed by means of acetate of barytes. The solution was filtered to separate the sulphate of barytes formed, and the liquid evaporated to dryness. The salt thus obtained was acetate of fixed alkali. It was reddened in a crucible. The charry residue was dissolved in water, filtered, and crystallized. It was now a fixed alkaline carbonate, easily distinguished by its properties.*

3. The third method has been practised by Davy. He fuses one part of the mineral under examination with two parts of boracic acid, dissolves the fused mass in diluted nitric acid, and concentrates the solution to separate the silica. The liquid is then mixed with carbonate of ammonia in excess, and boiled and filtered. By this means all the earthy and metallic ingredients are separated. The liquid is then mixed with a sufficient quantity of nitric acid, and evaporated till the whole of the boracic acid separates. Nothing now remains but the nitric acid, combined with the alkaline constituents of the mineral and with ammonia. The dry saline mass is freed from the nitrate of ammonia by a heat of 500°; and the nitrate of potash or soda, which remains, may easily be recognized by its properties.†

But simple stones have been recently discovered to contain fluoric acid; and the methods hitherto described are not sufficient to detect and appreciate the quantity of that substance. The method practised by Klaproth to detect the presence of this acid, is to heat the mineral containing it with sulphuric acid in a glass retort. The corrosion of the retort, and the siliceous deposite made on the water contained in the receiver, show sufficiently the pre-

* Klaproth, Beitrage, iii. 240.　　† Nicholson's Jour. xiii. 86.

sence of fluoric acid. To detect its quantity the mineral is fused with potash, and the silica separated as usual. The remaining liquid is precipitated by means of carbonate of potash; and the liquid, being neutralized, is mixed with lime water. The precipitate of fluate of lime, thus obtained, is heated to redness. He estimates the fluoric acid contained in the mineral at 0·48 of this fluate of lime.*

Analysis of saline stones,

In this manner may simple stones and aggregates be analysed. As to saline stones, their analysis must vary according to the acid which they contain. But almost all of them may be decomposed by one or other of two methods; of each of which I shall give an example.

1. *Analysis of Carbonate of Strontian.*

Of carbonates,

Klaproth analysed this mineral by dissolving 100 parts of it in diluted muriatic acid: during the solution 30 parts of carbonic acid escaped. The solution crystallized in needles; and when dissolved in alcohol burnt with a purple flame. Therefore it contained strontian. He dissolved a grain of sulphate of potash in six ounces of water, and let fall into it three drops of the muriatic solution. No precipitate appeared till next day. Therefore the solution contained no barytes; for if it had, a precipitate would have appeared immediately.

He then decomposed the muriatic acid solution by mixing it with carbonate of potash. Carbonate of strontian precipitated. By the application of a strong heat, the carbonic acid was driven off. The whole of the earth which remained was dissolved in water. It crystallized; and, when dried, weighed 69½.†

2. *Analysis of Sulphate of Strontian.*

Sulphates.

Vauquelin analysed an impure specimen of this mineral as follows:

On 200 parts of the mineral diluted nitric acid was poured. A violent effervescence took place, and part of the mineral was dissolved. The undissolved portion, after being heated red-hot, weighed 167. Therefore 33 parts were dissolved.

The nitric solution was evaporated to dryness: a reddish

* Gehlen's Jour. iii. 595.   † Klaproth, Beitrage, i. 260.

substance remained, which indicated the presence of oxide Chap. IV. of iron. This substance was redissolved in water, and some ammonia mixed with it; a reddish precipitate appeared, which, when dried, weighed one, and was oxide of iron. The remainder of the solution was precipitated by carbonate of potash. The precipitate weighed, when dried, 20, and possessed the properties of carbonate of lime. Therefore 200 parts of this mineral contain 20 of carbonate of lime, 1 of oxide of iron, and the remainder of the 33 parts he concluded to be water.

The 167 parts, which were insoluble in nitric acid, were mixed with 500 parts of carbonate of potash and 7000 parts of water, and boiled for a considerable time. The solution was then filtered, and the residuum washed and dried. The liquid scarcely effervesced with acids; but with barytes it produced a copious precipitate, totally indissoluble in muriatic acid. Therefore it contained sulphuric acid.

The undissolved residuum, when dried, weighed 129 parts. It dissolved completely in muriatic acid. The solution crystallized in needles; when dissolved in alcohol, it burnt with a purple flame; and, in short, had all the properties of muriate of strontian. Therefore these 129 parts were carbonate of strontian. Now, 100 parts of this carbonate contain 30 of carbonic acid; therefore 129 contain 38·7. Therefore the mineral must contain in 200 parts 90·3 of strontian.

Now, the insoluble residuum of 167 parts was pure sulphate of strontian; and we have seen that it contained 90·3 of strontian. Therefore the sulphuric acid must amount to 76·7 parts.*

Nearly in the same manner as in the first of these examples may the analysis of carbonate of lime and barytes be performed; and nearly in the same manner with the second we may analyse the sulphates of lime and barytes.

Phosphate of lime may be dissolved in muriatic acid, the Phos- excess of acid may be driven off as far as possible, and the phates, lime precipitated by oxalic acid; and the oxalate, calcined in a platinum crucible, leaves the lime. The liquid solution may be evaporated to dryness, and then melted to a glass, which will give us the weight of the acid.

The fluate of lime may be mixed with sulphuric acid and Fluates.

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* Jour. de Min. No. xxxvii. 1.

Book III. distilled. The fluoric acid will come over in the form of gas. What remains in the retort, which will consist chiefly of sulphate of lime, may be analysed by the rules already laid down.

Borates. 　The borate of lime may be dissolved in nitric or sulphuric acid. The solution may be evaporated to dryness, and the boracic acid separated from the residuum by means of alcohol, which will dissolve it without acting on any of the other ingredients. The remainder of the dry mass may be analysed by the rules laid down in this section.

SECT. II.

OF THE ANALYSIS OF COMBUSTIBLES.

THE only combustibles of whose analysis it will be necessary to speak are coals and sulphur; for the method of analysing the diamond and oil has already been given in the first part of this work.

Method of analysing coal. 　Coal is composed of charcoal, bitumen, and some portion of earth. The earths may be detected by burning completely a portion of the coal to be analysed. The ashes which remain after incineration consist of the earthy part. Their nature may be ascertained by the rules laid down in Sect. I. of this chapter.

For the method of ascertaining the proportion of charcoal and bitumen in coal, we are indebted to Mr. Kirwan.

When nitre is heated red-hot, and charcoal is thrown on it, a violent detonation takes place; and if the quantity of charcoal be sufficient, the nitre is completely decomposed. Now, it requires a certain quantity of pure charcoal to decompose a given weight of nitre. From the experiments of Lavoisier, it follows, that when the detonation is performed in close vessels under water, 13·21 parts of charcoal are capable of decomposing 100 parts of nitre.* But when the detonation is performed in an open crucible, a smaller proportion of charcoal is necessary, because part of the nitre is decomposed by the action of the surrounding air. Scheele found, that under these circumstances 10 parts of plumbago were sufficient to decompose 96 parts of nitre; and Mr.

* Mem. Scav. Etrang. xi. 626.

Kirwan found, that nearly the same quantity of charcoal was sufficient for producing the same effect.

Macquer long ago observed that no volatile oily matter will detonate with nitre, unless it be previously reduced to a charcoal; and that then its effect upon nitre is precisely proportional to the charcoal which it contains.* Mr. Kirwan, upon trying the experiment with *vegetable pitch* and *maltha*, found that these substances did not detonate with nitre, but merely burn upon its surface with a white or yellow flame; and that after they were consumed, nearly the same quantity of charcoal was necessary to decompose the nitre which would have been required if no bitumen had been used at all.† Now coals are chiefly composed of charcoal and bitumen. It occurred therefore to Mr. Kirwan, that the quantity of charcoal which any coal contains may be ascertained by detonating it with nitre: for since the bitumen of the coal has no effect in decomposing nitre, it is evident that the detonation and decomposition must be owing to the charcoal of the coal; and that therefore the quantity of coal necessary to decompose a given portion of nitre will indicate the quantity of carbon which it contains: and the proportion of charcoal and earth which any coal contains being ascertained, its bituminous part may be easily had from calculation.

The crucible which he used in his experiments was large; it was placed in a wind furnace at a distance from the flue, and the heat in every experiment was as equal as possible. The moment the nitre was red-hot, the coal, previously reduced to small pieces of the size of a pin-head, was projected in portions of one or two grains at a time, till the nitre would no longer detonate; and every experiment was repeated several times to ensure accuracy.

He found that 480 grains of nitre required 50 grains of Kilkenny coal to decompose it by this method. Therefore 10 grains would have decomposed 96 of nitre; precisely the quantity of charcoal which would have produced the same effect. Therefore Kilkenny coal is composed almost entirely of charcoal.

Cannel coal, when incinerated, left a residuum of 3·12 in the 100 parts of earthy ashes. 66·5 grains of it were re-

* Macquer's Dictionary, 2 edit. p. 481.   † Miner. ii. 522.

quired to decompose 480 grains of nitre; but 50 parts of charcoal would have been sufficient: therefore 66·5 grains of cannel coal contain 50 grains of charcoal and 2·08 of earth; the remaining 14·42 grains must be bitumen. In this manner may the composition of any other coal be ascertained.

As for sulphur, in order to ascertain any accidental impurities with which it may be contaminated, it ought to be boiled in thirty times its weight of water, afterwards in diluted muriatic acid, and lastly treated with nitro-muriatic acid. These substances will deprive it of all its impurities without acting on the sulphur itself, at least if the proper cautions be attended to. The sulphur may then be dried and weighed. The deficiency in weight will mark the quantity of the substances which contaminate the sulphur. The solutions may be evaporated and examined, according to the rules laid down in the first and third sections of this chapter.

SECT. III.

ANALYSIS OF ORES.

No general method. THE diversity of metallic ores is so great, that no general method of analysis can be given. Let us therefore follow the different orders, one by one, and point out the proper method of analysing each. In the rules which I propose to give I shall follow Bergman, to whom we are indebted for the first precise treatise on the analysis of ores, except when his methods have been superseded by the improvements of succeeding chemists.

1. *Gold Ores.*

Analysis of native gold. The presence of gold may easily be detected by treating the mineral supposed to contain it with nitro-muriatic acid, and dropping muriate of tin into the solution. If the solution contains any gold, a purple precipitate immediately appears.

Native gold ought to be dissolved in nitro-muriatic acid: the silver, if any be present, falls to the bottom in the state of muriate, and may be separated by filtration, and weighed.

Pour sulphate of iron into the solution, and the gold is precipitated in the metallic state. The copper, if any be present, may be precipitated by means of a plate of iron. The presence of iron may be ascertained by dropping tincture of nutgalls into a portion of the solution.*

The auriferous pyrites may be treated with diluted nitrous acid, which dissolves the iron and separates the sulphur. The gold remains insoluble, and is found in the state of small grains.

2. *Ores of Platinum.*

The grains of crude platina, which constitute the only ore of this metal, are exceedingly complex in their nature, containing not fewer than eight metals, and sometimes even more. These are mercury, gold, platinum, iron, palladium, rhodium, osmium, and iridium.

The mercury may be driven off by heat, and the gold then becomes visible, and may be picked out, as it is in grains merely mixed with the others. The iron exists, in part at least, in the state of iron-sand, and may be separated by the magnet. The portion combined with the platinum, if there be any such, is not so easily separated. The ore thus purified is mixed with diluted nitro-muriatic acid, which dissolves the rest of the gold. Strong nitro-muriatic acid, assisted by heat, dissolves the platinum, the palladium, and the rhodium. The black powder and the metallic scales which remain undissolved are composed of osmium and iridium, which may be separated by the alternate action of potash and muriatic acid. No good method is known of separating the portion of these metals, which dissolves along with the platinum without loss. The platinum is precipitated by a concentrated solution of muriate of ammonia, and the palladium by a solution of prussiate of mercury. The rhodium is obtained by adding common salt to the solution thus freed from the other metals, evaporating to dryness, and digesting the dry mass in alcohol. For a fuller account of these processes, the reader is referred to the dissertations of Wollaston, Tennant, Desfontaines, Fourcroy and Vauquelin.†

* Bergman, ii. 410.
† See these dissertations quoted in Vol. I. of this work, under the head of the respective metals.

3. *Ores of Silver.*

The analysis of the ores of silver has been always considered as very important, on account of the great value of the metal which they contain in greater abundance.

Analysis of native silver, 1. Native silver is to be dissolved in nitric acid. The gold, if the ore contains any, remains in the state of a black powder, and may be dried and weighed. The silver may be precipitated by common salt. One hundred parts of the precipitate dried denote about 75 parts of silver. The presence of copper may be ascertained by the greenish-blue colour of the solution, and by the deep blue colour which it assumes on adding ammonia. The copper may be precipitated by a plate of iron, or by the rules laid down hereafter. When the ore contains arsenic, its proportion may be estimated by weighing before and after fusion ; for the arsenic is dissipated by heat, or the ore may be dissolved as before in nitric acid, which acidifies the arsenic. After the separation of the silver, the arsenic acid may be precipitated by nitrate of lead.

Antimonial silver, 2. Alloy of silver and antimony is to be treated with nitric acid, which dissolves the silver and oxidizes the antimony. The silver is estimated as above. The oxide of antimony is to be dissolved in muriatic acid, and the metal thrown down by means of a plate of iron.*

Sulphuret, 3. Sulphuret of silver is to be treated with diluted nitric acid, which dissolves the silver, leaving the greater part of the sulphur untouched. The residuum is to be dried, and then the sulphur burnt off. The loss of weight gives the sulphur. The residuum, if any, is undecomposed sulphuret, to be treated as at first. The silver is to be precipitated by common salt; and the other metals, if any be present, may be ascertained as above. Part of the sulphur is always acidified. The acid thus formed may be precipitated by nitrate of barytes, 100 parts of the dried precipitate indicating about 14·5 of sulphur.†

Antimoniated silver. 4. Antimoniated silver ore was analysed by Klaproth in the following manner : 100 parts of it were boiled in diluted nitric acid. The residuum, washed and dried, was 26. These 26 were digested in nitro-muriatic acid. The re-

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* Klaproth, iii. 175.   † Ibid. i. 172.

siduum now weighed 13 (so that 13 had been dissolved,) 12 of which were sulphur, and burnt away, leaving behind them one part of silica. The nitro-muriatic solution, when diluted largely with water, let fall a precipitate which weighed 13 (or 10 of pure antimony,) and had the properties of oxide of antimony; for they did not evaporate till heated to redness, but at that temperature were dissipated in a grey smoke.

The nitric solution was green. Common salt occasioned a precipitate which weighed 87·75, equivalent to 65·81 of pure silver. After the separation of this muriate of silver, sulphate of soda occasioned no precipitate. Therefore the solution contained no lead. When supersaturated with soda, a grey precipitate fell, weighing five parts. On burning coals this precipitate gave out an arsenical smell. It was redissolved in nitric acid; sulphureted alkali occasioned a smutty brown precipitate; and prussic alkali a prussian blue, which, after torrefaction, was magnetic. Hence he concluded, that these five parts were a combination of iron and arsenic acid.

The nitric solution which had been supersaturated with ammonia was blue; he therefore suspected that it contained copper. To discover this, he saturated it with sulphuric acid, and put into it a polished plate of iron. The quantity of copper was so small, that none could be collected on the iron.*

5. Black silver ore may be analysed as No. 2, separating the copper, if any be present, by means of an iron plate, and estimating the carbonic acid that escapes when the ore is heated or dissolved in nitric acid. **Black silver ore,**

6. Red silver ore was analysed by Vauquelin in the following manner: one hundred parts of it were digested in 500 parts of nitric acid previously diluted with water.† The undissolved residuum, being washed and dried, weighed 42·06. Being treated with muriatic acid, it was all dissolved except 14·66 parts which were sulphur. The muriatic solution, when diluted with a great quantity of water, deposited a white powder, which weighed 21·25, and was **Red silver ore,**

* Klaproth, Beitrage, i. 163.
† No effervescence occurred during the solution; a proof that the metals existed in the ore in the state of oxides.

Book III. oxide of antimony. The nitric acid solution remained still to be examined. Muriatic acid occasioned a heavy precipitate, which weighed 72·66 parts, and which was muriate of silver. Reagents showed that the acid retained no other substance in solution. *

Chloride,   8. Chloride of silver was analysed by Klaproth in the following manner: one hundred parts of it were mixed with thrice their weight of pure carbonate of potash, and melted together in a glass retort. The mass was dissolved in water, and the solution filtered. A residuum remained, which was dissolved in nitric acid, with the exception of a red powder; which, treated with nitro-muriatic acid, was dissolved, except a little chloride of silver, which, when reduced, yielded ·5 of pure silver. Ammonia precipitated from the nitro-muriatic solution 2·5 parts of oxide of iron. The nitric solution was precipitated by common salt; the chloride of silver, thus obtained, yielded, when reduced, 67·25 of pure silver.

The original aqueous solution of the alkaline mass was saturated with acetic acid, on which it deposited 1·75 parts of alumina. The solution was evaporated to dryness, and the dry mass treated with alcohol, which dissolved the acetate of potash. The residuum, amounting to 58·75 parts, was dissolved in water; and being treated with muriate of barytes, 15 parts of sulphate of barytes precipitated, indicating the presence of about ·5 of sulphuric acid, or 0·75 sulphate of potash. The remaining 58 parts were muriate of potash, indicating about 21 parts of muriatic acid.†

4. Ores of Mercury.

Native mercury,   1. Native mercury and amalgam may be dissolved in nitric acid. The gold, if any be present, remains in the state of powder, and may be estimated by its weight. The affusion of water precipitates the bismuth, if the solution happens to contain any. Common salt precipitates the silver, and also part of the mercury; but the latter may be redissolved by a sufficient quantity of water, or, which is far better, of oxy-muriatic acid, while the muriate of silver remains insoluble. Lastly, the mercury may be precipi-

* Jour. de Min. No. xvii. p. 2.   † Klaproth, Beitrage, i. 132.

tated by sulphate of iron, and estimated.* Or the mercury may be separated at once from the ore by distillation.

2. Cinnabar may be dissolved in muriatic acid, assisted by the gradual addition of nitric acid. The sulphur partly separates, and may be weighed, and is partly converted into sulphuric acid; which may be separated by muriate of barytes, and the portion of sulphur ascertained. The mercury may be separated by distilling a portion of the ore with half its weight of iron filings. †

3. The analysis of the hepatic ore is conducted in a simi- lar way. The small portion of foreign bodies are to be ascertained by the processes already laid down. ‡

4. Muriate of mercury may be digested in muriatic acid till the whole is dissolved. Muriate of barytes precipitates the sulphuric acid, 100 parts of which are equivalent to 186 of sulphate of mercury; and the proportion of this salt being known, we have that of the muriate.§ Or, perhaps, a better mode of analysis would be to boil the salt with carbonate of potash till it is decomposed.

5. Ores of Copper.

1. Native copper sometimes contains gold, silver, or iron. It may be dissolved in nitric acid; the gold remains in the state of a blackish or rather violet-coloured powder; the silver may be separated by a polished plate of copper (or it may be precipitated from a separate portion of the solution by common salt); the iron may be separated by boiling the solution to dryness, and treating the residuum with water. By this process, the nitrate of iron is decomposed; the oxide of iron remains, while the water dissolves the nitrate of copper.‖ This last salt may be decomposed by boiling it with potash; the precipitate, dried in a red heat, is black oxide of copper. One hundred parts of it denote 80 of metallic copper.**

2. Sulphuret of copper may be dissolved in muriatic acid by the help of nitric acid. Part of the sulphur separates, part is acidified. The solution being divided into two

* Bergman, ii. 421.   † Klaproth, Gehlen's Jour. v. 436.
‡ See the analysis by Klaproth, Gehlen's Jour. v. 437.
§ Bergman, ii. 423.   ‖ Ibid. ii. 427.
** Chenevix, Phil. Trans. 1801, p. 209.

Book III. parts; from the one the copper may be precipitated by an iron plate, and from the other the iron by ammonia.* The variegated copper ore, and copper pyrites, yield to the same mode of analysis.

Grey copper ore,   3. Grey ore of copper was thus analysed by Klaproth. Heated to redness in a retort, the sulphur and arsenic were driven off. The sublimate, being weighed, was digested in potash, which separated the sulphur, and left the arsenic. The roasted ore was then dissolved in nitric acid, except a small portion which yielded to muriatic acid. These solutions being mixed, a little muriate of silver fell, which was separated and reduced. The solution, mixed with sulphuric acid, was evaporated to dryness, and redissolved in water. Ammonia threw down the iron from this solution, and a plate of zinc the copper.†

Red copper ore,   4. Red copper ore has only to be dissolved in muriatic acid, and the copper precipitated by a plate of iron; 88 parts of the precipitated copper being equivalent to 100 of the orange oxide of which the ore is composed.

5. The analysis of the oxides and carbonates of copper scarcely requires any remarks. The water and carbonic acid must be estimated by distillation in close vessels, and collecting the products. The ore may then be dissolved in nitric acid, and its copper ascertained as above.

Arseniate,   6. Arseniate of copper was analysed by Mr. Chenevix in the following manner: The ore was dissolved in diluted nitric acid, and nitrate of lead poured in. The solution was evaporated till a precipitate began to appear, and then mixed with alcohol. Arseniate of lead precipitated. One hundred parts of this salt indicate 33 of arsenic acid. The copper was separated from the nitric acid by boiling it with potash.‡

4. Ores of Iron.

Notwithstanding the great variety of iron ores, they may be all, as far as analysis is concerned, arranged under three heads; namely, 1. Sulphurets; 2. Oxides; and 3. Salts.

Pyrites,   1. Pyrites, or sulphureted iron, may be treated repeatedly with boiling nitric acid till the sulphur is acidified,

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* Klaproth, ii. 279.   † Gehlen's Jour. v. 5.
‡ Phil. Trans. 1801, p. 195.

Muriatic acid is then to be added, and the digestion con- Chap. IV. tinued till the whole be dissolved.* Muriate of barytes is then to be added to precipitate the sulphuric acid; 100 of the dried precipitate indicates 14·5 of sulphur. If the solution contains only iron, it may be precipitated by carbonate of soda, calcined to redness, and weighed. But if earths or manganese be present, we must proceed by the rules laid down in the First Section of this Chapter.

2. If the oxides of iron be pure, that is to say, contain Oxides, nothing but iron, we have only to dissolve them in muriatic acid, and precipitate them as above. But it is very seldom that ores possess this perfect degree of purity. The iron is usually combined with manganese, alumina, silica, or with all of these together. The analysis is to be conducted exactly according to the rules laid down in the First Section of this Chapter.

3. The sparry iron ore may be analysed in the same manner, excepting only that the carbonic acid gas must be separated by distillation or solution in close vessels, and estimated by the rules laid down in the Fourth Chapter of the last Book.†

4. Arseniate of iron was analysed by Mr. Chenevix in the Arseniate, following manner: 100 parts of it were boiled with potash till the arsenic acid was separated. Nitrate of lead was mixed with the solution; 100 parts of the precipitate indicated 33 of arsenic acid. That portion of the ore which eluded the action of the potash was treated with muriatic acid; the undissolved residuum was silica. The muriatic acid was supersaturated with ammonia. The iron precipitated; but the copper was dissolved by the ammonia.‡

7. *Ores of Tin.*

For the method of analysing the ores of tin we are indebted solely to Klaproth; the mode of analysis indicated by Bergman does not succeed.

1. The sulphuret of tin was thus analysed by Klaproth: Sulphuret, 120 parts of the ore were digested with nitro-muriatic acid. Forty-three parts remained undissolved. Of these, 30

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* If any siliceous gangue be mixed with the ore, of course it will remain undissolved, and must be analysed according to the rules laid down in the First Section of this Chapter.

† See vol. iii. p. 223.   ‡ Phil. Trans. 1801, p. 219.

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Book III. burnt away with a blue flame, and were sulphur; of the remaining 13, eight dissolved in nitro-muriatic acid. The undissolved five were heated with wax, and yielded a grain of iron attracted by the magnet. The rest was a mixture of alumina and silica. The nitro-muriatic solution was completely precipitated by potash, and the precipitate redissolved in muriatic acid. A cylinder of tin precipitated 44 parts * of copper from this solution, and lost itself 89 parts of its weight. A cylinder of zinc precipitated 130 parts of tin; so that, deducting the 89 parts of tin dissolved during the precipitation of the copper, 41 remain for the tin contained in the ore.†

Tin-stone.   2. Tin-stone was thus analysed by the same celebrated chemist. One hundred parts of the ore were heated to redness, with 600 parts of the potash, in a silver crucible; and the mixture being treated with warm water, 11 parts remained undissolved. These 11, by a repetition of the treatment with potash, were reduced to $1\frac{1}{4}$th. This small residuum dissolved in muriatic acid. Zinc precipitated from the solution one-half part of tin, and the Prussian alkali gave a blue precipitate, which indicated one-fourth part of iron.

The alkaline solution was saturated with muriatic acid; a white precipitate appeared, but it was redissolved by adding more acid. The whole was precipitated by carbonate of soda. The precipitate, which had a yellowish colour, was redissolved in muriatic acid: and a cylinder of zinc being inserted into the solution, 77 of tin were obtained, indicating nearly 98 parts of oxide of tin.‡

8. *Ores of Lead.*

Sulphuret,   1. Sulphuret of lead usually contains a little silver, and sometimes also antimony and zinc. It may be treated with diluted nitric acid, which leaves only the sulphur undissolved, the weight of which is to be taken, and its purity determined by combustion. If antimony be present, it will either remain in the state of a white oxide, or, if dissolved, it will be precipitated by diluting the solution with water. Muriatic acid is to be added, and the solution evaporated

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* One part of this was found to be tin, by digesting it in nitric acid.
† Observations on the Fossils of Cornwall, p, 38. English Translation.
‡ Beitrage, ii. 254.

till it is reduced to a small portion. Muriate of lead and of silver precipitate. The first of these may be dissolved in boiling water, the second remains insoluble. Westrumb separated the muriate of silver by digesting the precipitate with ammonia. The liquid from which the muriates were separated may contain iron, zinc, copper. The iron may be precipitated by ammonia added in excess; the copper, by a plate of zinc : the zinc may be precipitated by carbonate of soda, reduced to the metallic state, and weighed; subtracting what had been separated from the plate of zinc.

2. Arseniated lead was thus analysed by Vauquelin : Arseniated lead, 100 parts roasted for half an hour, and occasionally treated with a little tallow, lost 38 parts, which were considered as oxide of arsenic. The residue was treated with concentrated muriatic acid, and boiled in it for a quarter of an hour. The liquid assumed a red colour, and emitted abundance of chlorine gas. A white needle-form salt was deposited, and some of it was obtained by evaporation. This salt, dissolved in water, and treated with sulphate of soda, yielded 25 parts of sulphate of lead, = 20·2 parts of lead. The liquor thus freed from lead was treated with ammonia. The precipitate obtained weighed 39 parts. It consisted of oxide of iron mixed with oxide of arsenic. The production of chlorine induced Vauquelin to consider the lead as in the state of peroxide.*

3. Carbonate of lead was thus analysed by Klaproth : Carbonate, 100 grains were thrown into 200 grains of nitric acid diluted with 300 grains of water. It dissolved completely with effervescence. The loss of weight was 16 grains. It was equivalent to the carbonic acid. The solution, which was colourless, was diluted with water, and a cylinder of zinc put into it. In 24 hours the lead was precipitated in the metallic state. It weighed 77 grains, = 82 grains oxide.

If muriatic acid be suspected, it may be easily detected, and its weight ascertained by means of nitrate of silver.

4. Sulphate of lead was thus analysed by Klaproth : 100 Sulphate, grains of the ore, heated to redness, lost two grains, which were considered as water. It was then mixed with 400 grains of carbonate of potash, and heated to redness in a

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* Ann. de Chim. xliii. 86.

Book III. platinum crucible. The reddish yellow mass thus obtained was digested in water, and the whole thrown on a filter. The oxide of lead thus obtained weighed 72 grains. It was dissolved in diluted nitric acid. One grain of oxide of iron remained behind. Into the solution a cylinder of zinc was put. The lead thrown down weighed $66\frac{1}{2}$ grains. The alkaline solution was supersaturated with nitric acid, and then treated with acetate of barytes. The sulphate of barytes obtained weighed 73 grains, which Klaproth considers as indicating 25 grains of sulphuric acid.*

Phosphate,   5. Phosphate of lead was thus analysed by Klaproth: 100 grains were dissolved in diluted nitric acid. Nitrate of silver dropped into the solution formed a precipitate weighing 11 grains, $= 1\cdot7$ grain muriatic acid. The solution was mixed with sulphuric acid. The sulphate of lead precipitated weighed 106 grains, $= 78\cdot4$ oxide of lead. The solution was freed from sulphuric acid by means of nitrate of barytes, and then almost neutralized with ammonia. Acetate of lead was then dropped in. The phosphate of lead which precipitated weighed 82 grains, $= 18\cdot37$ phosphoric acid. The solution was now mixed with muriatic acid, evaporated to dryness, and the dry mass washed in alcohol. The alcohol, when evaporated, left a small residue, which dissolved in water, and formed Prussian blue with prussiate of potash. It contained about $\frac{1}{10}$ grain of oxide of iron.†

Molybdate,   6. Molybdate of lead was thus analysed by Mr. Hatchett. The ore was boiled repeatedly with sulphuric acid till the acid refused to dissolve any more. The solution contained the molybdic acid. The undissolved powder (sulphate of lead) was boiled for an hour with carbonate of soda, and then washed. Nitric acid now dissolved it, except a little silica. The lead was precipitated from this solution by sulphuric acid; after which ammonia separated a little oxide of iron. The sulphuric acid solution was diluted with 16 parts of water, and saturated with ammonia; a little oxide of iron gradually precipitated. The solution was now evaporated to dryness, and the mass strongly heated to separate the sulphate of ammonia. The residuum

* Beitrage, iii. 163.   † Ibid. 151.

repeatedly treated with nitric acid was converted into yellow- molybdic acid.

9. *Ores of Nickel.*

No exact method of analysing the ores of nickel has as yet been published.

1. Copper nickel may be dissolved in nitric acid, by Copper which the greatest part of the sulphur will be separated. nickel, The arsenic may be afterwards precipitated by the affusion of water. A plate of iron will expel the copper, if any be present. Precipitate by potash added in excess, and boil the precipitate, which will separate the arsenic and sulphur completely. Dissolve the precipitate (previously exposed moist for some time to the air) in acetic acid, and add an excess of ammonia. The iron is precipitated; but the cobalt and nickel remain in solution. Evaporate, and the cobalt is deposited; then by continuing the evaporation to dryness the nickel is obtained.

10. *Ores of Zinc.*

1. Blende may be treated with diluted nitric acid, which Blende, will separate the sulphur, the siliceous gangue, &c. The purity of the sulphur is to be ascertained by combustion, and the residuum analysed in the manner formerly decribed. Precipitate the nitric solution by soda, redissolve in muriatic acid, precipitate the copper (if any be present) by a plate of iron; separate the iron by adding an excess of ammonia.* The zinc now only remains in the solution, which may be obtained by evaporating to dryness, redissolving in muriatic acid, and precipitating by soda.

2. Calamine may be digested in nitric acid, noting the Calamine, loss of weight for carbonic acid, and the insoluble residuum boiled with muriatic acid repeatedly; what remains after dilution with boiling water is silica. The nitric solution contains zinc, and probably also iron and alumina; evaporate to dryness, redissolve, and add an excess of ammonia. The iron and alumina either remain undissolved or are precipitated, and they may be separated by potash. The zinc may be precipitated by an acid, or by evaporation to dryness. The muriatic solution probably contains iron

* Boil this precipitate in potash, to separate the alumina.

and alumina, which may be precipitated by the rules al‑ready laid down.

11. *Ores of Antimony.*

Native an‑timony,　　1. Native antimony was thus analysed by Klaproth: 100 grains were digested in nitric acid till the whole was converted into a white powder. When the acid emitted no longer any nitrous gas, the mixture was diluted with water and thrown upon a filter. The solution was then treated with nitrate of silver. The precipitate yielded by reduction one grain of silver. The prussiate of potash threw down from the residuum solution a precipitate which contained $\frac{1}{4}$th grain of iron. The white oxide formed by the nitric acid was digested in muriatic acid; the whole dissolved and formed a transparent solution. It was di‑luted with six times its weight of water, and the precipitate redissolved in muriatic acid, and a cylinder of zinc put into it. The antimony obtained weighed 98 grains.*

Sulphuret,　　2. Sulphuret of antimony is to be treated with nitro‑muriatic acid. The sulphur and the muriate of silver (if any silver be present) will remain. Water precipitates the antimony; sulphuric acid, the lead; and ammonia, the iron.

Red ore of antimony,　　3. Klaproth analysed the red ore of antimony as follows: 100 grains were digested in muriatic acid till the whole dissolved, except $1\frac{1}{2}$ grains of sulphur. A little sulphuret of antimony rose with the sulphureted hydrogen gas ex‑haled, and was deposited in the beak of the retort. The solution was diluted with water. The whole precipitated in the state of a white powder; for potash threw nothing from the liquid. The powder was redissolved in muriatic acid, an excess added, and the solution diluted. A plate of iron threw down $67\frac{1}{2}$ grains of antimony. The ore then contained 78·3 grains of oxide of antimony. One hundred grains of the ore yielded by solution in muriatic acid 37 cubic inches of sulphureted hydrogen gas. From this Klaproth concluded that it contained 20 grains of sulphur.†

12. *Ores of Bismuth.*

Native bis‑muth,　　Native bismuth may be treated with nitric acid. Re‑

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* Klaproth, iii. 171.　　　　　　† Beitrage, iii. 179.

peated concentrations and affusions of water precipitate the bismuth, and perhaps the arsenic; but this last may be re-dissolved in boiling water. The cobalt remains, and may be examined by the rules to be hereafter laid down. The same analysis succeeds with the other ores of bismuth. The sulphur when present remains undissolved.

I shall give, as an example of these ores, Klaproth's analysis of a sulphuret of bismuth. Fifty grains of the ore were digested in nitric acid. The whole was dissolved except $2\frac{1}{2}$ grains of sulphur. The solution being diluted with water, a white powder precipitated. The filtered solution was treated with common salt : at first it produced no change, but by and by the whole became milky. The precipitate consisted, like the last, of oxide of bismuth. The solution continuing clear for some time, indicated that no silver was present. The white precipitate was not altered by exposure to the light; an additional proof that no silver was present.*

13. *Ores of Tellurium.*

Klaproth dissolved the white gold ore of Fatzbay in nitro-muriatic acid, and added potash in excess to the solution. A brown precipitate remained undissolved, which was a mixture of gold and iron. It was re-dissolved in nitro-muriatic acid, the gold first precipitated by nitrate of mercury, and then the iron by potash. The potash in the first solution being saturated with muriatic acid, the oxide of tellurium precipitated.† White gold ore,

The other ores may be analysed in the same manner; only the precipitate occasioned by the potash must be treated according to the metals of which it consists. The rules have been already laid down.

14. *Ores of Arsenic.*

1. Native arsenic may be treated with nitro-muriatic acid. The silver and gold remain; the first in the state of a muriate; the second may be dissolved by means of nitro-muriatic acid, and precipitated by sulphate of iron. The arsenic may be precipitated by concentrating the nitric solution, and then diluting with water. The iron may then be precipitated by ammonia. Native arsenic,

* Beitrage, i. 255.   † Crell's Annals, 1798, i. 95.

Book III.   2. The sulphureted ores of arsenic may likewise be treated with diluted nitro-muriatic acid. The sulphur remains undissolved; the arsenic may be precipitated by concentration and the affusion of water; the iron by ammonia.

Oxide,   3. Oxide of arsenic may be dissolved in 16 parts of water. The solution displays acid properties, and nitrate of silver and of mercury occasion precipitates in it.

15.   Ores of Cobalt.

White cobalt ore,   1. White cobalt ore was thus analysed by Tassaert. To ascertain the proportion of arsenic, he treated the ore with diluted nitric acid, and obtained a complete solution. Crystals of white oxide of arsenic were deposited, and by repeated evaporations he separated the whole of the arsenic, and ascertained its weight. He then boiled a new portion of the ore with four times its weight of nitric acid, and thus acidified the arsenic, and obtained a solution. This solution was treated with potash, which retained the arsenic acid, and separated the other bodies. A precipitate of arseniate of cobalt, which had fallen when the nitric solution was diluted with water, was treated with potash for the same reason. The residuum, together with the precipitate occasioned by the potash, was dissolved in nitric acid, and ammonia added in excess. Part was retained in solution by the ammonia; but part was precipitated. The precipitate was dissolved in acetic acid, and the solution repeatedly evaporated to dryness. By this process the oxide of iron gradually separated in the form of a red powder. The dissolved part was acetate of cobalt. It was decomposed by the addition of ammonia in excess, which redissolved the cobalt. By these processes the arsenic and iron were separated; the cobalt was retained by the ammonia, and was obtained by evaporation. To ascertain the proportion of sulphur in the ore, a new portion was boiled with nitric acid. On cooling, crystals of white oxide of arsenic were deposited. These being separated, nitrate of barytes was added to the solution; 100 parts of the dried precipitate indicated 14·5 of sulphur.*

The other ores of cobalt may be analysed nearly in the same way.

* Ann. de Chim. xxviii. 92.

16. Ores of Manganese.

1. Barytated manganese was treated by Vauquelin with muriatic acid; chlorine gas passed over, and the whole was dissolved except a little charcoal and silica. The solution when evaporated yielded crystals of muriate of barytes. These were separated; and the liquid, evaporated to dryness, yielded a yellow mass soluble in alcohol, and tinging its flame with yellow brilliant sparks. The proportion of barytes was ascertained by precipitating it in the state of a sulphate; the manganese, by precipitating it by carbonate of potash.*

2. The grey ore of manganese was treated by the same chemist with muriatic acid; some silica remained undissolved. Carbonate of potash was added to the solution. The precipitate was at first white, but became black when exposed to the air. It was treated with nitric acid, which dissolved every thing but the manganese and iron (if any had been present.) The nitric solution, when mixed with carbonate of potash, deposited only carbonate of lime. The black residuum was mixed with sugar, and treated with nitric acid. The solution was complete; therefore no iron was present.

The same processes will succeed with the other ores of manganese. When iron is present, it may be separated either as above, or by the rules laid down in the first Section of this Chapter; or we may dissolve the mixture in acetic acid, and evaporate to dryness two or three times repeatedly. The oxide of iron is left behind; while the acetate of manganese continues soluble in water.

17. Ores of Tungsten.

1. Wolfram was analysed by the Elhuyarts, and by Vauquelin and Hecht, nearly as follows: the ore was boiled with muriatic acid, and then digested with ammonia alternately till the whole was dissolved. The ammoniacal solutions being evaporated to dryness and calcined, left the yellow oxide of tungsten in a state of purity. The muriatic solutions were mixed with sulphuric acid, evaporated to dryness, and the residuum re-dissolved in water. A little silica remained. Carbonate of potash precipitated a

* Jour. de Min. No. xix.40.

Book III. brown powder from this solution. This powder was treated with boiling nitric acid repeatedly, till the iron which it contained was oxidized to a maximum. It was then di-. gested in acetic acid, which dissolved the manganese, and left the iron. Finally, the manganese was precipitated by an alkali.

Tungstate of lime,   Tungstate of lime was thus analysed by Klaproth. One hundred grains of it were digested in nitric acid. The yellow coloured residue was washed and digested in ammonia. The residue was digested in nitric acid and ammonia alternately till a complete solution was obtained. Two grains of silica remained behind. The nitric acid solution was mixed with ammonia, but no precipitate appeared. It was then mixed with a boiling solution of carbonate of soda. The precipitate dried weighed 33 grains. It was carbonate of lime; but when re-dissolved in nitric acid, it left one grain of silica. Thirty-two grains of carbonate are equivalent to 17·6 of lime. The ammoniacal solution, by evaporation, yielded small needleform crystals. When heated to redness in a platinum crucible, they left $77\frac{3}{4}$ grains of oxide of tungsten.*

18. Ores of Molybdenum.

Molybdena,   Molybdena may be treated with nitric acid, successively boiled upon it till it is converted into a white powder. This powder, washed and dried, is molybdic acid. The liquid obtained by washing the acid, on the addition of potash, deposits some more molybdic acid. This being separated, muriate of barytes is to be dropped into it as long as any precipitate appears. One hundred parts of this precipitate indicate 14·5 of sulphur.

19. Ores of Uranium.

Pech-blende,   1. Pechblende, or the black ore of uranium, was dissolved by Klaproth in nitric acid. The undissolved part is a mixture of Silica and sulphur. By evaporating the solution, nitrate of lead was precipitated; then nitrated uranium in crystals. The solution being now evaporated to dryness, and treated again with nitric acid, left the iron in the state of red oxide.

Beitrage, iii. 45.

2. Uranitic ochre may be treated with nitric acid, which dissolves the uranium, and leaves the iron. The purity of the iron may be tried by the rules already laid down.

3. Green mica was dissolved by Klaproth in nitric acid, and ammonia added in excess to the solution. The oxide of uranium was precipitated; that of copper retained.

(Marginal note: Chap. IV. Uranitic ochre, Green mica,)

20. *Ores of Titanium.*

The ores of titanium, reduced as usual to a fine powder, are to be fused with potash or its carbonate. The melted mass is then to be dissolved in hot water. A white precipitate gradually separates, which is the white oxide of titanium. This is all that is necessary to analyse the oxides; but when iron and silica are present, the following method of Chenevix may be adopted: saturate the alkaline solution with muriatic acid. White oxide of titanium precipitates. Separate the precipitate, and evaporate the solution to dryness. Redissolve the residuum in water. The silica remains behind. Precipitate the solution by an alkali; add the precipitate to the white oxide obtained at first, and dissolve the whole in sulphuric acid. From this solution phosphoric acid precipitates the titanium, but leaves the iron.*

(Marginal note: Menacha-nite,)

The species which contains lime, and no iron, is to be fused with potash, dissolved in muriatic acid, and the silica separated in the usual way. After this the titanium is first to be separated from the muriatic solution by ammonia; and afterwards the lime by an alkaline carbonate.

21. *Ores of Chromium.*

1. Vauquelin analysed the chromate of lead in the following manner: when boiled with a sufficient quantity of carbonate of potash, a lively effervescence takes place; the acid combines with the potash; and carbonate of lead is formed, and remains undissolved. It may be dissolved in nitric acid, and its quantity ascertained by precipitation with sulphuric acid. Or the chromate may be treated with muriatic acid; muriate of lead precipitates, and chromic acid remains in solution. This process must be repeated till the whole of the ore is decomposed. There

(Marginal note: Chromate of lead,)

* Nicholson's Jour. v. 132.

Book III. remains in solution chromic acid mixed with a little muriatic, which may be separated by means of oxide of silver.

Chromate of iron.

2. Tassaert analysed the chromate of iron as follows: it was melted with eight times its weight of potash in a crucible. The resulting mass dissolved in water except a brown powder. This residuum was treated with muriatic acid, which dissolved a part of it. The residuum was treated, as at first, with potash and muriatic acid, till the whole was dissolved. The alkaline solution contained the chromic acid; the muriatic solution the iron, still mixed with a little chromium. It was precipitated by potash, and the precipitate boiled with that alkali, to separate the whole of the chromic acid. What remained was pure oxide of iron. The chromic solutions were saturated with nitric acid, and mixed with nitrate of lead. The resulting precipitate indicated the proportion of chromic acid; for 100 parts of chromate of lead indicate about 35 of chromic acid.

SECT. IV.

METHOD OF OBTAINING PURE METALS.

THE method of analysing the different ores with precision being ascertained, we have it in our power to obtain the metals in a state of purity, which is often necessary for chemical purposes. In this Section I shall give a short view of the processes commonly employed for that purpose.

1. *Gold.* To obtain pure gold, we have only to dissolve the gold of commerce in nitro-muriatic acid, and precipitate the metal by dropping in a solution of sulphate of iron, the powder which precipitates, after being well washed and dried, is pure gold.

2. *Platinum.* Platinum can scarcely be obtained perfectly pure in the malleable state, at least in any considerable quantity; because a sufficient heat for melting it cannot be obtained. But its powder may be procured pure from the muriate of platinum and ammonia, prepared by the rules laid down in the last section. This salt is to be decomposed by heat, and the residuum, if necessary, may

be redissolved in nitro-muriatic acid, and precipitated again.

3. *Silver.* Dissolve the silver of commerce in nitric acid, and precipitate with a diluted solution of sulphate of iron. The precipitate is pure silver. Or precipitate with common salt; form the precipitate into a paste with soda; put it into a crucible lined with soda, and fuse it with a brisk heat. This process gives a button of pure silver.

4. *Mercury* may be obtained pure by distilling a mixture of two parts cinnabar and one part iron-filings in an iron retort. The mercury comes over, and the sulphuret of iron remains behind; or corrosive sublimate may be decomposed by ammonia, and the precipitate heated either by itself or mixed with oil.

5. *Copper* may be dissolved in muriatic acid, and the copper precipitated by a polished plate of iron; or the black oxide of copper, obtained by decomposing cuprated ammonia, may be melted with its own weight of pounded glass and pitch.

6. *Iron* can scarcely be obtained perfectly free from carbon. The processes described in a former part of this work furnish it as pure as it can be procured.

7. *Tin* may be obtained pure by solution in strong nitric acid; the peroxide of tin is formed, which is insoluble. Let it be digested first with muriatic acid, and afterwards with aqua regia. Mix the oxide thus purified with its weight of pitch and a little borax, and melt it in a crucible.

8. *Lead* may be obtained pure from the carbonate by solution in diluted nitric acid, and precipitation by a cylinder of zinc; from the sulphuret, by solution in nitric acid, mixing the solution with muriatic acid, and crystallizing. The crystals of muriate of lead are to be dissolved in boiling water, and then evaporated to dryness. The mass is to be melted in a crucible with $2\frac{1}{2}$ times its weight of black flux.

9. Chemists have hitherto failed in their attempts to obtain *nickel* in a state of absolute purity. The great difficulty is to separate it from cobalt; upon which all reagents have nearly the same action. The following ingenious method has been proposed by Mr. Phillips: dissolve the nickel of commerce in nitric acid to saturation. Throw

down the arsenic acid by nitrate of lead. Then, after filtration, add an excess of nitric acid, and introduce an iron rod into the solution to throw down the copper. After this, precipitate the whole by carbonate of potash, and digest the precipitate in liquid ammonia. The cobalt and nickel are taken up; the iron and lead remain. Dilute the solution with water; add an excess of ammonia; then pour potash into the solution. The cobalt remains in solution, but the nickel precipitates in the state of a pure oxide, and may be reduced by exposure to a strong heat.* The process of Richter is complicated, and cannot easily be reduced to a formula.

I conceive that nickel in a state of sufficient purity may be procured by the process which I have described in volume I. p. 391 of this work.

10. *Zinc* may be dissolved in sulphuric acid, and a plate of zinc allowed to remain for a considerable time in the solution. It is then to be filtered, and the zinc to be precipitated with carbonate of soda. The precipitate, edulcorated and dried, is to be mixed with half its weight of pure charcoal, and distilled in an earthen-ware retort. The zinc is found pure in the neck of the retort.

11. *Antimony* may be dissolved in nitro-muriatic acid, and precipitated by the affusion of water. The precipitate is to be mixed with twice its weight of tartar, and fused in a crucible. A button of pure antimony is obtained.

12. *Bismuth*, if impure, may be dissolved in nitric acid, and precipitated by water. The edulcorated precipitate, formed into a paste with oil, and rapidly fused with black flux, gives a button of pure bismuth.

13. *Tellurium* was obtained pure by Klaproth, by forming its oxide into a paste with oil, and heating it to redness in a retort. The metal was rapidly revived.

14. *Arsenic*, in the state of white oxide, may be mixed with black flux and distilled.

15. *Cobalt* may be obtained pure, in all likelihood, by following the process proposed by Philips for the purification of nickel. The following is a much cheaper process recommended by Trommsdorf: mix a pound of the best smalt with four ounces of nitre and two ounces of charcoal

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* Phil. Mag. xvi. 312.

powder, and throw the mixture at intervals into a red hot crucible. This process is to be repeated three times. The mixture is then to be kept in a strong heat for an hour, stirred well, then mixed with four ounces of black flux, and kept in the strong heat of a forge for an hour longer. The cobalt, reduced by this treatment, is still impure. It is to be mixed again with thrice its weight of nitre, and defla-grated in a red hot crucible by small portions at a time. By this process the iron is peroxidized, and the arsenic acidi-fied. The mass is to be well washed, and the oxide of cobalt separated by filtration. This oxide is to be dissolved in nitric acid, and evaporated to dryness. A fresh portion of acid is to be added, and the mass exposed to a moderate heat. Dilute with water, and filter to separate the remains of the iron. Precipitate by pure potash, and reduce the oxide.*

16. *Manganese.* Digest the black oxide of manganese repeatedly in nitric acid; then mix it with sugar, and dis-solve it in nitric acid. Filter the solution, precipitate by an alkaline carbonate, form the white carbonate thus ob-tained into a paste with oil, and put it into a crucible well lined with charcoal. Expose the crucible for an hour to the strongest heat of a forge.

17. *Tungsten* was obtained by Elhuyart by heating the yellow oxide violently in a crucible lined with charcoal: but this process has not succeeded with other chemists.

18. *Molybdenum* may be obtained by forming molybdic acid into a paste with oil, and heating it violently in a cru-cible lined with charcoal.

19. *Uranium* is procured by forming the yellow oxide of that metal into a paste with oil, drying it in a moderate heat, putting it into a crucible lined with charcoal, with a little lamp-black strewed over it. After luting on the cover, it is to be heated, at first gently, and then violently, for three quarters of an hour.

20. *Titanium,* in a very small proportion indeed, was ob-tained in the metallic state by mixing together 100 parts of the red oxide of the metal, 50 parts of borax, and five parts of charcoal, and forming the mixture into a paste with oil. This paste was put into a crucible lined with

* Jour. de Chim. iv. 75.

Book III. charcoal, and exposed for an hour and a half to the violent heat of a forge.*

21. *Chromium* was obtained by Vauquelin in the metallic state, by putting a portion of chromic acid into a charcoal crucible, inclosed in a common crucible lined with charcoal, and exposing it for an hour to the violent heat of a forge.

22. *Cerium* is easily separated from the other substances with which it is combined by means of the oxalate of ammonia. And by exposing the oxalate of cerium to a red heat the oxide of cerium is obtained. We are not in possession of any method of procuring cerium in the metallic state.

23. For *tantalum* I refer the reader to what I said on the subject when treating of that metal, Vol. I. p. 556.

* A heat of 166° W. See Vauquelin and Hecht, Jour, de Min. xv. 20.

END OF VOL. III.