A

SYSTEM

OF

CHEMISTRY.

IN FIVE VOLUMES.

By THOMAS THOMSON,

[illegible]

THE FOURTH EDITION.

VOL. III.

EDINBURGH:
PRINTED FOR BELL & BRADFUTE.
SOLD BY JOHN MURRAY, LONDON; AND GILBERT & HODGES,
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CONTENTS

OF

VOLUME THIRD.

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CHEMISTRY.

BOOK II. DIVISION III. OF PART I.

CONTINUED.

GENUS VIII. SULPHITES.

Book II. Division III.

Preparation.

THESE salts are formed by saturating the alkaline and earthy bases with sulphurous acid. The easiest process is that which was followed by Berthollet, and afterwards by Vauquelin and Fourcroy. The proper mixture of sulphuric acid and mercury for obtaining sulphurous acid is to be put into a glass vessel, from which there passes a tube into a small bottle containing a little water. From this bottle there passes another tube into one of Woulfe's bottles, which contains the alkaline or earthy base designed to be combined with sulphurous acid, either dissolved or suspended in water. When the apparatus is properly adjusted, heat is applied to the mixture of mercury and acid ; sulphurous acid gas passes over first into the bottle with water, where the sulphuric acid, if any, passes along with it, is detained ; thence it passes into the Woulfe's bottle, where it combines with the base. When the base is saturated, crystals of sulphite often form spontaneously, or they may be obtained by evaporating the solution.

The sulphites were first pointed out by Stahl; but scarcely any of them were examined, except sulphite of potash, till Berthollet made a set of experiments on them about the year 1790 *. But a much more complete description of them was published by Fourcroy and Vauquelin, from their own experiments, in the year 1797 †.

Sulphites are distinguished by the following properties:

Characters.

1. A disagreeable taste, analogous to that of burning sulphur.

2. When heated, they emit sulphurous acid and water, and then sulphur, which takes fire and burns with a violet flame, if the experiment be performed in an open crucible. A portion of sulphate remains behind.

3. When exposed to the air in a state of solution, they absorb oxygen, and are converted into sulphates.

4. When they are dropt into nitric acid, red vapours are disengaged in abundance, and the salts are converted into sulphates. Oxymuriatic acid produces the same effect, but partially.

The sulphites at present known amount to eight.

I. SOLUBLE SULPHITES.

Sp. 1. *Sulphite of Potash.*

THIS salt was formed by Stahl, but was first accu-

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* *Ann. de Chim.* ii. 54.

† Ibid. xxiv. 229.

rately described by Berthollet, Fourcroy, and Vauquelin. It was formerly known by the name of *sulphureous salt of Stahl.* It may be formed by passing sulphurous acid into a saturated solution of carbonate of potash till all effervescence ceases. The solution becomes hot, and crystallizes by cooling *.

Properties.

Its crystals are white and transparent; their figure, that of rhomboidal plates. Its crystallization often presents small needles diverging from a common centre †. Its specific gravity is 1·586 ‡. Its taste is penetrating and sulphureous. At the common temperature of the atmosphere it is soluble in its own weight of water, but much more soluble in boiling water. When exposed to the air, it scarcely changes its appearance, loses about 2 *per cent.* of its weight, and then is gradually, but very slowly, converted into sulphate of potash. When exposed to a sudden heat, it decrepitates, loses its water and a portion of its acid; then a quantity of sulphur is disengaged from the remaining acid, and the residuum is sulphate of potash, with a slight excess of alkali. Nitric acid converts it into sulphate of potash by imparting oxygen. So does oxymuriatic acid, but imperfectly, as it drives off a portion of its acid unchanged.

It decomposes the oxides of gold, silver, mercury, the red oxide of lead, the black oxide of manganese, and the brown oxide of iron. When the green oxide of iron, or the white oxide of arsenic, is boiled with it in water, and an acid added, a precipitate takes place, consisting of these oxides united to some sulphur, and

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* Fourcroy and Vauquelin, Nicholson's *Journal*, i. 317.

† Ibid. ‡ Hassenfratz, *Ann. de Chim.* xxviii. 12.

the salt is converted into a sulphate; at the same time sulphureted hydrogen gas is emitted.

Composition.

From a course of experiments which I have made on this salt, it follows, that its component parts are in the following proportions:

43·5	acid
54·5	potash
2·0	water
100·0	

Sp. 2. *Sulphite of Soda.*

This salt was first accurately described by Fourcroy and Vauquelin. It is white and perfectly transparent. Its crystals are four-sided prisms, with two very broad sides and two very narrow ones, terminated by dihedral summits. Its specific gravity is 2·9566[*]. Its taste is cool and sulphureous. It is soluble in four times its weight of cold water, and in less than its weight of boiling water. By exposure to the air it effloresces, and is slowly converted into a sulphate. When exposed to heat it undergoes the watery fusion, and afterwards exhibits precisely the same phenomena as the sulphite of potash. Metallic oxides and salts affect it precisely as they do sulphite of potash.

It is composed of

31	acid
18	soda
51	water
100	

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[*] Hassenfratz, *Ann. de Chim.* xxviii. 12.

Sp. 3. *Sulphite of Ammonia.*

THIS salt was first described by Fourcroy and Vauquelin [*]. It crystallizes in six-sided prisms, terminated by six-sided pyramids; or in four-sided rhomboidal prisms, terminated by three-sided summits. Its taste is cool and penetrating, like that of the other ammoniacal salts, but it leaves a sulphureous impression in the mouth. It is soluble in its own weight of cold water, and much cold is produced. Its solubility is increased by heat; so that a saturated boiling solution crystallizes on cooling. When exposed to the air it attracts moisture, and is soon converted into a sulphate. No other sulphite undergoes this change so rapidly. When heated it decrepitates, a little ammonia is disengaged, and the salt then sublimes in the state of supersulphite of ammonia. Its habitudes with metallic oxides and salts are nearly the same with those of the above described sulphites, only it is capable of forming with several of them triple salts [†].

It is composed of	60 acid
	29 ammonia
	11 water
	100

Sp. 4. *Sulphite of Magnesia.*

THIS salt has only been examined by Fourcroy and Vauquelin. It is prepared, like the others, by saturating carbonate of magnesia with sulphurous acid; a vio-

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[*] Nicholson's *Jour.* i. 317.

[†] Ibid.

Book II. Division III.

lent effervescence takes place, and the liquid becomes warm. The sulphite as it forms remains at the bottom in the form of a white powder: But if an excess of acid be added, it dissolves, and may be obtained in crystals by subsequent exposure to the air. Its crystals are white and transparent, and in the form of depressed tetrahedrons. Its specific gravity is 1·3802 *. Its taste is mild and earthy at first, and afterwards sulphureous. It becomes opaque when exposed to the air; but is very slowly converted into a sulphate. At the temperature of 60° it is soluble in 20 parts of water. Boiling water dissolves a greater proportion of it; but the solution crystallizes on cooling. When its solution in water is exposed to the air, this salt is very soon converted into a sulphate. By exposure to heat, it softens, swells up, and becomes ductile like gum, and loses 0·45 parts of its weight. In a strong heat the acid is disengaged, and the earth remains pure.

It is composed of, ...	39 acid
	16 magnesia
	45 water
	100

Sp. 5. *Sulphite of Ammonia-and-Magnesia.*

THIS salt has only been mentioned by Fourcroy. It may be formed by mixing together the solution of sulphite of ammonia and sulphite of magnesia, or by pouring ammonia into the sulphite of magnesia. Its crystals are transparent, but the figure has not been determined. It is less soluble in water than either of its

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* Hassenfratz, *Ann. de Chim.* xxviii. 12.

Chap. III.

component parts. When exposed to the air, it is gradually converted into sulphate.

Its other properties have not been examined.

II. Insoluble Sulphites.

Sp. 6. *Sulphite of Lime.*

This salt was first mentioned by Berthollet, and described by Fourcroy and Vauquelin.

When obtained by the above described process, it has the form of a white powder; but if an excess of sulphurous acid be added, it dissolves, and crystallizes on cooling in six-sided prisms, terminated by long six-sided pyramids. It has scarcely any taste; however, when kept long in the mouth, it communicates to the tongue a taste which is manifestly sulphureous. It requires about 800 parts of water to dissolve it. When exposed to the air it effloresces very slowly, and its surface is changed into sulphate of lime. When heated, it loses its water of crystallization, and falls to powder. A violent heat disengages some sulphur, and converts it into sulphate of lime.

It is composed of 48 acid
47 lime
5 water

100

Sp. 7. *Sulphite of Barytes.*

This salt was mentioned by Berthollet; but it was first described by Fourcroy and Vauquelin. When prepared by the above described process, it is in the state of a white powder; but it may be obtained cry-

Book II.
Division III.

stallized in opaque needles, or in transparent tetrahedrons with their angles truncated, by dissolving it in sulphurous acid and evaporating slowly. It has but very little taste. Its specific gravity is 1·6938[*]. It is insoluble in water.

When heated strongly, sulphur is disengaged, and sulphate of barytes remains. A long exposure to the air is necessary before it is converted into a sulphate.

It is composed of 39 acid
59 barytes
2 water
100

Sp. 8. *Sulphite of Strontian.*

Unknown.

Sp. 9. *Sulphite of Alumina.*

This salt was first formed by Berthollet; it has been described by Fourcroy and Vauquelin.

When formed by the usual process it remains in the state of a white powder, and does not crystallize though dissolved in an excess of acid.

It is white and soft, and has an earthy and sulphureous taste. It is insoluble in water. When exposed to the air, it is gradually converted into sulphate. Its solution in sulphurous acid undergoes this change much more rapidly. When heated, its acid disengages, and the alumina remains behind, mixed however with a small proportion of sulphate of alumina.

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[*] Hassenfratz, *Ann. de Chim.* xxviii. 12.

It is composed of 32 acid
44 alumina
24 water

100

Such are the properties of the sulphites, as far as they have been hitherto investigated. The following Table exhibits the solubility of each in water, and the proportion of base and water combined with 100 acid.

Sulphites of	Solubility in 100 Water.	Constituents.		
		Acid.	Base.	Water.
Magnesia	5	100	41	115
Ammonia	100	100	48·3	18·3
Soda	25	100	58	164
Lime	0·12	100	97·9	10·5
Potash	100	100	125	4·6
Alumina	0	100	137·5	75
Barytes	0	100	151	5·1

III. Uses of the Sulphites.

Hitherto the sulphites have not been applied to any use, if we except the sulphite of barytes, which Fourcroy has proposed as a test of the purity of sulphurous acid, or of its being free from sulphuric acid. If the salt occasion a precipitate in the sulphurous acid, we may conclude that sulphuric acid is present.

Genus IX. Nitrates.

The most important of the nitrates have been long known; and in consequence of the singular properties which they possess, no class of bodies has excited greater attention, or been examined with more unwearied industry. They may be distinguished by the following properties:

Characters.

1. Soluble in water, and capable of crystallizing by cooling.

2. When heated to redness along with combustible bodies, a violent combustion and detonation is produced.

3. Sulphuric acid disengages from them fumes, which have the odour of nitric acid.

4. When heated along with muriatic acid, oxymuriatic acid is exhaled.

5. Decomposed by heat, and yield at first oxygen gas.

The nitrates at present known are twelve in number. Few of them combine with an excess of acid or of base, so that there are hardly any supernitrates or subnitrates.

I. SOLUBLE NITRATES.

Sp. 1. *Nitrate of Potash.*

History.

As this salt, known also by the name of *saltpetre*, is produced naturally in considerable quantities, particularly in Egypt, it is highly probable that the ancients were acquainted with it: but scarcely any thing certain can be collected from their writings. If Pliny mentions it at all, he confounds it with soda, which was known by the names of *nitron* and *nitrum*. It is certain, however, that it has been known in the East from time immemorial. Roger Bacon mentions this salt in the 13th century under the name of *nitre*.

Origin.

No phenomenon has excited the attention of chemical philosophers more than the continual reproduction of nitre in certain places after it had been extracted from them. Prodigious quantities of this salt are necessary for the purposes of war; and as Nature has not laid up great magazines of it, as she has of some other salts, this annual reproduction is the only source from which it can be procured. It became, therefore, of the utmost consequence, if possible, to discover the means which nature employed in forming it, in order to enable us to imitate her processes by art, or at least to accelerate and facilitate them at pleasure. Numerous attempts accordingly have been made to explain and to imitate these processes.

Stahl, setting out on the principle that there is only one acid in nature, supposed that nitric acid is merely sulphuric acid combined with phlogiston, and that this combination is produced by putrefaction; he affirmed, accordingly, that nitre is composed by uniting together potash, sulphuric acid, and phlogiston. But this opinion, which was merely supported by very far-fetched analogies, could not stand the test of a rigorous examination.

Lemery the Younger accordingly advanced another, affirming, that all the nitre obtained exists previously in animals and vegetables, and that it is formed in these substances by the processes of vegetation and animalization. But it was soon discovered that nitre exists, and is actually formed, in many places where no animal nor vegetable substance had been decomposed: and consequently this theory was as untenable as the former. So far indeed is it from being true that nitre is formed by these processes alone, that the quantity of nitre in plants has been found to depend entirely on the soil in which they grow *.

At last, by the numerous experiments of several French philosophers, particularly by those of Thouvenel, it was discovered that nothing else is necessary for the production of nitre but a basis of lime, heat, and an open, but not too free communication with dry atmospheric air. When these circumstances combine, the acid is first formed, and afterwards the alkali makes its appearance. How the air furnishes materials for this production is easily explained, now that the component parts of the nitric acid are known to be oxygen and azote: but how lime contributes to their union it is not so easy to see. The appearance of the potash is equally extraordinary. If any thing could give countenance to the hypothesis that potash is composed of lime and azote, it was this singular fact.

Preparation.

Nitre is found abundantly on the surface of the earth in India, South America, South Africa, and even in some parts of Spain. In Germany and France it is obtained by means of artificial *nitre* beds. These consist of the refuse of animal and vegetable bodies undergoing putrefaction, mixed with calcareous and other earths. It has been ascertained, that if oxygen gas be presented to azote at the instant of its disengagement, nitric acid is formed. This seems to explain the origin of the acid

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* Bouillon.

in these beds. The azote disengaged from these putrefying animal substances combines with the oxygen of the air. The potash is probably furnished, partly at least, by the vegetables and the soil.

The nitre is extracted from these beds by lixiviating the earthy matters with water. This water, when sufficiently impregnated, is evaporated, and a brown coloured salt obtained, known by the name of *crude nitre*. It consists of nitre, common salt, nitrate of lime, and various other salts. The foreign salts are either separated by repeated crystallizations, or by washing the salt repeatedly with small quantities of water; for the foreign salts being more soluble are taken up first.

Properties.

Nitre, when slowly evaporated, is obtained in six-sided prisms, terminated by six-sided pyramids; but for most purposes it is preferred in an irregular mass, because in that state it contains less water. The primitive form of its crystals, according to Hauy, is a rectangular octahedron, composed of two four-sided pyramids applied base to base; two of the sides are inclined to the other pyramid at the angle of 120°; at the other two at the angle of 111°. The form of its integrant particles is the tetrahedron. The six-sided prism is the most common form which it assumes. Sometimes, instead of six-sided pyramids, these prisms are terminated by 18 facets, disposed in three ranges of six, as if three truncated pyramids were piled on each other; sometimes it crystallizes in tables [*].

The specific gravity of nitre, as ascertained by Dr Watson, is 1·933 [†]. Its taste is sharp, bitterish, and

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[*] *Traité de Mineralogie*, ii. 346.

[†] *Essays*, v. 67. Wallerius makes it 1·900 (*Chemistry*, p. 266); Has-

cooling. It is very brittle. It is soluble in seven times its weight of water at the temperature of 60°, and in rather less than its own weight of boiling water*. It dissolves in 1·04 parts of water at the temperature 144° †. Alcohol, of the specific gravity ·878, dissolves $\frac{1}{100}$th of its weight of this salt, but stronger alcohol takes up no sensible portion of it ‡. It is not altered by exposure to the air.

When the solution of nitre is exposed to a boiling heat, part of the salt is evaporated along with the water, as Wallerius, Kirwan, and Lavoisier, observed successively. When exposed to a strong heat it melts, and congeals by cooling into an opaque mass, which has been called *mineral crystal.* Whenever it melts, it begins to disengage oxygen ; and by keeping it in a red heat, about the third of its weight of that gas may be obtained : towards the end of the process azotic gas is disengaged. If the heat be continued long enough, the salt is completely decomposed, and pure potash remains behind.

It detonates more violently with combustible bodies than any of the other nitrates. When mixed with one third part of its weight of charcoal, and thrown into a red hot crucible, or when charcoal is thrown into red hot nitre, detonation takes place, and one of the most brilliant combustions that can be exhibited. The residuum is carbonate of potash. It was formerly called *nitre fixed by charcoal.* The alchymists performed this

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senfratz found it 1·9369 (*Ann. de Chim.* xxviii. 12.) ; Fahrenheit had stated it as long ago as 1724 at 2·150 (*Phil. Trans.* xxxiii. 114.).

[*] Bergman, i. 134. [†] Wenzel, p. 309. [‡] Kirwan.

experiment in a tubulated earthen retort, to which an apparatus of glass vessels was luted. After every portion of nitre and charcoal which they threw in, they shut up the retort. The carbonic acid and azotic gas which were disengaged often burst their apparatus. To the small quantity of water which they obtained in their vessels, they gave the name of *clyssus*, and ascribed to it a great many virtues. A still more violent detonation is produced by using phosphorus instead of charcoal. When a mixture of nitre and phosphorus is struck smartly with a hot hammer, a very violent detonation is produced[*].

Nitre oxidizes all the metals at a red heat, even gold and platinum[†].

The composition of nitre, according to the most exact analyses hitherto made, is as follows:

Composition.

	‡	§	‖	¶
Acid	33	44	46·7	52
Base	49	51·8	53·3	48
Water	18	4·2		
Total	100	100	100	100

Of these analyses, those of Kirwan and Richter, which

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[*] Brugnatelli, *Ann. de Chim.* xxvii. 74.

[†] Tennant, Bergman, and Morveau.

[‡] Bergman, i. 135.

[§] Kirwan, Nicholson's *Quarto Jour.* iii. 215.

[‖] Richter, *Statique Chimique*, p. 136.

[¶] Wenzel's *Verwandtschaft*, p. 80.

Book II. Division III.

differ but little, appear to approach much more to accuracy than the others.

Sp. 2. *Nitrate of Soda.*

THIS salt was obtained at first by distilling a mixture of common salt in nitric acid in a retort, dissolving the residue in water, and evaporating. It was called *cubic nitre*, and is occasionally mentioned by the chemical writers of the early part of the last century; but it was Margraf who first analysed it, pointed out the method of procuring it in a state of purity, and described its properties with accuracy *. His experiments were afterwards repeated by Dr Lewis †.

It may be prepared by direct solution, or by mixing nitrate of lime and sulphate of soda together, filtering the solution, and evaporating. The crystals are transparent, and have a rhomboidal form. This salt is of the specific gravity 2·0964 ‡. It has a cool sharp taste, and is somewhat more bitter than nitre. It is soluble in about three parts of water at the temperature of 60°, in its own weight of water at the temperature of 126° §, and in less than its weight of boiling water. When exposed to the air it rather attracts moisture. Its phenomena in the fire are the same with those of nitre, excepting that it does not melt so easily.

The following Table exhibits the result of the experiments hitherto made to ascertain its constituents:

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* *Opusc.* ii. 331.

† *Phil. Com.* p. 643.

‡ Hassenfratz, *Ann. de Chim.* xxviii. 12.

§ Wenzel, p. 309.

	*	†	‡	§	||
Acid	43	53·21	57·55	62·1	62·5
Base	32	40·58	42·45	37·9	37·5
Water	25	6·21			
Total	100	100	100	100	100

Sp. 3. *Nitrate of Ammonia.*

THIS salt has been long known: It was formerly distinguished by the names of *nitrum semivolatile* and *nitrum flummans*. Berthollet examined it in the course of his experiments on the component parts of nitric acid: and Mr Davy has added considerably to our knowledge of its composition and decomposition ¶. It may be prepared by dissolving carbonate of ammonia in diluted nitric acid, and evaporating the solution till the salt crystallizes.

Properties.

The appearance of this salt varies very much, according to the temperature at which its solution is evaporated. In a moderate heat, 70° or 100° for instance, and by slow cooling, it is obtained in six-sided prisms, terminated by long six-sided pyramids. When the solu-

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* This is said in chemical books to be the result of Bergman's analyses; but I do not know where he published it. The very same proportions are given by him to the constituents of nitrate of lime.

† Kirwan, Nicholson's *Quarto Jour.* iii. 215. The salt was dried in the temperature of 400°.

‡ Kirwan, Ibid. The salt was ignited.

§ Richter, *Statique Chimique*, i. 36.

|| Wenzel, *Verwandtschaft*, p. 81.

¶ Davy's *Researches*, p. 71.

tion is evaporated at the temperature of 212°, the crystals are channelled and have a fibrous texture, or they are formed of long soft elastic threads. When dried in a heat of about 300°, it assumes the form of a white compact mass. These differences are owing to different proportions of water of crystallization which the salt contains.

Nitrate of ammonia has a very acrid, bitter, disagreeable taste. Its specific gravity is 1·5785 *. At the temperature of 60° this salt is soluble in two parts of water: it dissolves in half its weight of boiling water †. It must be observed, however, that its solubility varies with the proportion of water of crystallization which it contains. When exposed to the air, nitrate of ammonia soon attracts moisture and deliquesces.

When this salt, in the state of fibrous or prismatic crystals, is heated, it becomes fluid at a temperature below 300°; between 360° and 400° it boils without decomposition; but when heated to 450°, or somewhat higher, it is gradually decomposed, without losing its water of crystallization. Compact nitrate, on the other hand, undergoes little or no change till it is exposed to a temperature higher than 260°. Between 275° and 300° it sublimes slowly without decomposition, and without becoming fluid. At 320° it melts, and at the same time is partly decomposed, partly sublimed ‡.

When this salt is decomposed in a temperature not exceeding 500°, it is wholly converted into nitrous oxide and water. From the experiments of Mr Davy,

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* Hassenfratz, *Ann. de Chim.* xxviii. 12.

† Fourcroy, iii. 195. Engl. Trans.

‡ Davy, p. 85.

it appears that these products are nearly in the proportion of four parts of gas to three parts of water[*]. When it is exposed to a heat above 600°, this salt explodes, and is totally decomposed, being converted into nitrous acid, nitrous gas, water, and azotic gas. This phenomenon, observed long ago, induced the older chemists to give the salt the name of *nitrum flammans*. The nature of the decomposition was first ascertained by Berthollet, and more lately it has been examined by Mr Davy.

The following Table exhibits the constituents of this salt according to the experiments hitherto made upon it by chemists:

	†	‡	§	‖	‖	‖
Acid	46	57	64·5	69·5	72·5	74·5
Base	40	23	32·1	18·4	19·3	19·8
Water	14	20	3·4	12·1	8·2	5·7
Total	100	100	100	100	100	100

Sp. 4. *Nitrate of Magnesia.*

THE composition of this salt was first ascertained by Dr Black. Bergman is the only chemist who has given a detailed description of it. It is usually prepared by saturating nitric acid with magnesia, and evaporating

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[*] Davy, p. 105.

[†] Fourcroy, iii. 196. Engl. Trans.

[‡] Kirwan, Nicholson's *Jour.* iii. 215.

[§] Wenzel, p. 83.

[‖] Davy's *Researches*, p. 71. In the first of these analyses the salt was prismatic, in the second fibrous, and in the third compact.

Properties.

to a proper consistency. The salt crystallizes as the solution cools. It crystallizes in rhomboidal prisms, and often in small needles attached to one another. Its taste is very bitter and disagreeable. Its specific gravity is 1·736 *.

At the temperature of 60° it is soluble in little more than its weight of water, and still more soluble in boiling water. Alcohol of about ·840 dissolves $\frac{1}{9}$th of its weight of it †. When exposed to the air it gradually attracts moisture and deliquesces. When heated, it undergoes the watery fusion; and when its water is evaporated, it assumes the form of a dry powder. In a strong heat it gives a little oxygen gas, then nitrous gas, and lastly nitrous acid; and the earth remains behind in a state of purity ‡. It scarcely detonates with any of the combustible bodies.

The following Table exhibits the constituents of this salt according to the analyses of different chemists:

	§	‖	**	¶
Acid	43	46	69·6	72
Base	27	22	30·4	28
Water	30	32?		
Total	100	100	100	100

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* Hassenfratz, *Ann. de Chim.* xxviii. 12.

† Bergman, i. 136.

‡ Wenzel, p. 85.

§ Bergman, i. 136

‖ Kirwan, Nicholson's *Jour.* iii. 215.

** Richter, *Statique Chimique*, p. 136.

¶ Wenzel, p. 85.

Sp. 5. *Nitrate of Lime.*

This salt has been long known to chemists. Native nitre is almost always contaminated with it. It may be prepared by dissolving carbonate of lime in nitric acid; evaporating the solution to the consistence of a syrup, and then allowing it to cool slowly. The salt is precipitated in the state of crystals.

Properties.

Its crystals are six-sided prisms, terminated by long pyramids; but it is oftener obtained in the form of long slender brilliant needles. Its taste is very acrid and bitter. Its specific gravity is 1·6207 *. Scarcely any salt is more soluble in water. At the temperature of 60°, one part of water dissolves four parts of nitrate of lime, and boiling water dissolves any quantity of it whatever. Boiling alcohol dissolves its own weight of it †. Considerable difficulty attends its crystallization, as is the case with all very soluble salts. When exposed to the air, it very soon attracts moisture, and melts altogether. This strong affinity for moisture renders it sometimes useful for drying the gases. They are made to pass through tubes containing dried nitrate of lime; and this salt, during their passage through it, abstracts great part of the water which they hold in solution.

This nitrate, when heated, readily undergoes the watery fusion. When the water of crystallization is evaporated, the salt becomes dry, and often acquires the property of shining in the dark. In that state it was formerly known by the name of *Balduin's phosphorus;* because this property of nitrate of lime was first point-

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* Hassenfratz, *Ann. de Chim.* xxviii. 12.

† Bergman, i. 136.

ed out by Balduin *. When strongly heated it is decomposed; nitrous gas, oxygen gas, and azotic gas are emitted, and the pure lime remains behind. This salt scarcely possesses the property of detonating with combustible bodies, in consequence probably of the great proportion of its water of crystallization.

The following Table exhibits the result of the experiments made to ascertain the constituents of this salt.

Composition.

	†	‡	§	‖
Acid	43	51·44	63·9	66·2
Base	32	32·00	36·1	33·8
Water	25	10·56		
Total	100	100	100	100

The analysis of Kirwan seems to be the most accurate of these. That of Richter differs very little from it.

Sp. 6. *Nitrate of Barytes.*

THIS salt was formed immediately after the discovery of barytes. Vauquelin has lately added considerably to our knowledge of its properties. It is usually prepared by dissolving native carbonate of barytes in nitric acid, or by decomposing sulphuret of barytes by means of nitric acid, and evaporating the filtered solution till the nitrate crystallizes.

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* His account of it was published in 1675, under the title of *Phosphorus Hermeticus, seu Magnes Luminaris.* See also *Phil. Trans.* Ab. ii. 368.

† Bergman, i. 136.

‡ Kirwan, Nicholson's *Jour.* ii. 315.

§ Richter, *Statique Chimique*, i. p. 136.

‖ Wenzel, p. 84.

Properties.

Its crystals are regular octahedrons, and often they adhere to each other in the form of stars. Sometimes it is obtained in small brilliant plates. Its specific gravity is 2·9149 *. It is very easily reduced to powder.

Its taste is hot, acrid, and austere. It is soluble in 12 parts of water at the temperature of 60°, and in about three or four parts of boiling water. As the solution cools, the salt may be obtained in crystals. It is but little altered by exposure to the air. When thrown on burning coals it decrepitates, undergoes a kind of fusion, and then becomes dry. When strongly heated in a crucible, the whole of the acid is gradually driven off, and the barytes remains pure. It detonates less violently with combustibles than most of the other nitrates.

Composition.

The constituents of this salt have been determined by chemists as in the following Table.

	†	‡	§
Acid	32	38	39
Base	57	50	61
Water	11	12	
Total	100	100	100

Sp. 7. *Nitrate of Strontian.*

THIS salt was first formed by Dr Hope; it was after-

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* Hassenfratz, *Ann. de Chim.* xxviii. 12.

† Kirwan, Nicholson's *Journal*, iii. 215.

‡ Fourcroy and Vaquelin, *Ann. de Chim.*

§ Richter, *Statique Chimique*, i. 236.

wards examined by Klaproth and Pelletier; but the most complete description of it was published by Vauquelin about the end of the year 1797 *. It may be prepared either by dissolving carbonate of strontian in nitric acid, or by decomposing sulphuret of strontian by means of that acid. The solution is to be evaporated to dryness, redissolved in water, and evaporated slowly till the salt crystallizes.

Properties.

Nitrate of strontian crystallizes in regular octahedrons, not unlike the crystals of nitrate of barytes. It has a strong pungent cooling taste. Its specific gravity is 3·006. It is soluble in its own weight of water at the temperature of 60°, and in little more than half its weight of boiling water. It is insoluble in alcohol. In a dry air it effloresces, but in a moist air it deliquesces. It deflagrates on hot coals. Subjected to heat in a crucible, it decrepitates gently, and then melts. In a red heat it boils, and the acid is dissipated. If a combustible substance be at this time brought into contact with it, a deflagration with a very vivid red flame is produced †. It is by means of this decomposition that strontian is obtained in the greatest purity. When a crystal of nitrate of strontian is put into the wick of a candle, it communicates a beautiful purple flame.

Its constituents have been ascertained by different chemists as follows:

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* *Jour. de Min.* An. vi. 7.

† Hope, *Edin. Trans.* iv. 11.

Composition.

	*	†	‡
Acid	31·07	48·4	51·4
Base	36·21	47·6	48·6
Water	32·72	4	
Total	100	100	100

Sp. 8. *Nitrate of Ammonia-and-Magnesia.*

This salt was first described by Fourcroy in 1790. It may be prepared by mixing together the solutions of nitrate of ammonia and nitrate of magnesia, or by decomposing either of these salts in part by the base of the other. When the two salts are mixed together, the nitrate of ammonia-and-magnesia gradually precipitates in crystals.

Properties.

These crystals are in the form of fine prisms. They have a bitter acrid ammoniacal taste. They are soluble at 60° in about 11 parts of water; but boiling water dissolves a greater proportion of them. When exposed to the air, they gradually attract moisture; but much more slowly than either of their component parts. The phenomena which this compound exhibits when heated are similar to those which its component parts exhibit in like circumstances. According to Fourcroy it is composed of ...... 78 nitrate of magnesia

22 nitrate of ammonia

100 §

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* Kirwan, Nicholson's *Jour.* iii. 215.

† Vauquelin, *Jour. de Min.* An. vi. 20.

‡ Richter, *Statique Chimique*, i. 136.

§ *Ann. de Chim.* iv. 215.

Sp. 9. *Nitrate of Alumina.*

THOUGH this salt has been known to chemists for many years past, it has not hitherto been examined with precision. It is prepared by dissolving alumina in nitric acid, and evaporating the solution till the salt crystallizes. This salt always contains an excess of acid, and is therefore one of the few *supernitrates* with which we are acquainted.

It crystallizes with great difficulty in thin soft plates, which have but little brilliancy. This salt has an acid and astringent taste. Its specific gravity is 1·645 *. It is exceedingly soluble in water, and when evaporated is converted into a glutinous mass of the consistence of honey. It often assumes on cooling the form of a jelly. When exposed to the air, it very soon attracts moisture and deliquesces. When heated, the acid is disengaged with great facility, and the earth remains behind in a state of purity.

Sp. 10. *Nitrate of Yttria.*

THIS salt was first formed by Mr Eckeberg: it has been more lately examined by Vauquelin. It may be prepared by dissolving yttria in nitric acid. The solution has a sweet astringent taste, and in most of its properties agrees with nitrate of glucina. Like it, this salt can scarcely be obtained in the state of crystals. If, during the evaporation, a heat somewhat too strong be applied, the salt becomes soft, and assumes the appearance of honey, and on cooling becomes hard and brittle

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* Hassenfratz, *Ann. de Chim.* xxviii, 12.

like a stone. When exposed to the air, it very soon attracts moisture, and deliquesces. When sulphuric acid is poured into this solution, crystals of sulphate of yttria are instantly precipitated *.

Sp. 10. *Nitrate of Glucina.*

THIS salt was first described by Vauquelin. It is prepared by saturating nitric acid with glucina. When this solution is evaporated by means of a low heat, the salt gradually assumes the form of a powder, but cannot be obtained in the state of crystals.

Its taste is sweet and astringent. It is exceedingly soluble in water; so much so indeed that it is very difficult to obtain it in a dry state. When evaporated, it becomes thick and glutinous like honey. When exposed to the air, it attracts moisture very rapidly. When heated, it readily melts ; and if the heat be increased, the acid escapes, and leaves the earth in a state of purity. When tincture of nut-galls is dropt into a solution of this salt, a yellowish brown precipitate immediately appears. Nitrate of glucina may be readily distinguished from nitrate of alumina by this property. The proportions of the component parts of this salt have not hitherto been ascertained.

Sp. 11. *Nitrate of Zirconia.*

THIS salt was first formed by Klaproth. Vauquelin has given us a detailed description of it. It may be easily formed by pouring nitric acid on newly precipitated zirconia.

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* *Ann. de Chim.* xxxvi. 156.

Properties.

It always contains an excess of acid. By evaporating, a yellowish transparent matter is obtained, exceedingly tenacious and viscid, and which dries with difficulty. It has an astringent taste, and leaves on the tongue a viscid matter, owing to its being decomposed by the saliva. It is only very sparingly soluble in water; the greatest part remains under the form of gelatinous and transparent flakes. Like all the other salts into which zirconia enters, it is decomposed by heat. It is decomposed also by sulphuric acid, which occasions a white precipitate soluble in excess of acid; by carbonate of ammonia, which produces a precipitate soluble by adding more carbonate; and by an infusion of nut-galls in alcohol, which produces a white precipitate soluble in an excess of the infusion, unless the zirconia contains iron; in which case the precipitate is a greyish blue, and part of it remains insoluble, giving the liquor a blue colour. This liquor, mixed with carbonate of ammonia, produces a matter which appears purple by transmitted light, but violet by reflected light. Gallic acid also precipitates nitrate of zirconia of a greyish blue, but the colour is not so fine. Most of the other vegetable acids decompose this salt, and form combinations insoluble in water *.

II. INSOLUBLE NITRATES.

ALL the alkaline and earthy nitrates have the property of dissolving in water. Of course the second division of this genus does not exist.

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* Vauquelin, *Ann. de Chim.* xxii. 199.

Such are the properties of the nitrates. The following Table exhibits their solubility in water, and the proportion of their constituents which seems most correct, the acid being always supposed 100.

Nitrates of	Solubility in 100 Water.	Constituents.		
		Acid.	Base.	Water.
Ammonia	50	100	40·38	35·1
Magnesia	100	100	47·64	
Lime	400	100	55·70	18·7
Soda	33	100	73·43	
Strontian	100·0	100	116·86	105·3
Potash	14·3	100	117·7	8·1
Barytes	8·3	100	178·12	34·3

The solubility of these nitrates in alcohol has not been examined with precision. In all probability pure alcohol will not be found capable of taking up a sensible quantity of any of them, except those which are very soluble in water, as nitrates of lime and magnesia.

III. Uses of the Nitrates.

By far the most important of all the nitrates is common *saltpetre*, or *nitre*. Indeed few of the rest have been applied to any useful purpose except in chemical analyses.

It furnishes all the nitric acid in all its states employed either by chemists or artists. When burnt with tartar it yields a pure carbonate of potash. In the assaying of various ores it is indispensable, and is equally necessary in the analysis of many vegetable and animal substances. But one of the most important compounds formed by means of nitre is *gunpowder*, which has completely changed the modern art of war. The discoverer of this compound, and the person who first thought of applying it to the purposes of war, are unknown. It is certain, however, that it was used in the 14th century. From certain archives quoted by Wiegleb, it appears that cannons were employed in Germany before the year 1372. No traces of it can be found in any European author previous to the 13th century; but it seems to have been known to the Chinese long before that period. There is reason to believe that cannons were used in the battle of Cressy, which was fought in 1346. They seem even to have been used three years earlier at the siege of Algesiras; but before this time they must have been known in Germany, as there is a piece of ordnance at Amberg, on which is inscribed the year 1303. Roger Bacon, who died in 1292, knew the properties of gunpowder; but it does not follow that he was acquainted with its application to fire-arms *.

Gunpowder.

Gunpowder is composed of nitre, sulphur, and charcoal reduced to powder, and mixed intimately with each other. The proportion of the ingredients varies

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* See Watson's *Chemical Essays*, vol. i. p. 327, for a full detail of the facts respecting this subject. From Borbon's life of Robert Bruce, it appears that guns were used by the English for the first time about the year 1320.

very considerably; but good gunpowder may be composed of the following proportions *.

Composition.

76 parts nitre
15 charcoal
9 sulphur

100

These ingredients are first reduced to a fine powder separately, then mixed intimately, and formed into a thick paste with water. After this has dried a little, it is placed upon a kind of sieve full of small holes, through which it is forced. By that process it is divided into grains, the size of which depends upon the size of the holes through which they have been squeezed. The powder, when dry, is put into barrels, which are made to turn round on their axes. By this motion the grains of gunpowder rub against each other, their asperities are worn off, and their surfaces are made smooth. The powder is then said to be glazed.

Decomposition.

Gunpowder, as is well known, explodes violently when a red heat is applied to it. This combustion takes place even in a vacuum; a vast quantity of gas is emited, the sudden production of which is the cause of all the violent effects which this substance produces. Their combustion is evidently owing to the decomposition of the nitre by the charcoal and sulphur. The products are carbonic acid gas, azotic gas, sulphurous acid gas, and probably sulphureted hydrogen. Mr Cruickshanks has ascertained that no perceptible quanti-

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* For a full detail of every thing respecting the proportions and manufacture of gunpowder, the reader is referred to a very interesting dissertation by Dr Watson, *Essays*, ii. 1. and to Baumé's *Chemistry*, i. 455.

ty of water is formed. What remains after the combustion is potash combined with a small portion of carbonic acid, sulphate of potash, a very small proportion of sulphuret of potash, and unconsumed charcoal *. This mixture soon attracts moisture, and the sulphuret which it contains enables it to act strongly on metallic bodies.

Fulminating powder.

When three parts of nitre, two parts of potash, and one part of sulphur, all previously well dried, are mixed together in a warm mortar, the resulting compound is known by the name of *fulminating powder*. If a little of this powder be put into an iron spoon, and placed upon burning coals, or held above the flame of a candle, it gradually blackens, and at last melts. At that instant it explodes with a very violent report, and a strong impression is made upon the bottom of the spoon, as if it had been pressed down very violently. This sudden and violent combustion is occasioned by the rapid action of the sulphur on the nitre. By the application of the heat, the sulphur and potash form a sulphuret, which is combustible at a lower heat probably than even sulphur. Sulphureted hydrogen gas, azotic gas, and perhaps also sulphurous acid gas, are disengaged almost instantaneously. It is to the sudden action of these on the surrounding air that the report is to be ascribed. Its loudness evidently depends upon the combustion of the whole powder at the same instant, which is secured by the previous fusion that it undergoes; whereas the grains of gunpowder burn in succession.

A mixture of equal parts of tartar and nitre, deflagra-

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* Cruickshanks, Nicholson's *Journal*, iv. 258.

ted in a crucible, is known by the name of *white flux*. It is merely a mixture of carbonate of potash with some pure potash. When two parts of tartar and one of nitre are deflagrated in this manner, the residuum is called *black flux* from its colour. It is merely a mixture of charcoal and carbonate of potash.

GENUS X. NITRITES.

THE existence of these salts was first pointed out by Bergman and Scheele; the two philosophers to whom we are indebted for the first precise notions concerning the difference between nitric and nitrous acids. They cannot be formed by combining directly nitrous acid with the different earthy and alkaline bases; nor have any experiments made to combine nitrous gas with the nitrates been attended with success.

How formed.

The only method of obtaining these salts at present known is that which was long ago pointed out by Bergman and Scheele [*]. It consists in exposing a nitrate to a pretty strong heat till a quantity of oxygen gas be disengaged from it. What remains in the retort after this process is a *nitrite*; but the length of time necessary for producing this change has not yet been ascertained with any degree of precision. If the heat be applied too long, the nitrate will be totally decomposed, and nothing but the base will remain, as happened to some of the French chemists on attempting to repeat the process of Bergman and Scheele.

Nitrite of potash is the only salt formed by this pro-

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[*] Bergman, iii. 308.—Scheele, i. 59.

Book II. Division III.

Process of Scheele.

cess, of which an account has been given. Scheele's process for obtaining it is as follows: Fill a small retort with nitre, and keep it red hot for half an hour. When it is allowed to cool, it is found in the state of a nitrite. It deliquesces when exposed to the air, and red vapours of nitrous acid are exhaled when any other acid is poured upon it.

As the nitrites have never been examined by chemists, and as it has not even been determined whether any considerable number of the nitrates can be converted into these salts, it would be in vain, in the present state of our knowledge, to attempt a particular description of them. It may, however, be considered as exceedingly probable that no such salts as the nitrites of ammonia, glucina, yttria, alumina, and zirconia, exist or can be formed, at least by the process of Scheele and Bergman; for the nitrates with these bases are decomposed completely by the action of a heat too moderate to hope for the previous emission of oxygen gas.

From the few observations that have been made, it may be concluded that the nitrites are in general deliquescent, very soluble in water, decomposable by heat as well as nitrates: that their taste is cooling like that of the nitrates, but more acrid and nitrous: that by exposure to the air they are gradually converted into nitrates by absorbing oxygen; but this change takes place exceedingly slowly *.

Mr Tennant has shown that the nitrite of potash has the property of precipitating gold from its solutions in the metallic state, the nitrous acid absorbing the oxygen of the oxide.

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* Fourcroy, iii. 155.

Chap. III.

This curious fact explains why gold or platinum, dissolved by fusion with nitre, is thrown down in the metallic state if the mass be dissolved in water, as Mr Tennant has shown to happen *.

GENUS XI. OXYMURIATES.

When the oxymuriatic acid is mixed with the alkaline or earthy bases, dissolved or suspended in water, it is decomposed, and resolved into muriatic and hyperoxymuriatic acid, each of which combines with a portion of the base. By this process we obtain muriates and hyperoxymuriates, but no combination of oxymuriatic acid and a base. The case seems to be different when oxymuriatic acid gas is passed over the dry bases. It does not seem to undergo any decomposition, but to unite unaltered with the base. This is the only method at present known of obtaining the oxymuriates.

As no set of experiments has been hitherto published upon this subject, we are but imperfectly acquainted with the properties of the oxymuriates. The only one which I have had an opportunity of seeing is the *oxymuriate of lime*, prepared by Messrs Tennant and Knox of Glasgow for the bleachers.

It is a white powder of a hot disagreeable taste, and a smell somewhat resembling that of sea-ware. When heated, it gives out oxygen gas ; but if it be mixed with sulphuric acid, oxymuriatic acid gas is disengaged by the heat of a lamp. It dissolves readily in water ; but the solution gradually emits bubbles of oxygen gas, and

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* Nicholson's *Quarto Jour.* ii. 30.

the salt is changed into muriate of lime. The disengagement of this gas becomes much more rapid when heat is applied to the solution. It is no doubt this facility with which this salt allows oxygen to separate from it, that makes it so useful in bleaching. Indeed the oxygen gas leaves solutions of this salt in water much more readily than it does liquid oxymuriatic acid.

Oxymuriate of lime, then, is decomposed by water and converted into common muriate. Probably all the other oxymuriates would undergo similar decompositions.

GENUS XII. HYPEROXYMURIATES.

THIS genus of salts was discovered by Berthollet in 1786; but, if we except the first species, they remained almost totally unknown till examined by Mr Chenevix in 1802. The most important of them may be prepared by the following process: Dissolve the base which is to be combined with the acid, or its carbonate, in water, or mix it with water if it happens to be insoluble, and putting it into one of Woulfe's bottles, cause oxymuriatic acid in the state of gas, distilled in the usual manner, to pass through it. The acid combines with the base, and at the same time (if a carbonate be used) an effervescence takes place, owing to the disengagement of the carbonic acid gas. As the base becomes saturated with acid, the hyperoxymuriate, in some cases, precipitates in the state of crystals.

Formation.

At the same time with the hyperoxymuriate a great quantity of common muriate is formed. The formation of the two salts was thus explained by Berthollet. He supposed that one part of the oxymuriatic acid is de-

Theory.

composed; that its oxygen combines with the other portion of acid, and forms what he termed *hyperoxygenated muriatic acid;* of course the salts obtained are hyperoxygenated muriate and common muriate [*]. Though this theory was probable, it remained supported merely by probable evidence, till the analytical skill of Mr Chenevix demonstrated its truth.

The hyperoxymuriates may be distinguished by the following properties:

Characters.

1. When raised to a low red heat, they give out a great quantity of oxygen gas, and are converted into common muriates.

2. When mixed with combustibles, they detonate with much greater violence than the nitrates. This detonation is occasioned not only by heat, but by friction and percussion, and often takes place spontaneously.

3. Soluble in water, and some of them in alcohol.

4. The acid is expelled from them in yellow or green fumes by sulphuric, nitric, and muriatic acids without heat; a little below a boiling heat by phosphoric, oxalic, tartaric, citric, and arsenic acids; but they are not acted on by benzoic, acetic, boracic, prussic, and carbonic acids. Those vegetable acids which are powerful enough to decompose them give out towards the end a gas of a peculiar nature, which has not so much smell as oxymuriatic acid, but which affects the eyes in a peculiar manner, and promotes an uncommon and rather painful secretion of tears. This gas has not been examined, because its separation is attended with an explosion and rupture of the vessels [†].

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[*] *Jour. de Phys.* xxxiii. 217.

[†] Chenevix, *Phil. Trans.* 1802.

Book II.
Division III.

Sp. 1. *Hyperoxymuriate of potash.*

THIS extraordinary salt, first formed by Berthollet [*], has been since examined by a great number of chemists. Lavoisier, Dolfuz [†], Van Mons, Fourcroy and Vauquelin [‡], Hoyle [§], Chenevix, &c. have investigated its properties, and discovered many of the singular effects which it produces. It is prepared by dissolving one part of carbonate of potash in six parts of water, putting the mixture into a Woulfe's bottle, and saturating the potash with oxymuriatic acid gas [||]. When the saturation is nearly completed the oxymuriate falls down in crystals. It may be purified by solution in boiling water. As the water cools, the pure hyperoxymuriate crystallizes. The crystals are to be dried between folds of blotting-paper.

Properties.

According to Hauy, the primitive form of the crystals of hyperoxymuriate of potash is an obtuse rhomboidal prism; but it is usually obtained in small thin plates of a silvery whiteness. It is only by allowing an unsaturated solution of it in boiling water to cool slowly, or by exposing a solution in cold water to spontaneous evaporation, that it is obtained in large regular rhomboidal crystals.

Its taste is cooling, austere, and disagreeable, some-

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[*] It was in fact first discovered by Dr Higgens, who described the method of forming it and some of its properties some time before Berthollet, under the name of saltpetre. See Higgins on *Acetous Acid*, p. 180.

[†] *Ann. de Chim.* i. 225.

[‡] *Ann. de Chim.* xxi. 235.

[§] *Manchester Memoirs*, v. 221.

[||] The bottle containing the alkali must be covered up from the light, otherwise no crystals of hyperoxymuriate can be obtained, as I have more than once experienced.

what analogous to that of nitre. Its specific gravity is 1·989 *. When rubbed smartly, it phosphoresces, or rather emits a number of sparks of fire †. It is soluble in about 16 parts of water at the temperature of 60°, and in $2\frac{1}{2}$ parts of boiling water ‡. It is not sensibly altered by exposure to the air. When heated, it readily undergoes the watery fusion. If the heat be raised to redness, it rapidly gives out more than the third of its weight of oxygen gas. It is from this salt that oxygen gas can be obtained in the state of the greatest purity. After the effervescence is over, there remains common muriate of potash.

Composition.

From the experiments of Chenevix, its constituents are................ 58·3 acid
39·2 potash
2·5 water

100·0

The most astonishing of its properties are those which is exhibits when mixed with combustibles. All combustible substances whatever are capable of decomposing it, and in general the decomposition is attended with violent detonations.

Detonates with combustibles.

When three parts of this salt and one part of sulphur are triturated in a mortar, the mixture detonates violently: the same effect is produced when the mixture is placed upon an anvil, and struck smartly with a hammer. Nay, it even sometimes detonates spontaneously without any perceptible friction, and ought not therefore to be kept ready mixed. Charcoal produces

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[*] Hassenfratz, *Ann. de Chim.* xxviii. 12.

[†] Fourcroy, iii. 221.

[‡] Hoyle, Nicholson's *Jour.* ii. 292.

the same effects, though not so violent. This property induced Berthollet to propose it as a substitute for nitre in the preparation of gunpowder. The attempt was made at Essone in 1788; but no sooner had the workmen begun to triturate the mixture of charcoal, sulphur, and oxymuriate, than it exploded with violence, and proved fatal to Mr Letors and Mademoiselle Chevraud. The force of this gunpowder when it is prepared is much greater than that of the common sort of powder; but the danger of preparing it, and even of using it after it is prepared, is so great, that it can hardly ever be substituted with advantage for common gunpowder.

Phosphorus also detonates with this salt either by trituration or percussion. The quantities of each used ought not to exceed half a grain, or at most a grain, otherwise the experiment may be attended with some danger. It detonates also when treated in the same way with almost all the metals, and likewise with cinnabar, pyrites, sugar, gums, oils, alcohol, &c. When thrown upon platinum heated to whiteness, it does not detonate, but sublimes. The surface of the platinum, however, is oxidized; for acetic acid dissolves a part of it; and when prussiate of lime is poured into the solution, the liquid becomes of a greenish white colour *. When this salt is triturated in a mortar with a little cotton cloth, small repeated explosions are heard similar to the crack of a whip, and if the cotton be dry and warm it sometimes takes fire. It always does so when, after the trituration has been continued for some time,

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* Morveau, *Ann. de Chim.* xxv. 18.

sulphuric acid is poured upon the cotton. When nitric acid is poured upon a mixture of oxymuriate of potash and phosphorus, flakes of fire are emitted at intervals for a considerable time *.

The theory of these explosions was first pointed out by Berthollet. The oxygen of the acid combines with the combustible, and at the same time lets go a quantity of caloric; and trituration or percussion acts merely by bringing the particles which combine within the sphere of each other's attraction.

The action of the acids on this salt has been treated of already in a former part of this Work †.

This salt was employed in bleaching after the discovery of the whitening property of oxymuriatic acid; but other compounds have been lately substituted in its place.

Sp. 2. Hyperoxymuriate of Soda.

Mr Chenevix must be considered as the first chemist who published a description of this salt; for the short notice of Dolfuz and Gadolin ‡ scarcely conveys any precise information. It may be prepared by the same process as hyperoxymuriate of potash; but it is difficult to obtain it pure, as it is nearly as soluble in water as muriate of soda. Mr Chenevix procured a little of it pure by dissolving the mixtures of muriate and hyperoxymuriate of soda in alcohol, and crystallizing repeatedly.

Properties.

It crystallizes in cubes, or in rhomboids differing little from that form. It produces a sensation of cold in

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* Collier, *Manchester Mem.* v. 229.

† Vol. II. p. 261.

‡ *Ann. de Chim* .i. 227

the mouth, and its taste is readily distinguished from that of muriate of soda. It is soluble in three parts of cold water, and still more soluble in warm water. When exposed to the air it is slightly deliquescent. It is soluble in alcohol, and has the property of rendering muriate of soda more soluble than usual in that liquid.

Composition.

It is composed of....66·2 acid
29·6 soda
4·2 water

100·0*

Sp. 3. *Hyperoxymuriate of Ammonia.*

This salt may be formed by pouring carbonate of ammonia into a solution of an earthy hyperoxymuriate. The carbonate of the earth precipitates, and hyperoxymuriate of ammonia remains in solution. This salt has been described by Mr Chenevix only. It is very soluble in water and in alcohol. It is decomposed at a very low temperature, and gives out gas, together with the smell of hyperoxymuriatic acid. The proportion of the constituents of this salt are still unknown.

Sp. 4. *Hyperoxymuriate of Magnesia.*

This salt may be prepared in the same way as hyperoxymuriate of lime, which it resembles in most of its properties.

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* Chenevix *On Hyperoxygenized Muriatic Acid. Phil. Trans.* 1802.

Its constituents are 60·0 acid
25·7 magnesia
14·3 water

100·0 *

Sp. 5. *Hyperoxymuriate of Lime.*

This salt may be procured and purified in the same way as the succeeding species. It is very deliquescent, and undergoes the watery fusion when slightly heated. Alcohol dissolves it copiously. Its taste is sharp and bitter; and when it dissolves in the mouth, it produces a strong sensation of cold. Its constituents are

55·2 acid
28·3 lime
16·5 water

100·0 †

Sp. 6. *Hyperoxymuriate of Barytes.*

It is much more difficult to procure the earthy hyperoxymuriates than the alkaline; the affinity between their constituents seems to be much weaker. The best method of obtaining the hyperoxymuriate of barytes is to pour warm water on a quantity of the earth procured by Vauquelin's method, and to pass a current of gas through this mixture kept warm. By this method the usual mixture of muriate and hyperoxymuriate is obtained. Now these two salts, when barytes is their

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* Chenevix *On Hyperoxygenized Muriatic Acid. Phil. Trans.* 1802.

† Chenevix, i. Ibid.

Formation of earthy hyperoxymuriates.

base, possess the same degree of solubility, and resemble each other in the form of their crystals, so that they cannot be obtained separate by repeated crystallizations. Mr Chenevix succeeded by the following ingenious method: Phosphate of silver, when boiled in solutions of the earthy muriates, has the property of decomposing them; the phosphoric acid combines with the earth, and the muriatic acid with the oxide of silver. But this salt produces no such change on the earthy hyperoxymuriates. Now both the phosphate of barytes and the muriate of silver are insoluble in water. Of course, when phosphate of silver is boiled in a solution of muriate and hyperoxymuriate of barytes, the whole muriate is decomposed into muriate of silver and phosphate of barytes, which are insoluble, and the only substance which remains in solution is hyperoxymuriate of barytes.

Properties.

This salt is soluble in four parts of cold water, and in a smaller portion of warm water. It is decomposed by all the acids placed in the tables of affinity above the benzoic; and the decomposition by the stronger acids is more frequently accompanied by a flash of light than the decomposition of the alkaline hyperoxymuriates. Its component parts are

Composition.

47·0	acid
42·2	barytes
10·8	water
100·0 [*]	

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[*] Chenevix *On Hyperoxygenized Muriatic Acid. Phil. Trans.* 1802.

Sp. 7. *Hyperoxymuriate of Strontian.*

This salt was prepared and purified by Mr Chenevix by the same processes as the last species, with which indeed it agrees in most of its properties. It is deliquescent, and more soluble in alcohol than muriate of strontian. It crystallizes in needles, which melt in the mouth, and produce the sensation of cold. Its constituents are..........46 acid

Composition.

Its constituents are	46 acid
	26 strontian
	28 water
	100[*]

II. Insoluble Hyperoxymuriates.

The hyperoxymuriates are all soluble in water. Of course the second division of them does not exist.

The following Table exhibits the solubility of these salts in water, and the proportion of their constituents (supposing the acid 100), according to the experiments of Chenevix:

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[*] Chenevix *On Hyperoxygenized Muriatic Acid. Phil. Trans.* 1802.

Sulphates of	Solubility in 100 Water.	Constituents.		
		Acid.	Base.	Water.
Magnesia		100	42·80	23·83
Soda	33	100	44·78	6·35
Lime		100	51·25	29·89
Strontian		100	56·52	60·87
Potash	6·2	100	67·24	4·30
Barytes	25·0	100	89·78	22·98

III. Uses.

None of the hyperoxymuriates have been hitherto applied to any useful purpose except that one which has potash for its base. This salt is much employed in chemical exhibitions. It furnishes pure oxygen gas, and a peculiar species of oxymuriatic acid. It was tried also as a substitute for nitre in gunpowder, and was found to answer; but the case with which it detonates with combustibles makes it too hazardous for common use.

Genus XIII. Arseniates.

The existence of this genus of salts was first discovered by Macquer; but their nature and composition was first pointed out by Scheele in his Dissertation on Arsenic, published in 1775. Since the researches of these two illustrious chemists, scarcely any addition has been made to our knowledge of the arseniates, if we except a few observations on some of these salts by Pelletier.

They may be distinguished by the following property:

Character.

When heated along with charcoal powder, they are decomposed, and arsenic sublimes.

I. Soluble Arseniates.

Sp. 1. *Arseniate of Potash.*

When arsenic acid is saturated with potash, it forms an incrystallizable salt, which deliquesces in the air, renders syrup of violets green, but does not alter the infusion of turnsole. When heated in a clay crucible, it is partly converted into a white glass, and partly changed into a super-arseniate of potash. When mixed with one-eighth of its weight of charcoal powder, and distilled in a retort, it swells and bubbles up violently, evidently in consequence of the disengagement of carbonic acid gas, and at the same time a quantity of arsenic is sublimed: the residuum is merely carbonate of potash and charcoal.

Sp. 2. *Super-arseniate of Potash.*

This salt was first formed by Macquer; and for that reason was long distinguished by the name of *arsenical neutral salt of Macquer*. He obtained it by distilling in a retort a mixture, consisting of equal parts of white oxide of arsenic and nitre. After the distillation, the white saline mass, which remained in the retort, was dissolved in hot water and filtered. When properly evaporated, beautiful transparent crystals of super-arseniate of arsenic are obtained *.

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* *Mem. Par.* 1746 and 1748.

Scheele first ascertained the composition of this salt, by discovering that it was obtained by adding arsenic acid to the arseniate of potash till the solution ceases to alter the colour of syrup of violets. It then reddens the infusion of turnsole, and yields by evaporation fine crystals of Macquer's neutral salt.

This salt crystallizes in four-sided prisms, terminated by four-sided pyramids, the edges of which correspond with those of the prism. It is soluble in water, and gives a red colour to vegetable blues. This salt is not decomposed by salts with base of lime or magnesia, as is the case with arseniate of potash [*].

Sp. 3. *Arseniate of Soda.*

When arsenic acid is saturated with soda, it yields by evaporation crystals of arseniate of soda, which, according to Scheele, are similar to those of the super-arseniate of potash: but, according to Pelletier, are regular six-sided prisms, not terminated by any pyramids. Its properties when heated, as far as they have been examined, coincide with those of arseniate of potash. When an excess of acid is added, this salt does not crystallize; and when evaporated to dryness, attracts moisture again from the air [†].

Sp. 4. *Arseniate of Ammonia.*

When arsenic acid is saturated with ammonia, the solution yields by evaporation crystals of arseniate of ammonia in rhomboidal prisms, which give a green colour to syrup of violets. With an excess of acid, it

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[*] Macquer and Scheele.

[†] Scheele, i. 144.

yields needle-form crystals of super-arseniate of ammonia, which deliquesce when exposed to the air.

When arseniate of ammonia is gently heated, it loses its transparency and part of its alkali. In a strong heat a portion of the ammonia is decomposed, water is formed, arsenic sublimed, and azotic gas disengaged. This was one of the experiments which first led Scheele to the discovery of the component parts of ammonia *.

Sp. 5. *Arseniate of Magnesia.*

MAGNESIA dissolves in arsenic acid; but when the acid is nearly saturated, the solution becomes thick and coagulates. The coagulum redissolves in an excess of acid, and yields when evaporated an incrystallizable gummy mass. This salt may be obtained also by mixing the alkaline arseniates with nitrate, muriate, and acetate of magnesia. When heated, it exhibits the same phenomena as the first species †.

Sp. 6. *Arseniate of Lime.*

WHEN arsenic acid is dropt into lime water, arseniate of lime is precipitated; but if an excess of acid be added, the salt is redissolved, and yields when evaporated small crystals of arseniate of lime, which are soluble in water, and decomposed by sulphuric acid. This salt may be formed also by dissolving chalk in arsenic acid, or by mixing the alkaline arseniates with the nitrate, muriate, or acetate of lime. Arseniate of lime, when heated, exhibits the same phenomena as the first species ‡.

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* Scheele, i. 145.

† Ibid. p. 159.

‡ Ibid. p. 157.

II. INSOLUBLE ARSENIATES.

Sp. 7. *Arseniate of Barytes.*

THIS salt was formed by Scheele by dissolving barytes in arsenic acid. When the saturation was nearly completed, the salt precipitated in the state of an insoluble powder. It may be formed also by mixing arseniate of potash with nitrate or muriate of barytes. This salt is insoluble in water, except there be an excess of acid. When exposed to a violent heat, it shows a tendency to melt, but is not decomposed *.

Sp. 8. *Arseniate of Alumina.*

ARSENIC ACID readily dissolves newly precipitated alumina. When the solution is evaporated, it gives a thick mass insoluble in water. This salt may be formed by mixing the alkaline arseniates with sulphate, nitrate, muriate, or acetate of alumina †.

Sp. 9. *Arseniate of Yttria.*

WHEN yttria is dissolved in arsenic acid, and the solution boiled, arseniate of yttria precipitates in the state of a white powder ‡. Arseniate of potash precipitates yttria from acids §.

SUCH is an imperfect account of the arseniates; a genus of salts which have not hitherto been applied to any useful purpose, and which have been very superficially examined.

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* Scheele, i. 163.

† Ibid. p. 160.

‡ Eckeberg, Crell's *Annals*, 1799, ii. 70.

§ Klaproth's *Beitrage*, iii. 76.

GENUS XIV. ARSENITES.

FOURCROY has given this name to the combinations formed between white oxide of arsenic, or arsenious acid as he calls it, and the alkalies and earths. They were formerly termed *livers* of arsenic, from some fancied resemblance which was traced between arsenic and sulphur. The alkaline arsenites may be prepared by dissolving the white oxide in alkaline solutions. They form a thick viscid yellow-coloured liquid, with a very nauseous odour. They do not crystallize; heat decomposes them by subliming the oxide, and almost all the acids precipitate the arsenic in the form of a white powder *.

The earthy arsenites, as far as they have been examined, are insoluble powders. Hence the reason that white oxide of arsenic occasions a precipitate when dropt into lime, barytes, or strontian water.

These salts have been but very superficially examined, and are by no means sufficiently known to admit of a detailed description.

GENUS XV. MOLYBDATES.

THIS genus of salts was first made known by Scheele. They have been but very imperfectly examined by chemists, owing partly to the scarcity of molybdic acid, and partly to the difficulty of obtaining it pure.

The greater number of the molybdates are colourless and soluble in water. They have a metallic taste,

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* Macquer's *Dictionary*.—Bergman, ii. 296.

usually weak. The prussiate of potash throws down from several of them a light-brown coloured precipitate.

If, into the solution of a molybdate, a cylinder of tin be put, and the liquid be mixed with a little muriatic acid, it gradually assumes a deep blue colour.

Sp. 1. *Molybdate of Potash.*

This salt may be formed either by uniting directly its acid and base, or by heating two parts of nitre and one of molybdic acid in a crucible, and lixiviating the mass obtained. The solution crystallizes by evaporation in small rhomboidal plates inserted into each other. They are bright, and have a metallic taste. When exposed to the blow-pipe upon charcoal, they melt without swelling, and are converted into small globules, which are quickly absorbed by the charcoal. When melted with a mixture of phosphate of soda and of ammonia (or microcosmic salt), they communicate a green tinge. Hot water dissolves them completely, and prussiate of potash occasions in this solution a reddish brown precipitate*. All the strong acids precipitate the molybdic acid from solutions of this salt.

Sp. 2. *Molybdate of Soda.*

This salt is very soluble in water. The solution, by evaporation, yields transparent crystals not altered by exposure to the air†. Neither the molybdate of potash nor soda can be volatilized by heat.

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* Klaproth, *Ann. de Chim.* viii. 106.

† Heyer, Gren's *Handbuch*, iii. 709.

Sp. 3. *Molybdate of Ammonia.*

This salt dissolves readily in water. The solution does not crystallize, but forms by evaporation a semitransparent mass. When heated the ammonia is partly driven off, partly decomposed, and the acid is reduced to the state of an oxide [*].

Sp. 4. *Molybdate of Magnesia.*

This salt, according to Heyer, is soluble in water, has a bitter taste, and does not crystallize [†].

Sp. 5. *Molybdate of Lime.*

This salt is obtained in the state of a powder by dropping molybdic acid into the solution of lime in nitric or muriatic acids. It does not appear to be soluble water [‡].

The remaining molybdates seem scarcely to have been examined by chemists.

GENUS XVI. TUNGSTATES.

Though Scheele first announced the existence of these salts, we owe the first observations concerning their properties to the De Luyarts; and the indefatigable Vauquelin, assisted by Mr Hecht, has lately given a detailed description of them from his own experiments [§]. These salts are combinations of the yellow oxide of tungsten with the alkalies and earths.

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[*] Bucholz, Gehlen's *Jour.* iv. 616.

[†] Gren's *Handbuch*, iii. 711.

[‡] Gren, Ibid.

[§] *Jour. de Min.* No. 19. p. 20.

Sp. 1. *Tungstate of Potash.*

THIS salt may be formed by dissolving oxide of tungsten in the solution of potash or carbonate of potash. The solution always retains an excess of potash, refusing to dissolve the oxide before the alkali be completely neutralized. By evaporation the tungstate of potash precipitates in the state of a white powder.

This salt has a metallic and caustic taste; it is soluble in water, and very soon deliquesces when exposed to the air. Its solution in water is decomposed by all the acids: they occasion a precipitate composed of the oxide, potash, and the acid employed. This precipitate or triple salt is the molybdic acid of Scheele *.

Sp. 2. *Tungstate of Soda.*

THIS salt may be formed by the same process as the last. When the solution is evaporated, the tungstate of soda crystallizes in elongated hexahedral plates.

It has an acrid and caustic taste; it is soluble in four parts of cold water, and in two parts of boiling water. Sulphuric, nitric, muriatic, acetic, and oxalic acids, occasion a precipitate in its solution, which is a triple salt, varying according to the acid employed. Phosphoric acid occasions no precipitate, nor is any precipitate produced when sulphuric acid is dropt in after phosphoric acid. No precipitate is occasioned by the sulphates of potash and of magnesia; but a white precipitate is occasioned by the following salts:

1. Muriates of lime and barytes; alum,
2. Almost all metallic salts †.

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* Vauquelin and Hecht, *Jour. de Min.* No. 19. p. 20.

† Ibid.

Sp. 3. *Tungstate of Ammonia.*

This salt may be formed by the same process as the others. By evaporating the solution, the tungstate of ammonia crystallizes, sometimes in small scales resembling boracic acid, and sometimes in four-sided prismatic needles. Its taste is metallic; it is soluble in water, does not deliquesce in the air, and is decomposed completely by heat. It is composed of

78 oxide
22 ammonia and water

100 *

Sp. 4. *Tungstate of Magnesia.*

When the yellow oxide of tungsten is boiled with carbonate of magnesia, the liquid yields, when evaporated, tungstate of magnesia in small brilliant scales. It is soluble in water, not altered by exposure to the air, and has a taste similar to that of the other species of tungstates. When an acid is dropt in, a white powder or triple salt precipitates.

Sp. 5. *Tungstate of Lime.*

This salt is found native, and is known to mineralogists by the name of *tungsten.* It was first described, and gave its name to the metallic oxide and to the whole genus. It is usually crystallized; and from the observations of Bournon, it appears that its primitive form is an octahedron composed of two four-sided pyramids,

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* Vauquelin and Hecht, *Jour. de Min.* No. 19. p. 20.

applied base to base; the faces are isosceles triangles; and the angle at the apex 44° 16′: each of the others 67° 52′. The solid angle at the apex, taken on the faces, is 48°; taken on the edges of the crystal, 64° 22′*.

It is of a yellowish grey colour, and sometimes crystallized, and always somewhat transparent. The primitive form of its crystals, according to Hauy, is the octahedron. Its specific gravity is about six, and its hardness is generally considerable. It is insoluble in water, and is not sensibly altered by exposure to heat. According to the analysis of Scheele, it is composed of

70 oxide of tungsten
30 lime

100

Sp. 6. *Tungstate of Barytes.*

An insoluble powder, not examined †.

Sp. 7. *Tungstate of Alumina.*

This salt is an insoluble powder.

Sp. 8. *Nitrated Tungstate of Potash.*

These tungstates are capable of combining with a number of acids, and forming with them a particular kind of neutral salts which have not been particularly examined, if we except *nitrated tungstate of potash*, which is the salt originally described by Scheele under the name of *acid of tungsten*.

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* Bournon, *Jour. de Min.* An. xi. No. 75. p. 161.

† Scheele, ii. 90.

This salt is obtained in the form of a white powder; it has an acid and bitter taste, reddens the infusion of turnsole, and is soluble in 20 parts of boiling water. The De Luyarts first showed it to be a compound of nitric acid, oxide of tungsten, and potash.

GENUS XVII. CHROMATES.

THIS genus of salts was first formed by Vauquelin. They have been lately examined in detail by M. Godon *.

Sp. 1. *Chromate of Potash.*

THIS salt is easily obtained by treating chromate of lead with liquid carbonate of potash. The solution formed is of an orange colour, and by evaporation yields chromate of potash in rhomboidal prisms.

Sp. 2. *Chromate of Soda.*

THIS salt is also of a yellow colour and susceptible of crystallizing.

Sp. 3. *Chromate of Lime.*

THIS salt is soluble in water, and may be obtained in regular crystals.

Sp. 4. *Chromate of Barytes.*

This salt is probably insoluble in water. It gives a yellowish green colour to porcelain.

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* *Ann. de Chim.* liii. 224.

Sp. 5. Chromate of Silica.

Chromic acid unites with silica when newly precipitated from potash, and forms a red powder insoluble in water, and not altered in the heat of a porcelain furnace *.

Genus XVIII. Columbates.

These salts, which have been examined only by Mr Hatchett, are too imperfectly known to admit of a generic description. Columbic acid combines with the fixed alkalies both by the dry and humid way; but it does not appear to combine with ammonia.

Sp. 1. Columbate of Potash.

When columbic acid is boiled in a solution of potash, a portion of it is dissolved, and the solution yields by evaporation a white glittering salt in scales, very much resembling boracic acid. Its taste is acrid and disagreeable. It is not altered by exposure to the air. Cold water dissolves it sparingly; but the solution is colourless and permanent. The acid is precipitated by nitric acid, and other acids, in the state of a white powder †.

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* The few preceding facts have been given in the report of Godon's *Memoire*, by Berthollet and Vauquelin. *Ann. de Chim.* liii. 225.

† Hatchett's Analysis of a Mineral from North America, *Phil. Trans.* 1802.

ORDER II.

COMBUSTIBLE SALTS.

GENUS I. ACETATES.

THIS genus of salts has been known almost since the commencement of chemistry. They may be distinguished by the following properties:

1. Decomposed by the action of heat; the acid being partly driven off, partly destroyed.

2. All very soluble in water.

3. When mixed with sulphuric acid and distilled in a moderate heat, acetic acid is disengaged, easily distinguishable by its smell.

4. When they are dissolved in water, and exposed to the open air, their acid is gradually decomposed.

I. SOLUBLE ACETATES.

Sp. 1. *Acetate of Potash.*

PLINY is supposed, but probably without any reason, to have been acquainted with this salt, because he recommends a mixture of vinegar and vine-ashes as a cure for a particular species of tumor *. It was first clearly described by Raymond Lully. It has received a great number of names; as, for instance, *arcanum tartari, secret foliated earth of tartar, essential salt of wine, regenerated tartar, diuretic salt, digestive salt of Sylvius.*

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* *Plinii*, lib. xxiii. *procemium*.

Products of distillation.

It is usually formed by dissolving carbonate of potash in distilled vinegar, and evaporating the solution to dryness in a moderate heat. By this process it is obtained in fine white plates. By a well managed evaporation it may be procured in regular prismatic crystals. This salt has a sharp warm taste. At the temperature of 60°, 100 parts of it are soluble in 102 parts of water[*]. It is soluble also in alcohol. When exposed to the air, it becomes moist; but the crystals obtained by spontaneous evaporation scarcely undergo any subsequent alteration in the air. When heated, it readily melts, and in a high temperature its acid is decomposed. A liquid passes over into the receiver, which sometimes contains a considerable portion of ammonia and prussic acid. What remains in the retort consists of charcoal mixed with the carbonates and prussiates of potash[†]. The presence of ammonia and prussic acid in the products of distillation of this salt, led Proust to consider azote as one of the constituents of acetic acid. But Trommsdorf and Proust himself have since shown, that pure acetate of potash yields neither ammonia nor prussic acid[‡]. When distilled along with white oxide of arsenic, it yields, according to Cadet, a white smoke, which has an odour intolerably offensive, and takes fire when it comes into contact with the air.

The following Table exhibits the constituents of this salt according to the experiments hitherto made.

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[*] Spielmann.

[†] Proust, *Ann. de Chim.* xlii. 231.

[‡] *Ann. de Chim.* lxi. 111.

Composition.

	*	†	‡
Acid	38·5	47·98	49·85
Base	61·5	52·02	50·15
Total	100·0	100	100

Sp. 2. *Acetate of Soda.*

THIS salt, which seems to have been first examined by Baron, was formerly known by the absurd name of *crystallized foliated earth.* It is usually prepared by saturating acetic acid with carbonate of soda, and evaporating the solution till a thin pellicle appears on its surface. When the solution is allowed to cool, the acetate of soda crystallizes in striated prisms, not unlike those of sulphate of soda. It has a sharp taste, approaching to bitter. It is soluble in 2·86 parts of water at the temperature of 60° §. Its specific gravity is 2·1 ||. It is not affected by exposure to the air. When heated, it first loses its water of crystallization; in a strong heat it melts, and in a still stronger its acid is destroyed. This salt can only be obtained in crystals when there is an excess of alkali in the solution.

The constituents of this salt, according to the experiments of Wenzel and Richter, are as follows:

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* Higgins *On Acetous Acid*, p. 8.

† Richter, *Statique Chimique*, i. 136.

‡ Wenzel, *Verwandtschaft*, p. 147.

§ Bergman, v. 78.

|| Hassenfratz, *Ann. de Chim.* xxviii. 12.

Composition.

	‡	§
Acid	60·39	63·28
Base	39·61	36·72
Total	100	100

Sp. 3. *Acetate of Ammonia.*

THIS salt was formerly called *spirit of Mindererus*. It may be prepared by the same process as the other acetates. It is too volatile to be easily crystallized: It may, however, by gentle evaporation, be made to deposite needle-shaped crystals. Mr de Lassone crystallized it by sublimation *. When the sublimation is slow, it forms long, slender, flatted crystals, terminating in sharp points, of a pearl-white colour, and about an inch and eight-tenths in length †. It impresses the tongue at first with a sense of coldness, and then of sweetness, which is followed by a taste resembling that of a mixture of sugar and nitre, in which the sweet does not predominate over the mawkish taste of the nitre ||. It is very deliquescent. It melts at 170°, and sublimes at about 250 ¶. When a watery solution of this salt is distilled, there comes over first a quantity of ammonia, next a quantity of acetic acid, and at last of the neutral salt itself. No such decomposition takes place when the crystals are distilled by a moderate heat **.

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‡ Wenzel, p. 147.

§ Richter, *Statique Chimique*, i. 136.

* *Mem. Par.* i. 775.

† Higgins *On Acetous Acid*, p. 188.

|| Higgins, Ibid. p. 192.

¶ Ibid.

** Ibid.

It constituents, as determined by Wenzel and Richter, are as follows:

	*	†
Acid	62·45	68·77
Base	37·55	31·23
Total	100	100

Sp. 4. *Acetate of Magnesia.*

THIS salt may be formed by dissolving magnesia or its carbonate in acetic acid. It is not crystallizable; but forms by evaporation a viscid mass ‡. It has a sweetish taste; leaving, however, a sense of bitterness §. Its specific gravity is 1·378 ‖. It is very soluble both in water and alcohol ¶. When exposed to the air, it deliquesces. Heat decomposes it.

The constituents of this salt, According to Wenzel and Richter, are as follows:

	**	††
Acid	65·96	70·65
Base	34·04	29·35
Total	100	100

---

[*] Wenzel, p. 149.

[†] Richter, *Statique Chimique*, i. 136.

[‡] Bergman, i. 388.

[§] Morveau, *Encycl. Method.* i. 9.

[‖] Hassenfratz, *Ann. de Chim.* xxviii. 12.

[¶] Bergman. i. 388.

[**] Wenzel, p. 150.

[††] Richter, *Statique Chimique*, i. 136.

Book II. Division III.

Sp. 5. *Acetate of Lime.*

THIS salt was first described accurately by Crollius. The ancients, however, used a mixture of lime and vinegar in surgery *. It is easily formed by dissolving chalk in acetic acid. When the solution is evaporated till a pellicle forms on its surface, it yields, on cooling, the acetate of lime in fine prismatic needles of a glossy appearance like satin. Its specific gravity is 1·005 †.

Its taste is bitter and sour, because it has an excess of acid. It is soluble in water. It is not altered by exposure to the air; at least Morveau kept some of it for a whole year merely covered with paper, and even quite uncovered for a month, without its undergoing any alteration ‡. Heat decomposes it by disengaging and at the same time partly decomposing its acid.

The constituents of this salt, according to the experiments hitherto made, are as follows:

	§	‖	¶	**
Acid	50	64·3	65·11	65·75
Base	50	35·7	34·89	34·25
Total	100	100	100	100

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* *Plinii*, lib. xxxvi. c. 24.

† Hassenfratz, *Ann. de Chim.* xxviii. 12.

‡ Morveau, *Encycl. Method.* i. 9.

§ Maret, Ibid. i. 9.

‖ Higgins *On Acetous Acid*, p. 47.

¶ Richter, *Statique Chimique*, i. p. 136.

** Wenzel, p. 150.

Sp. 6. Acetate of Barytes.

This salt may be formed by dissolving barytes or its carbonate in acetic acid, or by decomposing the sulphuret of barytes by that acid. By spontaneous evaporation the acetate crystallizes in fine transparent prismatic needles. Its specific gravity is 1·828 *. It has an acid and somewhat bitter taste; it is soluble in water, and does not deliquesce when exposed to the air, but rather effloresces. It is decomposed by the fixed alkalies †, by the alkaline carbonates, and by almost all the sulphates. Hence it is often employed to detect the presence of sulphuric acid in solutions. From the experiments of Bucholz, it appears, that 100 of water at the temperature of 60° dissolve about 88 of this salt, and 96 parts when boiling hot. Pure alcohol dissolves $\frac{1}{100}$th part of its weight while cold, and heat scarcely increases the solvent power of this liquid ‡.

According to the experiments of Bucholz and Richter, this salt is composed of the following proportions of its constituents:

	§	‖
Acid	35	39·98
Base	58	60·02
Water	7	
Total	100	100

---

* Hassenfratz, *Ann. de Chim.* xxviii. 12.

† D'Arcet, *Ann. de Chim.* lxi. 247.

‡ *Beitrage*, iii. 102.

§ Bucholz, *Beitrage*, iii. 102.

‖ Richter, *Statique Chimique*, i. 136.

Book II. Division III.

Sp. 7. Acetate of Strontian.

This salt, which was first examined by Dr Hope, and afterwards by Vauquelin, is easily formed by dissolving strontian or its carbonate in acetic acid. By evaporation it is obtained in small crystals, which are not affected by exposure to the atmosphere. Forty-nine parts of it are soluble in 120 parts of boiling water: it seems to be nearly as soluble in cold water. It renders vegetable colours green [*]. Its taste is not unpleasant. When heated, its acid is decomposed, as happens to all the other acetates. According to Richter, its constituents are..............Acid 52·69

Base 47·31

Total 100·00 [†]

Sp. 8. Acetate of Alumina.

This salt can only be formed by digesting acetic acid on alumina recently precipitated. By evaporation needle-shaped crystals are obtained, which are very deliquescent. This salt has an astringent taste. Its specific gravity is 1·245 [‡].

Its constituents, according to Wenzel and Richter, are as follows:

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[*] Hope, *Trans. Edin.* iv. 14.

[†] *Statique Chimique*, i. 136.

[‡] Hassenfratz, *Ann. de Chim.* xxviii. 12.

Chap. III.

Composition.

	*	†
Acid	73·81	92·06
Base	26·19	7·94
Total	100	100

Sp. 9. *Acetate of Yttria.*

YTTRIA dissolves readily in acetic acid, and the solution yields by evaporation crystals of acetate of yttria. These crystals have most commonly the form of thick six-sided plates obliquely truncated. Their colour is amethyst red. They are not altered by exposure to the air ‡.

Sp. 10. *Acetate of Glucina.*

ACETIC acid readily dissolves glucina; but the solution, as Vauquelin informs us, does not crystallize, but is converted by evaporation into a gummy mass, which becomes slowly dry and brittle. Its taste is sweet and astringent.

Sp. 11. *Acetate of Zirconia.*

THIS salt may be formed by pouring acetic acid on newly precipitated zirconia. It has an astringent taste. It does not crystallize; but when evaporated to dryness, it forms a powder, which does not attract moisture from

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* Richter, *Statique Chimique*, i. 136. † Wenzel, p. 157.

‡ Eckeberg, Crell's *Annals*, 1799, ii. 69; and Klaproth's *Beitrage*, iii. 70.

the air as acetate of alumina does *. It is very soluble in water and in alcohol. It is not so easily decomposed by heat as nitrate of zirconia, probably because it does not adhere so strongly to water †.

II. Insoluble Acetates.

All the acetates being soluble in water, the second division of this genus does not exist.

Such are the properties of the acetates. The following Table exhibits their solubility in water and the proportion of their constituents, according to the most accurate analyses hitherto published.

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[*] Klaproth, *Jour. de Phys.* xxxvi. 188.

[†] Vauquelin, *Ann. de Chim.* xxii. 206.

Acetates of	Solubility in 100 water.	Constituents.		
		Acid.	Base.	Water.
Alumina		100	35·48	
Magnesia		100	41·55	
Ammonia		100	45·40	
Lime		100	53·58	
Soda	35	100	58·04	
Strontian	40	100	89·80	
Potash	99	100	108·45	
Barytes	80	100	165·72	20

III. Uses of the Acetates.

Except in medicine and in chemical preparations, few of the acetates have been applied to any useful purpose. The acetate of potash is often employed in the preparation of strong acetic acid. When mixed with nitrate of mercury it gives, by double decomposition, acetate of mercury: a salt often employed in medicine, especially in this country. The acetate of ammonia is used occasionally as a medicine. Acetate of barytes sometimes makes an excellent reagent for detecting sulphuric acid.

Genus II. Benzoates.

Though these salts have been long known, their properties hitherto have been but superficially examined

Lichtenstein * and Tromsdorff † are the only chemists who have attempted any thing like a detailed description of them. To them we are chiefly indebted for the following facts.

Sp. 1. *Benzoate of Potash.*

This salt forms pointed feathery crystals. It has a saline sharp taste. It is very soluble in water. It deliquesces when exposed to the air.

Sp. 2. *Benzoate of Soda.*

The crystals of this salt are larger, but its taste is the same with that of benzoate of potash. It is also very soluble in water. It effloresces in the air.

Sp. 3. *Benzoate of Ammonia.*

This salt crystallizes with difficulty. Its crystals are feather-shaped. It deliquesces. It is very soluble in water.

Sp. 4. *Benzoate of Magnesia.*

This salt forms feather-shaped crystals of a sharp bitter taste, and easily soluble in water.

Sp. 5. *Benzoate of Lime.*

This salt forms white, shining, pointed crystals, of a sweetish taste, much more soluble in hot than in cold water. It exists in abundance in the urine of cows ‡.

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* Crell's *Neu. Entdeck.* 1782, iv. 9.

† Crell's *Annals*, 1790, ii 303.

‡ Fourcroy and Vauquelin.

Sp. 6. *Benzoate of Barytes.*

This salt crystallizes, is soluble in water, not altered by exposure to the air, but decomposed by heat and by the stronger acids.

Sp. 7. *Benzoate of Alumina.*

This salt forms dendritical crystals. It has a sharp bitter taste, is soluble in water, and deliquesces when exposed to the air.

The other benzoates are entirely unknown. They have not hitherto been applied to any use.

Genus III. Succinates.

This genus of salts is as imperfectly known as the preceding. For the few experiments that have been made, we are indebted to Stockar, Wenzel*, Leonhardi†, and Bergman‡. But Mr Gehlen has announced his intention of publishing a very full description of these salts from his own experiments§.

Sp. 1. *Succinate of Potash.*

This salt, according to Leonhardi and Stockar, cry-

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* Wenzel's *Verwandtschaft der Korper*, 1777.

† *De Salibus Succinatis*, 1775.

‡ *On Elective Attractions*, *Opusc.* iii. 291.

§ The alkaline succinates have been introduced by this chemist with great advantage to precipitate iron from its solution in acid, which it does more completely and in greater purity than any other known substance. See Klaproth's *Beitrage*, iii. 63.

stallizes in three-sided prisms. It has a bitter saline taste, is very soluble in water, and deliquesces when exposed to the air. When exposed to heat, it decrepitates and melts; and in a strong heat is decomposed.

Sp. 2. Succinate of Soda.

When pure succinic acid is saturated with soda, the solution by spontaneous evaporation yields beautiful transparent crystals of succinate of soda; some of which are four-sided prisms with dihedral summits; others six-sided prisms, terminated by an oblique face *. This salt has a bitter taste, is less soluble in water than common salt, and does not deliquesce when exposed to the air.

This salt is decomposed completely when exposed to a sufficient heat in close vessels.

Sp. 3. Succinate of Ammonia.

This salt forms needle-shaped crystals, but it crystallizes with difficulty. It has a sharp, bitter, and cooling taste; when exposed to heat, it sublimes without decomposition.

Sp. 4. Succinate of Magnesia.

This salt has the form of a white, glutinous, frothy mass, which when dried by the fire attracts moisture from the air, and deliquesces.

Sp. 5. Succinate of Lime.

This salt forms oblong, pointed, non-deliquescent

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* Morveau, *Ann. de Chim.* xxix. 166.

crystals, which are difficultly soluble even in boiling water. It is not altered by exposure to the air. It is decomposed by muriate of ammonia, and by the fixed alkaline carbonates.

Sp. 6. *Succinate of Barytes.*

This salt, according to Bergman, is difficultly soluble in water.

Sp. 7. *Succinate of Alumina.*

This salt, according to Wenzel, crystallizes in prisms, and is easily decomposed by heat *.

Sp. 8. *Succinate of Glucina.*

Eckeberg has announced, that Glucina is precipitated from its solution in acids by the succinates. The succinate of glucina is of course insoluble, or nearly so †.

Sp. 9. *Succinate of Yttria.*

Yttria is not precipitated from its solution in acids by the succinates, according to Eckeberg ‡. This however must be understood with some limitation; for as the succinate of yttria is but sparingly soluble in water, it precipitates in crystals, if a concentrated solution of an alkaline succinate be mixed with a saturated solution of yttria in an acid. Thus, when the succinate of soda is dropt into concentrated muriate or acetate of yttria, small cubic crystals fall, which are succinate of yttria §.

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[*] Verwandt, p. 243.

[†] *Ann. de Chim.* xliii. 277.

[‡] Ibid.

[§] Klaproth's, *Beitrage*, iii. 76.

Book II. Division III.

Such is an imperfect account of the properties of the succinates. The following Table exhibits the proportion of their constituents, according to the experiments of Richter *.

Succinate of	Acid.	Base.
Alumina	100	43·42
Magnesia	100	50·87
Ammonia	100	55·58
Lime	100	65·59
Soda	100	89·45
Strontian	100	109·93
Potash	100	132·75
Barytes	100	183·78

GENUS IV. MOROXYLATES.

This genus of salts, made known by Klaproth, has been too imperfectly examined to enable us to ascertain its peculiar characters, or indeed to place the peculiar nature of the acid beyond the reach of doubt. But the celebrity, skill, and candour of its discoverer, entitles it to at least a provisional place among chemical substances.

Two salts only belonging to this genus have been hitherto formed; namely, moroxylate of lime, and moroxylate of ammonia.

Sp. 1. *Moroxylate of Lime.*

This salt was found on the bark of a mulberry-tree

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[*] *Statique Chimique*, i. 136.

in Naples. It is crystallized in short needles, not altered by exposure to the air. At the temperature of the atmosphere, 100 parts of water dissolve 1½ parts of this salt, and 3½ at a boiling heat. It has a taste resembling succinic acid. When heated, it swells and emits a vapour which irritates the organs of smell. Its solution precipitates acetate of lead, nitrate of silver, and nitrate of mercury.

Sp. 2. *Moroxylate of Ammonia.*

THIS salt may be formed by pouring carbonate of ammonia into the solution of the moroxylate of lime. The solution, when evaporated, yields crystals of moroxylate of ammonia in long slender prisms*.

GENUS V. CAMPHORATES.

THESE salts have been examined by Bouillon Lagrange with much care. They possess the following properties:

Characters.

1. A taste which is usually bitterish.
2. Decomposed by heat: the acid sublimes, and the base remains in a state of purity.
3. Before the blow-pipe they burn with a blue flame.

Sp. 1. *Camphorate of Potash.*

To prepare this salt, carbonate of potash is to be dissolved in water, and the solution saturated with camphoric acid. When the effervescence is over, the liquor is to be evaporated by a gentle heat to the proper con-

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* Klaproth, Nicholson's *Jour.* vii. 130.

sistence, and crystals of camphorate of potash will be deposited when the liquor cools. Camphorate of potash is white and transparent; its crystals are regular hexagons. Its taste is bitterish and slightly aromatic.

Water at the temperature of 60° dissolves $\frac{1}{100}$th part of its weight of this salt; boiling water dissolves $\frac{1}{4}$th part of its weight. It is soluble in alcohol, and the solution burns with a deep blue flame. When exposed to a moist air, it loses a little of its transparency; but in dry air it suffers no change. When exposed to heat it melts, swells, and the acid is volatilized in a thick smoke, which has an aromatic odour. Before the blow-pipe it burns with a blue flame, and the potash remains behind in a state of purity[*].

Sp. 2. *Camphorate of Soda.*

This salt may be formed precisely in the same manner as the camphorate of potash. It is white and transparent; its taste is somewhat bitter; its crystals are irregular. Water at the temperature of 60° dissolves less than $\frac{1}{100}$ part of its weight of this salt; boiling water dissolves $\frac{1}{8}$th of its weight. It is also soluble in alcohol. When exposed to the air it loses its transparency, and effloresces slightly, but is never completely reduced to powder. Heat produces the same effect upon it as on camphorate of potash: the acid burns with a blue flame, which becomes reddish towards the end[†].

Sp. 3. *Camphorate of Ammonia.*

This salt may be prepared by dissolving carbonate of

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[*] Bouillon Lagrange, *Ann. de Chim.* xxvii. 24.

[†] *Ann. de Chim.* xxvii. 26.

ammonia in hot water, and adding camphoric acid slowly till the alkali is saturated. It must then be evaporated with a very moderate heat, to prevent the disengagement of the ammonia. It is very difficult to obtain this salt in regular crystals. When evaporated to dryness, there is left a solid opaque mass of a sharp and bitterish taste. Water at the temperature of about 60° dissolves nearly $\frac{1}{100}$th part of its weight of this salt; boiling water dissolves $\frac{1}{3}$d of its weight: But all the alkaline camphorates are much more soluble when there is excess of base. It is completely soluble in alcohol.

When exposed to the air it attracts moisture, but not in sufficient quantity to enable it to assume a liquid form. When exposed to heat it swells, melts, and is converted into vapour. Before the blow-pipe it burns with a blue and red flame, and is entirely volatilized. Most of the calcareous salts form triple salts with camphorate of ammonia. It decomposes in part all the aluminous salts except the sulphate of alumina [*].

Sp. 4. *Camphorate of Magnesia.*

THIS salt may be prepared by mixing water with carbonate of magnesia, and adding crystallized camphoric acid: heat is then applied, the solution is filtrated, and evaporated to dryness. The salt obtained is dissolved in hot water, passed through a filter, and evaporated by means of a moderate heat till a pellicle forms on the surface of the solution. On cooling the salt is deposited in thin plates. The second solution is intended

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[*] *Ann. de Chim.* xxvii. p. 31.

to remove any excess of magnesia that may happen to be present.

This salt does not crystallize. It is white, opaque, and has a bitter taste. It is scarcely more soluble in water than camphorate of lime. Alcohol has no action on it while cold; but when hot it dissolves the acid and leaves the magnesia, and the acid precipitates again as the alcohol cools. When exposed to the air it dries, and becomes covered with a little powder; but this effect is produced slowly, and only in a warm place. When this salt is placed on burning coals, the acid is volatilized, and the magnesia remains pure. Before the blow-pipe it burns, like the other camphorates, with a blue flame. The nitrates, muriates, and sulphates, do not completely decompose this salt, if we except the nitrate of lime and muriate of alumina *.

Sp. 5. *Camphorate of Lime.*

THIS salt may be prepared by dropping into lime-water crystallized camphoric acid. The mixture is then to be made boiling hot, passed through a filter, and evaporated to about $\frac{3}{4}$ths of its volume. On cooling camphorate of lime is deposited. It has no regular shape; but if the evaporation has been properly conducted, it is in plates lying one above another. It is of a white colour, and has a taste slightly bitter.

Water at the temperature of 60° dissolves very little of this salt; boiling water is capable of dissolving about $\frac{1}{200}$th part of its weight of it. It is insoluble in alcohol. When exposed to the air, it dries and falls into

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* *Ann. de Chim.* xxvii. p. 21.

powder. When exposed to a moderate heat, it melts and swells up; when placed on burning coals, or when heated in close vessels, the acid is decomposed and volatilized, and the lime remains pure. When sulphuric acid is poured into a solution of this salt, it produces an insoluble precipitate. Nitric and muriatic acids precipitate the camphoric acid.

It is composed of 50 acid
43 lime
7 water
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100

Sp. 6. *Camphorate of Barytes.*

In order to prepare this salt, barytes is to be dissolved in water, and camphoric acid added to the solution; the mixture is then to be boiled, and afterwards filtered and evaporated to dryness. Camphorate of barytes does not crystallize; when the evaporation is conducted slowly, the salt is deposited in thin plates one above another, which appear transparent while immersed in the liquor, but become opaque whenever they come into contact with the air. It has very little taste, though it leaves at last upon the tongue a slight impression of acidity mixed with bitterness. Water dissolves only a very small quantity of this salt, boiling water being capable of taking up only $\frac{1}{200}$th part of it. It is not altered by exposure to the air. When exposed to heat, it melts easily, and the acid is volatilized. When the heat is considerable, the acid burns with a lively blue flame, which becomes red and at last white *.

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* *Ann. de Chim.* xxvii. 28.

Sp. 7. Camphorate of Alumina.

To prepare this salt, alumina, precipitated by means of ammonia and well washed, is to be mixed with water, and crystals of camphoric acid added. The mixture is then to be heated, filtered, and concentrated by evaporation. This salt is a white powder, of an acid bitterish taste, leaving on the tongue, like most of the aluminous salts, a sensation of astringency. Water at the temperature of 60° dissolves about $\frac{1}{200}$th part of its weight of this salt. Boiling water dissolves it in considerable quantities; but it precipitates again as the solution cools. Alcohol, while cold, dissolves it very sparingly; but when hot it dissolves a considerable quantity of it, which precipitates also as the solution cools. This salt undergoes very little alteration in the air; but it rather parts with than attracts moisture. Heat volatilizes the acid; and when the salt is thrown on burning coals, it burns with a blue flame *.

GENUS VI. OXALATES.

THIS genus of salts was first made known by Bergman, who described the greater number of them in his dissertation on oxalic acid, published in 1776 †. These salts may be distinguished by the following properties:

Characters.

1. When exposed to a red heat, their acid is decomposed and driven off, and the base only remains behind, usually in the state of a carbonate.

2. Lime-water precipitates a white powder from

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* *Ann. de Chim.* xxvii. 34.

† *Opusc.* i. 260.

their solutions, provided no excess of acid be present. This powder is soluble in acetic acid, after being exposed to a red heat.

3. The earthy oxalates are in general nearly insoluble in water: the alkaline oxalates are capable of combining with an excess of acid, and forming superoxalates much less soluble than the oxalates.

4. The insoluble oxalates are rendered easily soluble by an excess of the more powerful acids.

I. SOLUBLE OXALATES.

Sp. 1. *Oxalate of Potash.*

THIS salt is easily formed by dissolving potash in oxalic acid; but the solution does not readily crystallize unless their be a slight excess either of the acid or the base. A solution, composed of two parts of carbonate of potash, dissolved in one part of acid, yields six-sided prisms, not unlike the crystals of oxalic acid. These crystals fall to powder when heated. They give a green tinge to litmus paper, but they redden tincture of litmus and syrup of violets [*].

When neutral, this salt crystallizes in flat rhomboids, commonly terminated by dihedral summits; the lateral edges of the prism are usually levelled. Its taste is cooling and bitter. At the temperature of 60°, it dissolves in thrice its weight of water. When dried on the sand bath, and afterwards exposed in a damp place, it absorbs a little moisture from the atmosphere. According to my experiments it is composed of

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[*] Bergman, i. 260.

44·87 acid
55·13 base and water

100·00

Sp. 2. *Superoxalate of Potash.*

THIS salt exists ready formed in *oxalis acetosella* or wood-sorrel, and in the *rumex acetosa;* from which it is extracted in some parts of Europe in great quantities. Hence it is known by the name of *salt of wood-sorrel,* and in this country is sold under the name of *essential salt of lemons.* It is mentioned by Duclos in the Memoirs of the French academy for 1668. Margraf first proved that it contained potash; and Scheele discovered its acid to be the oxalic. A great many interesting experiments had been previously made on it by Wenzel and Wiegleb.

It may be formed, as Scheele has shown, by dropping potash very gradually into a saturated solution of oxalic acid in water: as soon as the proper quantity of alkali is added, the superoxalate is precipitated. But care must be taken not to add too much alkali, otherwise no precipitation will take place at all *. Its crystals are small opaque parallelopipeds †. It has an acid, pungent, bitterish taste. It is soluble in about ten times its weight of boiling water, but much less soluble in cold water. It is not altered by exposure to the air. Heat decomposes it. The salt is capable of combining with most of the alkalies and earths, and of forming with them triple salts, which have not been accurately

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* Crell's *Annals*, i. 107. Eng. Transl.

† Romé de Lisle.

examined. Dr Wollaston has shown that it contains exactly double the proportion of acid which oxalate of potash contains.

Sp. 3. *Quadroxalate of Potash.*

This curious salt has been lately discovered by Dr Wollaston. When nitric or muriatic acids are made to act upon superoxalate of potash, they deprive it of one half of its alkali. There remains behind an oxalate containing exactly four times the proportion of acid that exists in oxalate of potash. Hence the name given it by Dr Wollaston. This salt may be purified by a second crystallization. After this, if three parts of it be decomposed by a red heat, and the alkali thus evolved be added to 1 part of the quadroxalate, it will just convert it into a neutral oxalate *.

Sp. 4. *Oxalate of Soda.*

When two parts of crystallized carbonate of soda are dissolved in one part of oxalic acid, the oxalate of soda partly precipitates, because it is but sparingly soluble in water. The remaining solution yields by evaporation crystalline grains, which give a green tinge to syrup of violets, and are perfectly soluble in hot water †. The taste of this salt is nearly the same as that of oxalate of potash. When heated it falls to powder, and loses the whole of its water of crystallization. It is then composed of 63·63 acid

36·37 base

100·00

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* Wollaston, on Superacid and Subacid salts. *Phil. Trans.* 1808.

† Bergman, i. 261.

This salt is also capable of combining with an excess of acid, and forming a superoxalate sparingly soluble in water; but the properties of this triple salt have not been much examined.

Sp. 5. *Oxalate of Ammonia.*

When oxalic acid is saturated with ammonia, the solution yields by evaporation oxalate of ammonia crystallized in four-sided prisms, terminated by dihedral summits. The lateral edges are often truncated, so as to make the prism six or eight-sided. Its taste is bitter and unpleasant, somewhat like that of sal ammoniac. At the temperature of 60° 100 parts of water dissolve only 4·5 parts of this salt. The specific gravity of the solution is 1·0186. This salt is insoluble in alcohol. When distilled, carbonate of ammonia is disengaged, a little of the acid is sublimed, and a residuum of charcoal remains behind. This salt is much used as a reactive to detect the presence of lime *. It is capable of combining with an excess of acid, and forming a superoxalate. Oxalate of ammonia is composed of

74·45 acid
25·55 base

100·00

Sp. 6. *Oxalate of Alumina.*

Oxalic acid readily dissolves alumina, and forms a salt which is uncrystallizable, but furnishes on evaporation a yellowish pellucid mass. It is sparingly so-

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* Bergman, i. 261.

luble in alcohol. It has a sweet astringent taste. It is composed of ....44 alumina
56 acid and water

100

When exposed to the air it deliquesces; and if it has been previously well dried, its weight is increased by $\frac{2}{3}$ds. It reddens turnsole *.

II. Insoluble Oxalates.

Sp. 7. *Oxalate of Magnesia.*

This salt may be obtained by saturating oxalic acid with magnesia, and evaporating the solution. It is in the form of a white powder. It is tasteless, and not sensibly soluble in water; yet when oxalate of ammonia is mixed with sulphate of magnesia, no precipitate falls. But if the solution be heated, and concentrated sufficiently, or if it be evaporated to dryness, and redissolved in water, in both cases the oxalate of magnesia separates in the state of an insoluble powder. The constituents of this salt are as follows:

	†	‡
Acid	65	73·68
Magnesia	35	26·32
Total	100	100

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* Ibid. ii. 387.

† Bergman, *Opusc.* i. 262 and 387.

‡ By my analysis.

Sp. 8. *Oxalate of Lime.*

Oxalic acid does not readily dissolve lime, on account of the insolubility of the oxalate of that base; but the salt may be easily formed by dropping oxalic acid into any of the acid solutions of lime. The oxalate of lime immediately precipitates in the state of a white insipid powder, insoluble in water, and communicating a green colour to the syrup of violets. This salt is in the form of a white powder, tasteless, and perfectly insoluble in water. But it dissolves in almost all acids with considerable facility; of course, it is not precipitated from liquids if they contain an excess of acid. The composition of this salt is as follows:

	*	†	‡
Acid	44·4	48	62·5
Base	55·6	46	37·5
Water		6	
Total	100·0	100	100

The numbers in the preceding Table, given both by Vauquelin and Bergman, I consider as very erroneous. Vauquelin's was the result not of experiment but calculation; and Bergman did not obtain the whole of the salt, but only a part.

No acid decomposes this salt completely except by destroying the oxalic acid, nor any alkaline or earthy

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* Vauquelin, *Ann. de Chim* lix. 164.

† Bergman, i. 262.

‡ By my analysis.

body; but the acid may be easily decomposed and driven off by the action of heat. Oxalate of lime is not rendered soluble by adding an excess of acid. Hence it is probable that no superoxalate of lime exists.

Sp. 9. *Oxalate of Barytes.*

When oxalic acid is dropt into barytes water, a white powder precipitates, which is oxalate of barytes. It is insipid and insoluble in water. If an excess of acid be added, the powder is again dissolved, and small needleform crystals are deposited on the sides of the vessel. These are superoxalate of barytes. The same crystals make their appearance when oxalic acid is dropt into concentrated muriate or nitrate of barytes; but if these solutions are largely diluted with water, no precipitate appears. When the superoxalate of barytes is boiled in water, the excess of acid is removed, and the salt falls down in the state of a white powder *.

The constituents of this salt are as follows:

41·16	acid
58·84	base
100·00	

Sp. 10. *Oxalate of Strontian.*

This salt, first examined by Dr Hope and afterwards by Vauquelin, may be readily formed by mixing together a solution of oxalate of potash and nitrate of strontian. The oxalate of strontian immediately precipitates.

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* Bergman, i. 263. See also Fourcroy and Vauquelin, *Mem. de l'Instit.* ii. 60. and Darracq, *Ann. de Chim.* xl. 69.

Book II.
Division III.

It is a white insipid powder; soluble in 1920 parts of boiling water. Heat decomposes it by destroying the acid *. In my experiments on the composition of this salt I obtained two oxalates, the first containing just double the proportion of strontian that the other did. The first was composed of

39·77	acid
60·23	base
100·00	

The second of

56·9	acid
43·1	base
100·0	

Sp. 11. *Oxalate of Yttria.*

When oxalic acid, or the oxalate of ammonia, is dropt into a solution of yttria in acids, a white insoluble powder precipitates, which is the oxalate of yttria †.

Such is an imperfect sketch of the properties of the oxalates. The following Table exhibits their composition according to my trials:

Oxalates of	Acid.	
Ammonia	100	34·12
Magnesia	100	35·71
Soda	100	57·14

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* Hope, *Edin. Trans.* iv. 14.

† Klaproth's *Beitrage*, iii. 75.

Oxalates of	Acid.	
Lime	100	60·00
Potash	100	122·86
Strontian	100	151·51
Barytes	100	142·86

III. Uses.

None of the oxalates have been hitherto applied to any use, except the oxalate of ammonia, which is often employed by chemists to detect the presence of lime, and to throw it down from liquids.

Genus VII. Mellates.

This genus of salts, in consequence of the scarcity of mellitic acid, is but imperfectly known. Hitherto they have been examined only by Klaproth and Vauquelin, and even by them too slightly to admit a description of their properties. The following are all the facts hitherto ascertained.

Mellate of potash,

1. When mellitic acid is neutralized by potash, the solution crystallizes in long prisms *. The acid appears capable of combining with this salt, and forming a supermellate of potash: For when the *mellite* (or native mellate of alumina) is decomposed by carbonate of potash, and the alkaline solutions mixed with nitric acid, crystals are obtained, consisting of mellitic acid combined with a small portion of potash †.

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* Klaproth's *Beitrage*, iii. 131.

† Vauquelin, *Ann. de Chim.* xxxvi. 203.

Soda.

2. When mellitic acid is neutralized by soda, the solution crystallizes in cubes or three-sided tables; sometimes insulated, sometimes in groups [*].

Ammonia.

3. When mellitic acid is saturated by ammonia, the solution yields fine transparent six-sided crystals, which become opaque when exposed to the air, and assume the white colour of silver [†].

Lime.

4. When mellitic acid is dropt into barytes water, strontian water, or lime water, a white powder immediately precipitates, which is redissolved by adding a little more of the acid [‡].

5. When the acid is mixed with a solution of sulphate of lime, very small gritty crystals precipitate, which do not destroy the transparency of the water: but the addition of a little ammonia renders the precipitate flaky [§]. The precipitate produced by this acid in lime water is redissolved by the addition of nitric acid [||].

Barytes.

6. When this acid is dropt into acetate of barytes, a flaky precipitate appears, which is dissolved by adding more acid. With muriate of barytes it produces no precipitate; but in a short time a group of transparent needleform crystals is deposited, consisting most likely of supermellate of barytes.

Alumina.

7. When this acid is dropt into sulphate of alumina it throws down an abundant precipitate in the form of a white flaky powder [¶].

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[*] Klaproth's *Beitrage*, iii. 131. [†] Klaproth, Ibid. [‡] Ibid.

[§] Vauquelin, *Ann. de Chim.* xxxvi. 210.

[||] Klaproth's *Beitrage*, iii. 131.

[¶] Vauquelin, *Ann. de Chim.* xxxvi. 210.

Several of the properties just mentioned point out a resemblance between the mellates and oxalates; but in others these two genera of salts differ materially. Oxalic acid, for instance, does not precipitate alumina from sulphuric acid, nor does it precipitate lime from the sulphate of that earth in the state of crystals.

GENUS VIII. TARTRATES.

THOUGH tartaric acid was first obtained by Scheele in a separate state, several of the tartrates had been previously examined, having been formed partly by decomposing tartar, and partly by combining it with other bases. Since the discovery of pure tartaric acid, they have been examined by Retzius, by Von Packen, and more lately by Thenard. They may be distinguished by the following properties:

Characters.

1. When exposed to a red heat, the acid is decomposed, and the base remains generally in the state of a carbonate, and mixed with charcoal.

2. The earthy tartrates are nearly insoluble in water; the alkaline are soluble; but they combine with an excess of acid, and are converted into supertartrates, which are much less soluble than the tartrates.

3. When boiled with sulphuric acid, the tartaric acid is separated, and may be detected by dropping in a solution of potash. Tartar precipitates in small gritty crystals like sand.

4. All the tartrates are capable of combining with another base, and forming triple salts.

Sp. 1. *Tartrate of Potash.*

OF this salt there are two varieties. The first, which contains an excess of acid, is usually called *tartar;* the second, which is neutral, was formerly distinguished by the name of *soluble tartar*, because it is much more soluble in water than the first variety.

Variety 1. *Supertartrate of Potash.* This salt is obtained, in a state of impurity, incrusted on the bottom and sides of casks in which wine has been kept. It is afterwards purified by dissolving it in boiling water, and filtering it while hot. On cooling, it deposits the pure salt in very irregular crystals. In this state it is sold under the name of *crystals* or *cream of tartar.*

History.

This salt attracted the peculiar attention of chemists, probably in consequence of the extravagant encomiums and invectives bestowed on it by Paracelsus. It is called *tartar*, says he, because it produces the oil, water, tincture, and salt, which burn the patient as *hell* does. According to him, it is the principle of every disease and every remedy, and all things coutain the germ of it. This ridiculous theory was combated by Van Helmont, who gives a pretty accurate account of the formation of tartar in wine casks*. It was known to Van Helmont, and even to his predecessors, that potash could be obtained from tartar ; but it was long a disputed point among chemists, whether that alkali existed in it ready formed. Duhamel, Margraf, and Rouelle, at last established that point beyond a doubt ; but the other component part of tartar was unknown, or very imperfectly known, till Scheele pointed out the method of extracting it.

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* *Tartari Vini Historia*, Van Helmont, p. 224.

Properties.

The crystals of tartar are very small and irregular. According to Monnet, they are prisms, somewhat flat, and mostly with six sides. Tartar has an acid, and rather unpleasant taste. It is very brittle, and easily reduced to powder. Its specific gravity is 1·953 †. It is soluble in about 60 parts of cold water. When boiled in water, the liquid takes up nearly $\frac{1}{14}$th part of the salt ‡. It is not altered by exposure to the air; but when its solution in water is allowed to remain for some time, the salt is gradually decomposed, a mucous matter is deposited, and there remains in solution carbonate of potash coloured with a little oil. This decomposition was first accurately described by Berthollet in 1782 *.

When tartar is heated, it melts, swells, blackens, and the acid is entirely decomposed. The same changes take place when the salt is distilled in close vessels. The phenomena of this distillation have been described with great care, and its products very attentively examined by chemists; because, before the discovery of the tartaric acid by Scheele, distillation was the only method thought of for obtaining any knowledge of the acid part of tartar. These products are an enormous quantity of gas, consisting of carbonic acid and carbureted hydrogen, an oil, and an acid; and, according to some chemists, *carbonate of ammonia*. The acid obtained was long considered as a peculiar body, and was denominated *pyro-tartarous* acid by the French chemists in 1787: But Fourcroy and Vauquelin have

Pyro-tartarous acid.

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† Hassenfratz, *Ann. de Chim.* xxviii. 12.

‡ Wenzel, *Verwandtschaft*, p. 311.

* *Mem. Par.*

lately demonstrated, that it is no other than acetic acid contaminated with a little empyreumatic oil *.

The tartar of commerce is never quite pure. All the specimens which I had an opportunity of examining contained rather more than 5 *per cent.* of tartrate of lime. A number of specimens were examined by Vauquelin and Boullay; they found the tartrate of lime to vary from 5 to 6 *per cent.* †.

The composition of pure tartar, according to the most accurate experiments hitherto made, is exhibited in the following Table.

Composition.

	‡	§	‖
Acid	57	73·4	77
Potash	33	26·6	23
Water	7		
Total	97	100	100

Variety 2. *Tartrate of Potash.*—This salt is usually prepared by adding at intervals tartar in powder to a hot solution of carbonate of potash till all effervescence ceases. The solution is then boiled for some time, and afterwards evaporated till a pellicle forms on its surface. On cooling, the tartrate of potash crystallizes in flat four-sided rectangular prisms, terminated by dihedral summits. This salt has an unpleasant bitter taste. Its spe-

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* *Ann. de Chim.* xxxv. 161.

† *Ann. de Chim.* lxii. 41.

‡ Thenard, *Ann. de Chim.* xxxviii. 39.

§ By my analysis.

‖ Bergman, *Opusc.* iii. 368.

cific gravity is 1·5567 *. According to Wenzel, it is soluble in its own weight of water at the temperature of 50°, and still more soluble in hot water †. When heated it melts, swells up, blackens, and is decomposed. It contains just half the proportion of acid which exists in tartar. Hence, abstracting the water of crystallization, of which it contains a good deal, it is composed of about

58	acid
42	base
100	

Sp. 2. *Tartrate of Soda.*

THIS salt may be formed by dissolving soda in tartaric acid. It crystallizes in fine needles. Its specific gravity is 1·7437 ‡. It is soluble in its own weight of cold water §. It is capable of combining with an excess of acid, and forming a *supertartrate* of soda, which is nearly as insoluble in water as tartar ||.

Sp. 3. *Tartrate of Ammonia.*

THE crystals of this salt are polygonous prisms, not unlike those of the last described salt. It has a cooling bitter taste like that of nitre. It is very soluble in water. Heat decomposes it. This salt also, as Retzius affirms, combines with an excess of acid, and forms a supertartrate almost as insoluble in water as tartar.

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* Hassenfratz, *Ann. de Chim.* xxviii. 12.

† *Verwandtschaft*, p. 308.

‡ Hassenfratz, *Ann. de Chim.* xxviii. 12.

§ Wenzel, p. 308.

|| Thenard, Ibid.

Sp. 4. *Tartrate of Potash-and-Soda.*

THIS salt is usually prepared by putting one part of tartar in five parts of boiling water, and adding gradually carbonate of soda in powder as long as it continues to produce an effervescence. The tartar gradually dissolves. When the saturation is complete, the solution is filtered and evaporated to the consistence of a syrup. On cooling, the tartrate of potash-and-soda crystallizes.

History.

This salt has been distinguished by the name of *salt of Seignette*, because it was first formed and introduced into medicine by Mr Seignette, an apothecary at Rochelle. This gentleman recommended it in a tract published in 1672. It was soon after introduced into practice in Paris by Lemery; and, becoming a fashionable medicine, made the fortune of the discoverer. For some time its composition was kept secret; but Boulduc and Geoffroy discovered its component parts in 1731.

This salt crystallizes in prisms of eight or ten unequal sides, having their ends truncated at right angles. They are generally divided into two in the direction of their axes; and the base on which they stand is marked with two diagonal lines, so as to divide it into four triangles. It has a bitter taste. It is almost as soluble as tartrate of potash. It effloresces when exposed to the air. Heat decomposes it. Its specific gravity is 1·757*.

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* Watson's *Chemical Essays*, v. 67.

According to the analysis of Vauquelin, it is composed of

54 tartrate of potash
46 tartrate of soda

100[*]

According to the experiments and calculations of Schulze, it is composed of

41·3 acid
14·3 potash
13·3 soda
31·1 water

100·0[†]

Sp. 5. *Tartrate of Potash-and-Ammonia.*

This triple salt may be formed by pouring ammonia into supertartrate of potash. Its crystals, according to Macquer, are prisms with four, five, or six sides: according to the Dijon academicians, parallelopipeds, with two alternate sloping sides.

It has a cooling taste. It is soluble enough in water. It effloresces in the air. Heat decomposes it.

Sp. 6. *Tartrate of Magnesia.*

This salt is insoluble in water except there be an excess of acid present. It then affords by evaporation small crystals in the form of hexangular truncated prisms[‡]. It has a more saline taste, and is more fusible

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[*] Fourcroy, vii. 246.

[†] Gehlen's *Jour.* iv. 210.

[‡] Bergman, i. 388.

than tartrate of lime [*]. Heat first melts and afterwards decomposes it.

Sp. 7. *Tartrate of Potash-and-Magnesia.*

THIS triple salt, first examined by the Dijon academicians, may be formed by dissolving magnesia or its carbonate in tartar. The solution, according to them, yields by evaporation needle-form crystals: but, according to Thenard, this triple salt does not crystallize; and when evaporated, it deliquesces [†].

Sp. 8. *Tartrate of Lime.*

THIS salt may be formed by dissolving lime in tartaric acid, or more economically by dissolving tartar in boiling water, and adding to the solution carbonate of lime in powder till it ceases to produce any effervescence, and to redden vegetable blues. Tartrate of lime precipitates in the state of a white powder, tasteless, nearly insoluble in cold water, but soluble in 600 parts of boiling water. It is rendered soluble in water by an excess of acid, or by being mixed with some of the soluble tartrates, as tartar and Rochelle salt. When in the state of a dry powder, it contains a very considerable proportion of water, from which it can only be freed by a long exposure to heat. According to my analysis, it is composed of

69 acid
31 lime

100

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[*] Von Packen *de Sale Essent. Acid. Tartar.*

[†] *Ann. de Chim.* xxxviii. 32.

Vauquelin and Boullay found the proportion of lime to amount to 35 *per cent* [*].

Sp. 9. *Tartrate of Potash-and-Lime.*

This salt was first pointed out by Thenard. It may be formed by pouring lime-water into the solution of tartrate of potash till a precipitate begins to appear, and then allowing the liquid to evaporate spontaneously. The triple salt gradually attaches itself to the sides of the vessel in crystals [†].

Sp. 10. *Tartrate of Barytes.*

Tartaric acid forms with barytes a soluble salt, the properties of which have not been examined. It is decomposed by oxalic acid [‡].

Sp. 11. *Tartrate of Strontian.*

This salt, first examined by Dr Hope, and afterwards by Vauquelin, may be formed by dissolving strontian in tartaric acid, or by mixing together solutions of nitrate of strontian and tartrate of potash. Its crystals are small regular triangular tables, having the edges and angles sharp and well defined. It is insipid. It dissolves in 320 parts of boiling water. It is composed of

47·12	acid and water
52·88	strontian
100·00 [§]	

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[*] *Ann. de Chim.* lxii. 41.

[†] Ibid. xxxviii. 32.

[‡] Fourcroy and Vauquelin, *Mem. de l'Instit.* ii. 61.

[§] Vauquelin, *Jour. de Min.* An. vi. p. 15.

Sp. 12. *and* 13. *Tartrate of Potash-and-Barytes, and Tartrate of Potash-and-Strontian.*

THESE two triple salts may be formed in the same way. They have been pointed out by Thenard; but, like the preceding salt, their properties are still undescribed[*].

Sp. 14. *Tartrate of Alumina.*

THIS salt does not crystallize, but forms by evaporation a clear transparent gummy mass. Its taste is astringent. It is soluble in water. It does not deliquesce in the air[†].

Sp. 15. *Tartrate of Potash-and-Alumina.*

THIS triple salt is formed by saturating tartar with alumina. It bears a very striking resemblance to the last described salt. Thenard has observed, that no precipitate is produced in this salt, either by the addition of alkalies or their carbonates[§].

Sp. 16. *Tartrate of Yttria.*

YTTRIA is precipitated from its solution in acids by tartrate of potash; but an addition of water dissolves the precipitate[‡]. Hence it follows that tartrate of yttria is soluble in water.

SUCH is an imperfect account of the tartrates. The

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[*] *Ann. de Chim.* xxxviii. 31.

[†] Von Packen.

[§] *Ann. de Chim.* xxxviii. 33.

[‡] Klaproth's *Beitrage*, iii. 75.

following Table gives the proportion of the constituents of these salts, according to the experiments of Richter *.

Tartrates of	Acid.	Base.
Alumina	100	31·06
Magnesia	100	36·30
Ammonia	100	39·67
Lime	100	45·81
Soda	100	50·80
Strontian	100	78·60
Potash	100	94·92
Barytes	100	131·41

III. Uses of the Tartrates.

The only tartrates hitherto applied to use are tartar, tartrate of potash, and Rochelle salt.

Tartar is useful in many of the arts, as dyeing, felting, &c. Tartaric acid is always procured from it. It likewise furnishes pure potash. In medicine it is extremely useful, especially in dropsical cases. The other two salts are employed chiefly as cooling purgatives.

Richter has pointed out a method of obtaining manganese in a state of purity by means of tartrate of potash. If that salt be mixed with an acid solution containing manganese, crystals of tartrate of manganese-and-potash gradually separate.

Genus IX. Citrates.

As the citric acid was first obtained in a state of pu-

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* *Statique Chimique*, i. 236.

rity by Scheele, we may consider him as the author of the first accurate remarks on the citrates. Several of them have been lately examined with considerable attention by Vauquelin; but they are still very imperfectly known.

The citrates may be distinguished by the following properties:

Characters.

1. The solution of barytes forms a precipitate in the alkaline citrates.

2. They are decomposed by the stronger mineral acids.

3. They are decomposed by the oxalic and tartaric acids, which occasion an insoluble precipitate in their solutions.

4. When distilled, they yield traces of acetic acid.

5. Their solution in water is gradually decomposed, depositing mucous flakes.

Sp. 1. *Citrate of Potash.*

This salt may be formed by dissolving carbonate of potash in citric acid, and evaporating the solution to the requisite consistency. It is very soluble in water; does not crystallize easily; and readily deliquesces when exposed to the air. It is composed, according to Vauquelin, of

55·55 acid
44·45 potash
100·00*

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* Fourcroy, vii. 207.

This salt, rather its solution in water, is often employed in this country as a medicine to allay sickness, and put a stop to vomiting.

Sp. 2. *Citrate of Soda.*

THIS salt may be formed by the same process as the last species. By proper evaporation, it is obtained crystallized in six-sided prisms, not terminated by pyramids. Its taste is salt and cooling, but mild. It is soble in $1\frac{2}{3}$ parts of water. When exposed to the air, it effloresces slightly. When heated, it melts, swells, bubbles up, blackens, and is decomposed. According to Vauquelin, it is composed of

60·7 acid
39·3 soda

100·0 [*]

Sp. 3. *Citrate of Ammonia.*

THIS salt, formed by dissolving carbonate of ammonia in citric acid, does not crystallize till its solution be evaporated to the consistency of a thick syrup. Its crystals are elongated prisms. It is very soluble in water. Its taste is cooling and moderately saline [†]. The ammonia is separated by the application of heat [‡].

According to Vauquelin, it is composed of

62 acid
38 ammonia

100 [§]

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[*] Fourcroy, vii. 207.

[†] Dobson.

[‡] Scheele.

[§] Fourcroy, vii. 208.

Sp. 4. *Citrate of Magnesia.*

This salt may be formed by dissolving carbonate of magnesia in citric acid. This solution, though evaporated to a thick syrup, does not crystallize; but it gradually assumes the form of a white opaque soft mass, which rises in the vessel like a mushroom. According to Vauquelin, it is composed of

66·66 acid
33·34 magnesia

100·00 [*]

Sp. 5. *Citrate of Lime.*

This salt is formed by dissolving carbonate of lime in citric acid. It is usually in the state of a white powder scarcely soluble in water; but it is soluble in an excess of acid, and may be obtained from that solution in crystals. According to Vauquelin, it is composed of

62·66 acid
37·34 lime

100·00 [†]

Sp. 6. *Citrate of Barytes.*

When barytes is added to a solution of citric acid, a flaky precipitate appears, which is at first dissolved again by agitation; but remains permanent when the saturation is complete. The citrate of barytes, thus formed, is precipitated in the state of a white powder;

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[*] Fourcroy, vii. 208.

[†] Ibid. 207.

but it gradually assumes the appearance of silky flakes, or forms a kind of vegetation very brilliant and beautiful. It requires a great quantity of water to dissolve it. This salt, according to Vauquelin, is composed of

50 acid crystallized
50 barytes

100 *

Sp. 7. *Citrate of Strontian.*

This salt was obtained by Vauquelin by mixing a solution of citrate of ammonia with nitrate of strontian. No precipitate appears; but when the liquid is slowly evaporated, small crystals of citrate of strontian are gradually formed. This salt is soluble in water, and exhibits nearly the same properties as the oxalate or tartrate of strontian †.

The remaining citrates have not hitherto been examined.

The following Table exhibits the proportions in which the constituents of these salts unite, according to the experiments of Richter ‡, which differ very materially from those given above by Vauquelin.

Citrates of	Acid.	Base.
Alumina	100	31·19
Magnesia	100	36·54
Ammonia	100	39·93
Lime	100	47·12
Soda	100	51·04

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* Fourcroy, vii. 207.

† *Jour. de Min.* An. vi. p. 16.

‡ *Statique Chimique*, i. 136.

Citrates of	Acid.	Base.
Strontian	100	78·97
Potash	100	95·36
Barytes	100	132·03

Scarcely any of these salts have been applied to use.

GENUS X. KINATES.

HITHERTO only one species of this genus of salts has been examined, the kinate of lime, which exists in a species of Peruvian bark. It was first extracted and described by Mr Deschamps junior, an apothecary at Lyons *, but was afterwards examined more in detail by Vauquelin, who ascertained its properties and its composition †.

The following are the only characters of this genus of salts which have yet been determined:

1. They are all soluble in water, and have the property of crystallizing.

2. They occasion no precipitate when dropt into the solutions of nitrates of silver, mercury, lead.

3. When exposed to sufficient heat they are decomposed, the acid is dissipated, and the base remains in the state of a carbonate, and mixed with charcoal.

Sp. 1. *Kinate of Lime.*

THIS salt may be obtained by macerating yellow peruvian bark in water, concentrating the liquid, and setting it aside for spontaneous evaporation.

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* *Ann. de Chim.* xlviii. 65.

† Ibid. lix. 162.

It is white, crystallizes in square or rhomboidal plates, has no taste, and is flexible under the teeth.

It dissolves in about five times its weight of water of the temperature of 55°. It is insoluble in alcohol.

On burning coals, it swells, giving out the smell of tartar, and leaving a mixture of carbonate of lime and charcoal.

The fixed alkalies and their carbonates precipitate lime from the solution of this salt, but ammonia produces no effect. Sulphuric and oxalic acids precipitate lime likewise; but neither acetate of lead nor nitrate of silver produce any effect.

100 parts of this salt dissolved in water require 22 parts of oxalic acid to precipitate all the lime. The oxalate of lime obtained amounted to 27 parts. Now the lime in 27 parts of oxalate amounts nearly to 17 parts. Hence the salt is composed of

17 lime
83 acid and water

100

Genus XI. Saccolates.

These salts, hitherto examined only by Scheele, are almost entirely unknown. The following are all the facts mentioned by that illustrious discoverer.

1. Saccolate of potash. Small crystals, soluble in eight times their weight of boiling water *.

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* Scheele on *Sugar of Milk.*

Book II.
Division III.

2. Saccolate of soda. The same; soluble in five times their weight of boiling water *.

3. Saccolate of ammonia. A salt which has a sourish taste. Heat separates the ammonia †.

4. Saccolate of barytes.
5. Saccolate of lime.
6. Saccolate of magnesia.
7. Saccolate of alumina.

These are salts insoluble in water ‡.

GENUS XII. SEBATES.

As the sebacic acid was, strictly speaking, unknown till the late experiments of Thenard, the description of the sebates published by former chemists cannot be admitted as exact till they be verified by a new examination. These salts of course are unknown, if we except the few facts pointed out by Thenard. This chemist, however, has announced his intention of publishing a detailed account of them §.

1. When sebacic acid is dropt into barytes water, lime water, or strontian water, it does not render these liquids turbid. Hence we learn, that the sebates of the alkaline earths are soluble in water.

2. The alkaline sebates are likewise soluble. Sebate of potash has little taste, does not attract moisture from the air; and when sulphuric, nitric, or muriatic acid is poured upon it, sebacic acid is deposited. When the concentrated solution of this salt is mixed with any of

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* Scheele on *Sugar of Milk.* † Ibid. ‡ Ibid.

§ The salts described by Crell as *Sebates*, appear to have been *Muriates.*

these acids, it becomes solid from the crystallization of the sebacic acid *.

GENUS XIII. URATES.

SOME of the properties of the urates were investigated by Scheele, the discoverer of uric acid. A few facts were pointed out by Fourcroy. But for the most complete account of them which has yet appeared we are indebted to Dr Henry. They may be obtained by boiling the base with an excess of acid in a proper quantity of water, filtrating the solution, and evaporating it to dryness. The following are the properties of these salts, as ascertained by Dr Henry.

The urates of potash, soda, ammonia, barytes, strontian, lime, magnesia, and alumina, obtained by the preceding process, are neutral, have no taste, and can scarcely be distinguished in appearance from pure uric acid. They are not altered by exposure to the air. They dissolve with great difficulty in water, urate of ammonia being the most soluble, and urate of barytes the most insoluble. Next to urate of ammonia are the fixed alkaline urates; then urates of lime, strontian, magnesia, and alumina. From a watery solution of any of the urates, the uric acid is precipitated in the state of a white powder by all the acids, except the prussic and carbonic. A white powder precipitates when the nitrates, acetates, or muriates of barytes, strontian, lime, magnesia, alumina, are mixed with the alkaline urates. A precipitate appears also when any metalline salt (ex-

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* Thenard, Nicholson's 8vo *Jour*. i. 34.

cept the salts of gold) is dropt into a solution of a urate. These precipitates are of difficult solubility. They have all a white colour except urate of iron, which is slightly red, and urate of copper, which has a shade of yellowish green.

The urates of the alkalies and alkaline earths dissolve in the solutions of their respective bases, forming suburates much more soluble than the neutral salts. These solutions are precipitated by all the acids (even by the carbonic and prussic). When a small quantity of acid is dropt in, the precipitate is a neutral urate; an excess of acid is necessary to procure the uric acid in a separate state.

GENUS XIV. MALATES.

THIS genus of salts is almost unknown, owing chiefly to the difficulty of procuring pure malic acid. The following are the only facts hitherto ascertained.

1. Malate of potash.
2. Malate of soda.
3. Malate of ammonia.

These salts were formed by Scheele. They are deliquescent and very soluble.

4. Malate of barytes. When malic acid is dropt into barytes water, a white powder precipitates, which is malate of barytes. According to Scheele, the properties of this salt resemble those of malate of lime.

5. Malate of strontian. Malic acid occasions no precipitate in strontian water. Hence it follows, that malate of strontian is more soluble than malate of barytes *.

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* Pelletier, *Ann. de Chim.* xxi. 141.

6. When malic acid is neutralized with lime, it forms a salt scarcely soluble in water, which may be obtained in crystals, by allowing the supermalate of lime to evaporate spontaneously. Crystals of neutral malate are formed in the solution [*]. But this acid has a strong tendency to combine in excess with lime, and to form a supermalate of lime. This salt is formed when carbonate of lime is thrown into malic acid, or into any liquid containing it. This supersalt exists in various vegetables, especially the sempervivum tectorum, and some of the sedums.

Supermalate of lime has an acid taste. It yields a precipitate with alkalies, sulphuric acid, and oxalic acid. Lime water saturates the excess of acid, and throws down a precipitate of malate of lime. When the supermalate of lime is evaporated to dryness, it assumes exactly the appearance of gum arabic; and if it has been spread thin upon the nail or wood, it forms a varnish. It is not so soluble in water as gum arabic, and the taste readily distinguishes the two. Supermalate of lime is insoluble in alcohol [†].

7. Malate of magnesia. This salt is very soluble in water, and when exposed to the air deliquesces [‡].

8. Malate of alumina. This salt is almost insoluble in water [§]. Of course it precipitates when malic acid is dropt into a solution containing alumina. Mr Chenevix has proposed this acid to separate alumina from magnesia; which earths, as is well known, have a strong affinity for each other [§].

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[*] Scheele, *Crell's Annals*, ii. 5. Eng. Trans.

[†] Ibid. Vauquelin, *Ann. de Chim.* xxxv. 154.

[‡] Schetle, Ibid. p. 10.

[§] *Ann. de Chim.* xxviii. 921.

Book II. Division III.

GENUS XV. FORMIATES.

THE salts belonging to this genus have been too imperfectly examined to admit of a detailed description. The striking analogy which they have to the acetates, has been observed by all those who have subjected them to an experimental investigation.

Formic acid saturated with potash yields a salt which crystallizes in prisms, but deliquesces again when exposed to the air. When distilled, it yields an acidulous water, and a quantity of ammonia. The residue in the retort is a mixture of charcoal and carbonate of potash *.

When saturated with ammonia, it yields a salt which, by distillation, gives a little ammoniacal liquor, and then is totally sublimed without decomposition †.

With lime it forms a salt, which yields crystals not altered by exposure to the air ‡.

The following Table exhibits the constituents of the formiates according to the statement of Richter §.

Formiates of	Acid.	Base.
Alumina	100	54·37
Magnesia	100	62·25
Ammonia	100	68·02
Lime	100	80·26
Soda	100	89·94
Strontian	100	134·51
Potash	100	162·45
Barytes	100	224·90

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* Margraf, *Opusc.* i. 302. † Ibid. p. 305. ‡ Ibid. p. 310.

§ *Statique Chimique*, i. 136.

GENUS XVI. SUBERATES.

THESE salts have been described with a good deal of detail by Bouillon Lagrange. They have in general a bitter taste, and are decomposed by heat.

Sp. 1. *Suberate of Potash.*

THIS salt ought to be formed by means of crystallized carbonate of potash. It crystallizes in prisms, having four unequal sides. It has a bitter saltish taste, and it reddens vegetable blues. It is very soluble in water. Heat melts it, and at last volatilizes the acid *.

Sp. 2. *Suberate of Soda.*

THIS salt does not crystallize. It reddens the tincture of turnsole. Its taste is slightly bitter. It is very soluble in water and in alcohol. It attracts moisture from the air. Caloric produces the same effect on it that it does on suberate of potash †.

Sp. 3. *Suberate of Ammonia.*

THIS salt crystallizes in parallelopipeds. Its taste is saltish, and it leaves an impression of bitterness. It reddens vegetable blues. It is very soluble in water. It attracts moisture from the air. When placed upon burning coals it loses its water of crystallization, and swells up; and before the blow-pipe it evaporates entirely ‡.

Sp. 4. *Suberate of Magnesia.*

THIS salt is in the form of a powder: it reddens the

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* *Ann. de Chim.* xxiii. 52. † Ibid. ‡ Ibid. xxxiii. 55.

Book II. Division III.

tincture of turnsole: it has a bitter taste; it is soluble in water, and attracts some moisture when exposed to the air. When heated it swells up and melts: before the blow-pipe the acid is decomposed, and the magnesia remains in a state of purity *.

Sp. 5. *Suberate of Lime.*

THIS salt does not crystallize. It is perfectly white: it has a saltish taste: it does not redden the tincture of turnsole. It is very sparingly soluble in water except when hot; and as the solution cools most of the salt precipitates again. When placed upon burning coals it swells up, the acid is decomposed, and there remains only the lime in the state of powder †.

Sp. 6. *Suberate of Barytes.*

THIS salt does not crystallize. Heat makes it swell up, and melts it. It is scarcely soluble in water except there be an excess of acid. It is decomposed by most of the neutral salts except the barytic salts and the fluate of lime ‡.

Sp. 7. *Suberate of Alumina.*

THIS salt does not crystallize. When its solution is evaporated by a moderate heat in a wide vessel, the salt obtained is of a yellow colour, transparent, having a styptic taste, and leaving an impression of bitterness on the tongue. When too much heat is employed, it melts and blackens. It reddens the tincture of turnsole, and attracts moisture from the air. Before the blow-pipe

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* *Ann. de Chim.* xxxiii. 55. † Ibid. xxiii. 53. ‡ Ibid. p. 52.

it swells up, the acid is volatilized and decomposed, and nothing remains but the alumina *.

Genus XVII. Gallates.

Whether gallic acid be capable of forming crystallizable salts with the different bases, is still a problem which chemists have not resolved.

Gallic acid forms a green solution with alkalies and alkaline earths.

1. When the alkalies are dropt into a solution of gallic acid in water, or into a solution containing gallic acid, it assumes a green colour. This change is considered by Proust as the most decisive test of the presence of gallic acid. The same change of colour takes place when gallic acid is poured into barytes water, strontian water, or lime water, and at the same time a powder of a greenish brown colour precipitates. The green liquid which remains contains only gallic acid combined with the earth employed in the experiment. But if we attempt to evaporate it to dryness, the green colour disappears, and the acid is almost completely decomposed.

Gallate of magnesia.

2. When magnesia is boiled with the infusion of nutgalls, the liquid becomes almost limpid, and assumes the same green colour as the former mixtures. From the experiments of Davy, it appears, that in this case all the extract of tan is separated from the infusion, together with a portion of the gallic acid; and that the liquid holds in solution nothing but a combination of that acid and magnesia. But in this case also the acid is decomposed, and the green colour disappears, when we attempt to obtain the composition in a dry state.

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* *Ann. de Chim.* xxiii. 55.

Book II. Division III.

Supergallate of alumina.

3. When a small portion of alumina is mixed with the infusion of nutgalls, it separates the whole of the tan and extract, and leaves the liquid limpid and of a very pale yellowish green colour. This liquid, by spontaneous evaporation, yields small transparent prismatic crystals, which, according to Mr Davy, are supergallate of alumina. They afford the only instance of a gallate capable of existing in the state of crystals. The quantity of alumina is very small; too small to disguise the properties of the acid.

GENUS XVIII. PRUSSIATES.

THE prussic acid presents so many anomalies, and its nature is so easily altered, that it has been hitherto impossible to ascertain with precision the properties of the compounds which it forms with the different bases. Indeed the salts formed by the prussic acid have scarcely any permanency unless they be united with a little of some metallic oxide, and therefore in the state of triple salts *. Mere exposure to the air, or to a heat

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* Curaudau, who has lately published a paper on the prussic acid, affirms that it exists in three states. When first prepared by the calcination of blood, it is merely a *carburet of azote*. The instant that this carburet comes in contact with water, it combines with its hydrogen, and forms a gaseous prussic acid, or *prussire* as he terms it. This prussire combines with alkalies and earths; but it has none of the properties of an acid. When it comes in contact with a peroxide, it is modified by the oxygen of that body, assumes acid properties, and forms triple prussiates. See *Ann. de Chim.* xlvi. 148.—These assertions are so contrary to the experiments of Scheele and Berthollet, and to the received opinions, that it would be necessary, before admitting them, to prove their truth by very unexceptionable evidence.

of 120°, is sufficient to decompose them. This want of permanency, rendering the pure prussiates of little importance, has prevented chemists from paying much attention to their properties. The only person, indeed, who has examined them at all is Scheele. But the triple prussiates, not being liable to spontaneous decomposition, have been employed with success as chemical reagents, and have excited a good deal of interest in consequence of the important purposes to which they may be applied.

Sp. 1. *Prussiate of Barytes.*

THIS salt is but sparingly soluble in water. The barytes is precipitated by sulphuric acid, and even by carbonic acid *.

Sp. 2. *and* 3. *Prussiates of the Fixed Alkalies.*

THESE salts, formed by dissolving the fixed alkalies in prussic acid, are very soluble in water, tinge vegetable blues green, and are partly decomposed by a very moderate heat †. They dissolve likewise in alcohol.

Sp. 4. *Prussiate of Lime.*

THIS salt may be formed by dissolving lime in prussic acid, filtering the solution, and separating the uncombined lime, which it still retains, by adding as much liquid carbonic acid as is just sufficient to precipitate all the lime from the same bulk of lime-water. It is then to be filtered again, and preserved in close vessels. It is decomposed by all the other acids and by the alka-

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* Scheele, ii. 167.

† Ibid. p. 166.

lies. When distilled, the prussic acid is separated, and the pure lime remains *.

Sp. 5. *Prussiate of Ammonia.*

This salt has the odour of pure ammonia; when heated it evaporates completely †.

Sp. 6. *Prussiate of Magnesia.*

This salt may be formed by putting pure magnesia into prussic acid. In a few days the earth is dissolved, and the compound formed. The magnesia is precipitated by the alkalies and lime, and by exposure to the air ‡.

Sp. 7. *Prussiates of Iron.*

As the prussiates of iron enter as ingredients into the triple salts formed by the prussic acid, it will be necessary to give some account of them before entering upon the consideration of these triple salts.

It has been demonstrated by chemists, that there are no fewer than four prussiates of iron: namely,

1. White prussiate,
2. Blue prussiate,
3. Yellow prussiate,
4. Green prussiate.

The white prussiate discovered by Mr Proust is composed of prussic acid and *protoxide* of iron. It becomes gradually blue when exposed to the atmosphere, because the oxide absorbs oxygen, and is converted into peroxide §.

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* Scheele, ii 168.

† Ibid. p. 166.

‡ Ibid. p. 167.

§ Nicholson's *Jour.* i. 453.

Blue prussiate, or prussian blue, is composed of prussic acid and the two oxides of iron. It is a deep blue powder, insoluble in water, and scarcely soluble in acids. It is composed, according to the most accurate experiments hitherto made, of equal parts of oxides of iron and prussic acid. It is not affected by exposure to the air. Heat decomposes it by destroying the acid, and the oxide of iron remains behind. The prussian blue of commerce, besides other impurities, contains mixed with it a great quantity of alumina.

Yellow prussiate is composed of prussic acid combined with an excess of peroxide of iron. It is therefore a sub-prussiate of iron. This prussiate is soluble in acids. It may be obtained by digesting the alkalies or alkaline earths with prussian blue. Part of the acid is carried off by these bodies, and the yellow prussiate remains in the state of a powder.

Green prussiate, first discovered by Berthollet, is composed of oxyprussic acid and peroxide of iron. It is therefore in fact an oxyprussiate.

Sp. 7. *Prussiate of Barytes-and-Iron.*

For the first accurate description of this salt we are indebted to the ingenious Dr William Henry. It may be formed by adding prussian blue to hot barytes water till it ceases to be discoloured. The solution, when filtered and gently evaporated, yields crystals of prussiate of barytes-and-iron.

These crystals have the figure of rhomboidal prisms; they have a yellow colour, and are soluble in 1920 parts of cold water, and in about 100 parts of boiling water. In a red heat they are decomposed, the acid being destroyed. They are soluble in nitric and muriatic acids;

sulphuric acid occasions a precipitate of sulphate of barytes *.

Sp. 8. *Prussiate of Strontian-and-Iron.*

This salt was also first examined by Dr Henry. It may be formed by the same process as the last species; but the solution does not crystallize nearly so readily. When evaporated to dryness it does not deliquesce, and is again soluble in less than four parts of cold water †.

Sp. 9. *Prussiate of Lime-and-Iron.*

This salt was perhaps first mentioned by Mr Hagen ‡; but we are indebted to Morveau for the first accurate account of its properties and preparation §.

Upon two parts of Prussian blue of commerce, previously well washed with a sufficient quantity of boiling water, to separate all the foreign salts, about 56 parts of lime-water are to be poured, and the mixture must be boiled for a short time till the lime is saturated with the prussic acid, which is known by its no longer altering paper stained with turmeric: it is then to be filtered.

This liquid, which contains the triple prussiate of lime in solution, has a greenish-yellow colour; its specific gravity is 1·005; and it has an unpleasant bitterish taste. When evaporated to dryness, it yields small crystalline grains, soluble without alteration in water. It is insoluble in alcohol.

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* Nicholson's *Journal*, iii. 170.

† Ibid. p. 171.

‡ Crell's *Annals*, 1784, i. 291.

§ *Encyc. Method. Chim.* i. 242.

This triple prussiate may be used with advantage as a test to ascertain the presence of metals held in solution. The only impurity which it contains is a little sulphate of lime.

Sp. 10. *Prussiate of Potash-and-Iron.*

THIS salt, known also by the names of *prussian alkali, phlogisticated alkali, prussian test, triple prussiate of potash,* &c. has been chosen by chemists as the best combination of prussic acid for detecting the presence of metals, and more especially for detecting the existence of iron. To chemists and mineralogists it is an instrument of some importance; as when properly prepared, it is capable of indicating whether most metallic substances be present in any solution whatever, and even of pointing out the particular metal, and of ascertaining its quantity. This it does by precipitating the metals from their solution in consequence of the insoluble compound which it forms with them. And the colour of the precipitate indicates the particular metal, while its quantity enables us to judge of the prportion of metallic oxide contained in any solution.

Importance.

In order to be certain of the accuracy of these results, it is necessary to have a prussian alkali perfectly pure, and to be certain beforehand of the quantity, or rather of the proportions, of its ingredients. To obtain a test of this kind has been the object of chemists ever since the discoveries of Macquer pointed out its importance. It is to the use of impure tests that a great part of the contradictory results of mineralogical analyses by different chemists is to be ascribed.

The great object of chemists at first was to obtain this prussiate entirely free from iron; but their attempts uniformely failed, because the oxide of iron is one of its necessary component parts. This was first properly pointed out by Morveau.

Often impure.

There are two* ways in which this test may be rendered impure, besides the introduction of foreign ingredients, which it is needless to mention, because it is obvious that it must be guarded against. 1. There may be a superabundance of alkali present, or, which is the same thing, there may be mixed with the prussian test a quantity of pure alkali; or, 2. There may be contained in it a quantity of yellow prussiate of iron, for which prussiate of potash has also a considerable affinity.

If the prussian test contain a superabundance of alkali, two inconveniences follow. This superabundant quantity will precipitate those earthy salts which are liable to contain an excess of acid, and which are only soluble by that excess: Hence alumina and barytes will be precipitated. It is to the use of impure tests of this kind that we owe the opinion, that barytes and alumina are precipitated by the prussian alkali, and the consequent theories of the metallic nature of these earths. This mistake was first corrected by Meyer of Stettin †.

Another inconvenience arising from the superabundance of alkali in the prussian test is, that it gradually decomposes the blue prussiate which the test contains, and converts it into a yellow prussiate. In what manner it does this will be understood, after what has been said, without any explanation.

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* See Kirwan's *Min.* i. 487.

† Crell's *Annals*, 1786. 142.

On the other hand, when the prussian alkali contains a quantity of yellow prussiate of iron, as great inconveniences follow. This yellow prussiate has an affinity for prussic acid, which, though inferior to that of the potash, is still considerable; and, on the other hand, the potash has a stronger affinity for every other acid than for the prussic. When, therefore, the test is exposed to the air, the carbonic acid, which the atmosphere always contains, assisted by the affinity between the yellow prussiate and the prussic acid, decomposes the prussiate of potash in the test, and the yellow prussiate is precipitated in the form of prussian blue; and every other acid produces the same effect. A test of this kind would indicate the presence of iron in every mixture which contains an acid (for a precipitation of prussian blue would appear), and could not therefore be employed with any confidence.

To describe the various methods proposed by chemists for preparing this salt would be unnecessary, as the greater number do not answer the purpose intended[*]. The method practised by Klaproth, first made known to chemists by Westrumb[†], and afterwards described in our language by Kirwan[‡], is considered as one of the best. It is as follows:

Preparation.

Prepare pure potash, by gradually projecting into a large crucible heated to whiteness a mixture of equal

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[*] A historical account of the different preparations, with their properties and defects, may be seen in Westrumb's Treatise, (Crell's *Neu. Endt. in d. Chim.* Th. xii.), in Morveau's Dissertations on the Prussic Acid (*Encyc. Method. Chim.* i. 225.), and Kirwan's Treatise on the Method of Analysing Minerals (Kirwan' *Min.* i 487.)

[†] Crell's *Annals*, 1785, i. 405.

[‡] *Mineralogy*, i. 494.

Book II Division III.

parts of purified nitre and crystals of tartar; when the whole is injected, let it be kept at a white heat for half an hour, to burn off the coal.

Detach the alkali thus obtained from the crucible, reduce it to powder, spread it on a muffle, and expose it to a white heat for half an hour.

Dissolve it in six times its weight of water, and filter the solution while warm.

Pour this solution into a glass receiver, placed in a sand furnace heated to 170° or 180°, and then gradually add the best prussian blue in powder, injecting new portions according as the former becomes grey, and supplying water as fast as it evaporates; continue until the added portions are no longer discoloured, then increase the heat to 212°, and continue it for half an hour.

Filter the ley thus obtained, and saturate it with sulphuric acid moderately diluted; a precipitate will appear: when this ceases, filter off the whole, and wash the precipitate.

Evaporate the filtered liquor to about one quarter, and set it by to crystallize: after a few days, yellowish crystals of a cubic or quadrangular form will be found mixed with some sulphate of potash and oxide of iron; pick out the yellowish crystals, lay them on blotting paper, and redissolve them in four times their weight of cold water, to exclude the sulphate of potash.

Essay a few drops of this solution in barytes water, to see whether it contains any sulphuric acid, and add some barytes water to the remainder if necessary: filter off the solution from the sulphate of barytes which will have precipitated, and set it by to crystallize for a few days; that the barytes, if any should remain, may be precipitated. If the crystals now obtained be of a pale yellow colour, and discover no bluish streaks when sprinkled over with muriatic acid, they are fit for use; but if they still discover bluish or green streaks, the solutions and crystallizations must be repeated.

These crystals must be kept in a well-stopped bottle, which to preserve them from the air should be filled with alcohol, as they are insoluble in it.

Before they are used, the quantity of iron they contain should be ascertained, by heating 100 grains to redness for half an hour in an *open* crucible: the prussic acid will be consumed, and the iron will remain in the state of a reddish brown magnetic oxide, which should be weighed and noted. This oxide is half the weight of the prussian blue afforded by the prussian alkali: its weight must therefore be subtracted from that of metallic precipitates formed by this test. Hence the weight of the crystals, in a given quantity of the solution, should be noted, that the quantity employed in precipitation may be known. Care must be taken to continue the calcination till the oxide of iron becomes brown; for while it is black it weighs considerably more than it should.

Another method.

Another good method of preparing this salt has been lately given by Dr Henry; but it is rather too expensive for general use. It consists in first forming a triple prussiate of barytes, and adding it in crystals to a solution of carbonate of potash till the solution no longer restores the colour of reddened litmus paper. After digesting the mixture for half an hour, filter the liquid, and evaporate it gently. The triple prussiate of potash crystallizes *.

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* Nicholson's *Jour.* iv. 31.

The triple prussiate of potash, when pure, forms fine transparent crystals of a yellow colour ; they have the form of cubes or parallelopipeds, and contain, when pre-prepared according to Klaproth's method, 0·24 parts of black oxide of iron. Proust has shown that they contain $\frac{1}{10}$th of their weight of water. Proust found that 100 parts of this prussiate contain as much potash as 116 parts of sulphate of potash, which amounts to about 60 parts. Hence we may consider this salt as composed of

6	acid
24	black oxide of iron
60	potash
10	water
100	

The proportion of acid seems excessively small. We should conceive the proportion of potash over-rated by Proust.

Sp. 11. *Prussiate of Soda-and-Iron.*

THIS salt has been lately examined by Dr John, who employed the same process for forming it as that described above for forming the triple prussiate of potash. Its colour is yellow. It crystallizes in four-sided prisms terminated at both extremities by dihedral summits. They are transparent, and have a bitter taste ; when left in a warm place they fall down in the state of a white powder, and lose 37½ *per cent.* of their weight. At the temperature of 55° they require 4½ times their weight of water to dissolve them ; but they are much more soluble in boiling water, a portion of the salt crystallizing as the solution cools. The specific gravity of the crystals is 1·458. They are insoluble in alcohol *.

Sp. 12. *Prussiate of Ammonia-and-Iron.*

THIS triple salt has also been employed as a test; but it is not so easy to obtain it in a state of purity as the other two. It was discovered by Macquer, and first recommended by Meyer.

It forms flat hexangular crystals, soluble in water, and deliquesces in the air. Heat decomposes it like the other prussiates †.

Sp. 13. *Prussiate of Magnesia-and-Iron.*

THIS triple salt was first examined by Hagen in 1782; but since that time scarcely any attention has been paid to it.

SECT. II.

OF METALLINE SALTS.

THE action of the acids on metallic bodies, and the saline compounds formed by their combination with them, were some of the first objects to which the earlier che-

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* Gehlen's *Jour.* 2d Series, iii. 171.

† Woulfe, *Jour. de Phys.* xxxiv. 101.—If we believe Van Mons, this is not a triple salt, but a prussiate of ammonia. According to him, ammonia is incapable of forming triple salts with prussic acid and oxides. See *Jour. de Chim.* iii. 280.

mists directed their attention. The facility with which several of these compounds change their state; the activity and corrosive nature of many of them, owing in a great measure to that facility; the permanency of others; and the apparent conversion of one metallic salt into another—were so many anomalies which remained long inexplicable: But they were of too interesting a nature not to excite attention; and to the successive researches of chemists into the properties of metallic salts must be ascribed a great part of the progress which chemistry has made. Many apparent anomalies have been happily explained by the successive labours of Bergman, Scheele, Bayen, Lavoisier, Proust, &c.; but there still remain a sufficient number of difficulties in this part of the science, to exercise the sagacity of the most acute philosophers, and discoveries to be made in it, which will fully compensate the most laborious investigation.

Number of metallic salts.

As there are 28 metallic bases from which these bodies derive their characteristic properties, this class of salts may be divided into 28 genera. Since there are 33 acids with which each base has to combine, it would seem at first sight that the number of species belonging to each genus ought to amount to 33, which would make the metallic salts in all 924. But it is not the metals which combine with acids, it is their oxides, or the compounds which they form with oxygen: the metals themselves, as far as is known at present, are not capable of combining with any acid. Now as most metals form more than one oxide, and as each of the oxides of a metal is often capable of combining with acids, it is evident that the number of metallic salts must greatly exceed this number. Thus iron being ca-

Chap. III.

pable of forming two oxides, the species of salts of iron, instead of 33, must amount to 66, provided each of these oxides be capable of combining with all acids: the contrary of which has not been proved.

Varieties.

It has been shown formerly, that the difference between the oxides of the same metal consists in the proportion of oxygen which they contain. Now, in general, all oxides which do not contain a maximum of oxygen have a tendency to absorb that principle, whenever it is presented to them, till they are completely saturated. This tendency displays itself with most energy when the oxides are combined with acids and in a state of solution; consequently all those metallic salts, whose bases do not contain a maximum of oxygen, are liable to absorb that principle, and by that means to change into a different salt. Thus *green vitriol* is a salt composed of sulphuric acid and black oxide of iron. When dissolved in water and exposed to the air, it very soon absorbs oxygen, the black oxide is changed into the red; and thus a new salt is formed composed of sulphuric acid and red oxide of iron. This is a change exactly the reverse of what happens to those earthy and alkaline salts which contain an acid with a minimum of oxygen; as the *sulphites* and *phosphites*. They also absorb oxygen indeed, and are converted into other salts; but the oxygen combines with the acid, whereas in the metallic salt it combines with the base. These different earthy and alkaline salts have been very happily distinguished by different terminations. Thus the sulph*ite* of potash contains the acid of sulphur with a minimum of oxygen; the sulph*ate* of potash contains the acid of sulphur with a maximum of oxygen. No attempt has hitherto been made to distinguish the different metallic salts of the same base with different doses of oxygen by any similar plan; yet such a distinction is absolutely necessary, if we wish to speak intelligibly about these salts. It is true the distinction is not so easily made in this case as in the other, on account of the indefinite number of oxides belonging to some of the metals; but this very number makes some distinction still more necessary.

It is only of late that chemists began to attend to the different salts which the same metallic base combined with different portions of oxygen is capable of forming with the same acid. Bergman, indeed, and Scheele, had given some striking instances: but Proust has since carried the subject much farther. It is to the newness of this branch of the science that we must ascribe the want of a nomenclature for the metallic salts. The French chemists seem to have been nearly strangers to it when they formed their chemical nomenclature in 1787; and even at present the subject is too imperfectly known to admit of a regular treatise: but I shall in this Section give a full view of all the facts which have been discovered.

Nomenclature.

I do not recollect at present any instance of more than two metallic salts with one acid and base, differing merely in the proportion of oxygen, if we except the prussiates. It will be sufficient, then, for the present, to generalize a mode of naming metallic salts which has been adopted in one class, I mean the metallic muriates. In these salts the compound, consisting of muriatic acid and a metal with a minimum of oxygen is called a *muriate;* the compound of the acid, and the same metal, with a maximum of oxygen, is called an *oxymuriate*. This mode of naming will apply very well to all those genera in which the metal is only capable of forming two oxides, and likewise to all those whose oxides are only capable of forming two salts with the same acid. Thus we may call the compound of sulphuric acid and black oxide of iron *sulphate of iron*; and the compound of the same acid and red oxide of iron, *oxysulphate* or *oxygenized sulphate of iron*. In the present state of the science, I shall satisfy myself with arranging these different bodies as varieties of the same species.

We have, then, 28 genera of metallic salts, 33 species belonging to each, and many of these species containing several varieties. We have likewise a very considerable number of triple salts, consisting of combinations of earthy or alkaline bases with the metallic salts. All these must swell the number of metallic salts to a very considerable amount. But we are very far from being fully acquainted with all these bodies; many of them are still unknown, and many have been merely pointed out without being described. It is even exceedingly probable that not a few of those combinations, which may be stated theoretically, cannot be formed at all: For as the oxides containing a minimum of oxygen have a strong affinity for that principle, it is clear that, instead of combining with those acids which part with their oxygen easily, they will decompose them altogether. This point can only be decided by experiment, as we have no other method of deciding the affinities which different bodies exert upon one another. Even in the present imperfect state of our knowledge, the number of species belonging to many of the genera is very considerable. To prevent the confusion which this is apt to produce, I shall subdivide the salts of every genus as far as possible into five heads. The first head will consist of the salts whose acids are supporters of combustion, excluding the metallic acids. Most of these salts have the property of detonating with phosphorus when struck smartly upon an anvil. They may therefore be distinguished by the epithet *detonating*. It is proper to describe them first, because they are often employed in the formation of the others. The second head will comprehend all the salts whose acids are products of combustion, or undecompounded. They are all incapable of combustion, and may therefore be distinguished by the epithet *incombustible*. The third head will consist of the salts whose acids are combustible [*]. They may be distinguished by the term *combustible*; not that they are all strictly capable of combustion, but because when distilled they all yield combustible products. The fourth head will consist of salts whose acids are metallic. They are all insoluble in water, and most of them are found native. The fifth head will comprehend the triple salts, or those metallic salts which contain not only an acid and metallic oxide, but likewise an alkali or earth. Thus the salts of every genus are subdivided into five parts; namely, I. Detonating. II. Incombustible. III. Combustible. IV. Metallic. V. Triple. But this division will be attended to only in the genera, which have been pretty fully investigated.

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[*] Excluding the sulphites and phosphites, which are better placed under the first head.

GENUS I. SALTS OF GOLD.

THOUGH gold was tortured with the most persevering industry by the alchymists and metallurgists, and has been an interesting object of examination to chemists in every period of the science, there is no genus of salts with which we are at present so little acquainted as those which have for their bases the oxides of that metal. This is not owing to the expence necessarily attending such investigations, but to the peculiar properties of gold itself. As that metal is not acted on by any of the acids except the nitric, oxymuriatic, and nitro-muriatic, none of the salts of gold can be formed directly except the nitrate and muriate: all the rest must be composed by precipitating the oxide of gold from its solution in nitro-muriatic acid, and afterwards dissolving it in the other acids. But this method was not thought of till the nature of the oxides of gold was known; and since that point was ascertained, no chemist has considered these salts as worth investigating. It is true, indeed, that they do not hold out those brilliant discoveries which attract adventurers to other parts of the science: yet it must be admitted that an accurate examination of the metallic salts requires as much address, ingenuity, and sagacity, and would contribute as much to the advancement of the science, as any other investigation whatever. It would throw a new light on mineralogy, and even on geology; it would enable us to develop with more precision the nature of affinity than has hitherto been done; and it would serve also as a touchstone to try the truth of several chemical theories which are at present in vogue.

There are two oxides of gold known, the purple and the yellow; but as far as is known at present, the first of these does not combine with acids at all. Consequently all the salts of gold are, strictly speaking, *oxygenized;* that is, composed of gold combined with a maximum of oxygen. We are only acquainted at present with two species of these salts, namely the *muriate* and the *nitrate*. Hence it is unnecessary to subdivide the genus.

The salts of gold may be ascertained by the following properties:

Characters.

1. They are soluble in water, and the solution has a yellow colour.

2. Triple prussiate of potash occasions a white or yellowish-white precipitate when poured into these solutions.

3. Gallic acid or the infusion of nutgalls gives these solutions a green colour, and a brown powder is precipitated, which is gold reduced.

4. A plate of tin or muriate of tin occasions the precipitation of a purple coloured powder.

5. Sulphate of iron precipitates the gold in the metallic state. Sulphurous acid produces the same effect.

Sp. 1. *Muriate of Gold.*

Formation.

This salt, which was well known to the alchymists, and much valued by them, may be formed by dissolving gold in a mixture composed of one part of nitric and four parts of muriatic acid. The metal is attacked instantly, and dissolves with a strong effervescence, occasioned by the emission of nitrous gas. The liquid, when saturated, which is known by its refusing to dissolve more gold, forms a solution of a deep yellow colour. It tinges the skin indelibly of a deep purple colour, and produces the same effect upon almost all animal and vegetable bodies, and even upon marble. The colour is owing to the partial reduction of the yellow oxide of gold, and its permanency to the strong affinity between metallic oxides and the epidermis.

When this solution is evaporated, muriate of gold is obtained in small crystals of a fine yellow colour, having the form of four-sided prisms or truncated octahedrons. They are obtained more readily if the solution be evaporated to half its bulk, and a little alcohol be afterwards added to it. This muriate is so liquifiable, so difficult to obtain dry, that it can scarcely be taken out of the retort without considerable loss. In summer it becomes liquid in the morning, and crystallizes towards evening, passing through this alternation during the continuance of the hot weather. Its taste is acerb with a little bitterness, but without that after-taste of metal which renders the solutions of silver, mercury, &c. so disagreeable. It dissolves readily in alcohol, and may be separated by distillation without undergoing any change *.

When its solution is heated gradually in a retort, there passes over oxymuriatic acid; and a minute quantity of muriate of gold is also carried along with it undecomposed †. The gold remains spongy, and without lustre at the bottom of the retort.

This salt is soluble in ether. The solution has a

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* Proust, Nicholson's *Jour.* xiv. 239.

† To the liquid obtained by distilling over the solution of gold in nitro-muriatic acid, the alchymists gave the name of *leo rubeus*, "red lion."

yellow colour; and the gold is gradually reduced to the metallic state, doubtless by the action of the ether on it. Ether seems to dissolve muriate of gold more readily than water; for when liquid muriate of gold is agitated with ether, the whole salt passes from the water to the ether.

It is decomposed by the alkaline earths; the yellow oxide of gold being separated. But ammonia redissolves this oxide, and so do the fixed alkalies if added in sufficient quantity, forming probably triple salts which have not been examined.

Decomposed by combustibles.

It is decomposed also while liquid by hydrogen gas, phosphorus, and sulphurous acid; and the gold is precipitated in the metallic state, being deprived of its oxygen by these combustible bodies; but when dry this decomposition does not happen. For these very interesting facts we are indebted to the ingenious Mrs Fulhame. She found, that when a piece of silk, dipt in a solution of gold in nitro-muriatic acid, is exposed to hydrogen gas while moist, the gold is instantly reduced; but if the silk be dried previously, the reduction does not take place. The same reduction takes place when the silk is dipt into phosphureted ether. If a bit of silk, moistened with phosphureted ether, be dipt into the nitro-muriatic solution, its surface is immediately gilt with a fine coat of gold, which adheres very strongly.

Mrs Fulhame ascertained, that this reduction of the gold does not happen in any case unless the salt be moistened with water: when perfectly dry, it is not altered. This is not peculiar to the action of combustibles on metallic salts: it holds also, as we shall see afterwards, with respect to the metals. But it is by no means easy to see what makes water so indispensibly necessary. It is not, as is commonly supposed, in order to secure the fluidity of the mixtnre: for Mrs Fulhame has shown that ether, though a liquid, has no effect in reducing gold unless water be present. She accounts very ingeniously for the phenomena, by supposing that the water is decomposed. The combustible combines with its oxygen, while its hydrogen combines with the oxygen of the gold, and reproduces water. This theory accounts very well for the phenomena; but it would require some direct proof to establish it completely.

Precipitated by metals.

The greater number of the metals, when plunged into the solution of muriate of gold, occasion a precipitate either of gold in the metallic state, or of its purple oxide; while at the same time a portion of the precipitating metal is oxidized and dissolved by the acid. Zinc, iron, bismuth, copper, mercury, precipitate it in the metallic state. Lead, silver, and tin, precipitate it in the state of purple oxide. The sulphate of iron precipitates it in the metallic state, and is at the same time converted into oxy-sulphate by the oxygen which it has absorbed; whereas the oxy-sulphate of iron produces no effect at all. The same thing happens with tin. The muriate of that metal precipitates the gold in the state of purple oxide, combined with oxide of tin; a precipitate well known by the the name of *precipitate of Cassius*, and used to give a red colour to porcelain and glass: But the oxymuriate of tin, which is already at a maximum of oxygen, produces no such effect; because it does not absorb oxygen from the gold.

Mr Proust has published a number of experiments

Book II. Division III.

on the *purple of Cassius*. He has endeavoured to prove that it is a compound of gold in the metallic state, and the peroxide of tin. His proofs that the gold is in the metallic state, do not appear to me quite convincing, though they certainly render the opinion plausible. There can be no doubt that the two constituents of this powder are chemically combined. When the liquid, from which purple of Cassius is precipitated, contains an excess of acid, the precipitation goes on very slowly. It is very much facilitated by the addition of potash; but care should be taken not to add this alkali in excess, otherwise the precipitate is contaminated with a mixture of uncombined oxide of tin. From Proust's experiments we learn, that this powder is a compound of one part of gold and three parts of peroxide of tin [*]. Aqua regia dissolves the gold and leaves the tin; on the other hand, muriatic acid dissolves the tin and leaves the gold. Nitric acid dissolves a portion of the tin, and brightens the colour of the powder; but is not capable of dissolving the whole.

These precipitations have been long known to chemists; but a satisfactory explanation of them was till lately considered as hopeless; and even at present, notwithstanding the progress which the science has made, there are several particulars attending them which are not fully understood. Bergman first threw light upon the subject, by showing that the precipitating metal absorbed oxygen from the other [†]. Berthollet has since rendered it probable that, in most cases, when the pre-

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[*] Nicholson's *Jour.* xiv. 336.

[†] See his Dissertation, *De Precipitatis Metallicis*, *Opusc.* ii. 349. His

cipitate is in the metallic state, it is combined with a portion of the precipitating metal, and therefore in the state of an alloy; and that when precipitated in the state of an oxide, it retains a portion of the acid with which it was combined, and is therefore in the state of a *sub-salt* *. But the full discussion of this subject belongs to the succeeding Book. Even the theory of that acute philosopher will not account for every thing. The precipitation does not succeed equally well in all circumstances. Every person must have observed, that in many cases, when the liquid is very much concentrated, a plate of metal produces no change in several hours; but the moment it is diluted, the dissolved metal precipitated in abundance.

Sp. 2. *Nitrate of Gold.*

BRANDT first observed, that nitrous acid has the property of dissolving gold, especially when assisted by heat; and this observation has been confirmed by the subsequent experiments of several other philosophers. Fourcroy has ascertained, that this effect is produced only when the acid contains a large portion of nitric oxide, and when the gold is very much divided, as in the state of gold leaf. The solution has an orange colour, and always retains an excess of acid. It cannot be evaporated to dryness without decomposition, as the nitrate of gold which it contains is decomposed by light and by heat. This salt is decomposed by muriatic acid †.

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explanation, when translated into the modern language, is, in effect, that given above.

* *Ann. de Chim.* xxxvii. 221.

† Fourcroy, vi. 397.

Book II.
Division III.

Genus II. Salts of Platinum.

As platinum agrees with gold in its power of resisting all the acids except the oxy-muriatic and nitro-muriatic, the same obstacles lie in the way of an examination of the salts of platinum which have prevented us from getting acquainted with the last genus. Indeed the scarcity of this metal, and the great difficulty of procuring it in a state of purity, render it still less easy to examine the salts which it forms. We need not be surprised, therefore, that this genus is scarcely farther advanced than the last.

The salts of platinum may be distinguished by the following properties.

Characters.

1. Their solution in water has a brown or yellowish-brown colour.

2. Triple prussiate of potash occasions no precipitate in these solutions.

3. Neither is any precipitate produced by gallic acid or the infusion of nutgalls.

4. Potash and ammonia occasion the precipitation of small orange-coloured crystals.

5. Sulphureted hydrogen precipitates the platinum in the metallic state.

Sp. 1. *Nitrate of Platinum.*

Nitric acid, as far as is known, is not capable of dissolving platinum, except when that metal is alloyed with gold; but the peroxide of platinum dissolves readily in this acid, and forms with it a nitrate, the properties of which have not been examined.

When this solution is evaporated to dryness, there remains a subnitrate of platinum easily decomposed by heat. From the experiments of Mr Chenevix, we learn that this subnitrate is composed of

89	peroxide of platinum
11	nitric acid and water
100 *	

Sp. 2. *Muriate of Platinum.*

Formation.

THIS salt may be formed by dissolving platinum in oxy-muriatic acid; but it is more easily obtained by means of nitro-muriatic acid. Sixteen parts of a mixture, composed of one part of nitric and three parts of muriatic acids, when boiled upon platinum previously reduced to powder, gradually dissolve it with a violent effervescence, during which hyperoxymuriatic acid gas is disengaged, as Mr Chenevix has ascertained. This solution assumes at first a yellow colour, which gradually deepens as the platinum dissolves; and when the solution is finished, it is of a very deep red or brown. It is exceedingly acrid and caustic, and tinges the skin indelibly of a dark brown colour. When it is sufficiently concentrated by evaporation, very small irregular crystals of muriate of platinum are deposited of a reddish brown colour: when properly edulcorated and dried, they are less soluble in water than sulphate of lime †. This salt has a disagreeably astringent metallic taste. Heat decomposes it by driving off the acid. The earths, as far as they have been tried ‡, decompose the

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* Chenevix on *Palladium*, p. 27.

† Bergman, ii. 167.

‡ Mr Chenevix found that lime precipitates only a portion of the oxide, and not the whole.

solution of this salt by precipitating its oxide: and the same effect, as Bergman first demonstrated, is produced by a sufficient quantity of soda *. But the other two alkalies combine with the muriate of platinum, and form triple salts.

When the solution of this salt is evaporated to dryness, the insoluble muriate which remains is composed of

70 peroxide of platinum
30 acid and water

100 †

Sp. 3. *Sulphate of Platinum.*

Though sulphuric acid has no action on platinum, it dissolves its oxide; but the properties of the salt formed have not been examined.

Mr Chenevix has ascertained, that this acid separates the peroxide of platinum from every other. The insoluble sulphate formed by evaporating to dryness a solution of muriate of platinum, decomposed by sulphuric acid, is composed of....54·5 peroxide
45·5 acid and water

100·0 ‡

Sp. 4. *Benzoate of Platinum.*

Only a small proportion of the oxide of platinum is dissolved by benzoic acid. The liquid, by evaporation, yields yellow crystals of benzoate of platinum, which

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* Bergman, p. 172.

† Chenevix on *Palladium*, p. 27.

‡ Ibid.

Chap. III.

are not altered by exposure to the air, are difficultly soluble in water, and not at all in alcohol. When exposed to the action of heat, the acid is driven off, and the oxide left behind *.

Sp. 5. *Oxalate of Platinum.*

Platinum is not acted on by any acid except the oxy-muriatic and nitro-muriatic; but its oxide is soluble in oxalic acid, and yields by evaporation yellow crystals of oxalate of platinum, the properties of which have not been examined †.

Sp. 6. *Prussiate of Platinum.*

Scheele ascertained that prussic acid has no action either on platinum or its oxide: neither is any precipitate occasioned by pouring the prussiates into a solution of platinum in nitro-muriatic acid. Consequently the prussiate of platinum is soluble in water ‡.

Sp. 7. *Muriate of Platinum-and-Potash.*

When potash is added to the solution of platinum in nitro-muriatic acid, small heavy crystals, of a red colour and octahedral form, are deposited, composed of muriatic acid, oxide of platinum, and potash. The same triple salt is obtained if, instead of potash, the sulphate, nitrate, muriate, or acetate of that alkali be employed. It is sometimes obtained also in the form of a yellow powder. It is soluble in water, and decomposed with difficulty by soda §.

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* Trommsdorf, *Ann. de Chim.* xi. 315.

† Bergman, i. 266.

‡ Scheele, ii. 172.

§ Bergman, ii. 168.

Book II.
Division III.

Sp. 8. *Muriate of Platinum-and-Ammonia.*

For the discovery of the nature of this salt we are likewise indebted to Bergman. When ammonia is added to the solution of platinum in nitro-muriatic acid, small crystalline grains are deposited, which have an octahedral form, a yellow colour, and are soluble in water. These crystals are composed of muriatic acid, oxide of platinum, and ammonia. They are obtained equally, though not in such abundance, if sulphate, nitrate, or muriate of ammonia, be employed instead of the pure alkali or its carbonate. Soda dissolves them; and when the solution is evaporated to dryness, the ammonia is volatilized, and the oxide of platinum separated [*]. When this or the preceding salt is exposed to a strong heat, the platinum is reduced. This is the usual method of purifying platinum.

Sp. 9. *and* 10. *Triple Nitrates of Platinum.*

Bergman has ascertained that potash and ammonia, or their saline compounds, produce the same effect upon the solution of nitrate of platinum that they do on the muriate; that is to say, they occasion a precipitate in crystals, constituting a triple salt; composed, in the first case, of nitric acid, oxide of platinum and potash; and in the second, of the same acid and oxide, combined with ammonia [†].

Sp. 11. *and* 12. *Triple Sulphates of Platinum.*

Bergman has proved, that when potash or ammo-

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[*] Bergman, ii. 174.

[†] Ibid. ii. 175.

nia, or their compounds, are dropt into the solution of sulphate of platinum, a triple salt is also precipitated; composed, in the first case, of sulphuric acid, oxide of platinum, and potash; and in the second, of the same bodies combined with ammonia *. It appears, then, that the oxide of platinum, with what acid soever it be united, has the property of combining with potash and ammonia, and of forming with them triple salts. In this respect the oxide of platinum agrees with the yellow oxide of tungsten; and it is not probable that the property is confined to these two metallic bodies.

GENUS III. SALTS OF SILVER.

SEVERAL of the acids are capable of oxidizing silver: but it resists the action of the greater number. The nitric dissolves it with great facility; hence it is the nitrate of silver with which we are best acquainted. Most of the other acids form with it compounds scarcely soluble in water. All the salts of silver, as far as is known, are decomposed by the alkalies and earths, except the muriate. Vauquelin has ascertained that the alkalies have no effect upon this salt, and that oxide of silver is capable of decomposing the alkaline muriates. The salts of silver may be easily ascertained by the following properties:

Characters.

1. When exposed to the action of the blow-pipe upon charcoal, they are reduced, and a globule of silver obtained.

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* Bergman, ii. 174.

2. The prussiates, when dropt into a solution of a salt of silver, occasion a white precipitate.

3. Hydrosulphuret of potash occasions a black precipitate.

4. Muriatic acid or the alkaline muriates occasion a white heavy flaky precipitate resembling curd.

5. Gallic acid and the infusion of nutgalls occasion a yellowish brown precipitate, at least in several of the solutions of silver.

6. When a plate of copper is put into a solution of silver, that last metal is precipitated in the metallic state, retaining, however, a little of the copper alloyed with it.

7. The solution of sulphate of iron precipitates the silver in the metallic state.

I. DETONATING SALTS.

Sp. 1. *Nitrate of Silver.*

THERE are two species of this salt. The first, which has been long known, is an oxynitrate containing the peroxide of silver; the second, recently described by Mr Proust, is a nitrate.

1. *Oxynitrate.* Nitric acid attacks silver with considerable violence, and dissolves about half its weight of it. The effervescence is occasioned by the disengagement of nitrous gas. The acid employed must be pure; if it contains any muriatic acid, as is always the case with the nitrous acid of commerce, a white insoluble muriate of silver falls to the bottom of the vessel. If the silver contain gold, that metal is also precipitated in the form of a black or very deep purple powder.

Properties. The solution is limpid and colourless, exceedingly heavy, and caustic. It gives the skin, hair, and almost all animal substances, an indelible black colour. Hence it is often used to dye hair, &c. When evaporated till a pellicle begins to form on its surface, it deposites, on cooling, transparent crystals of oxynitrate of silver. These crystals are brilliant and very irregular; sometimes assuming the form of six-sided, sometimes of four-sided, and sometimes of three-sided, thin plates. Their taste is intensely bitter and metallic.

This salt, at the temperature of 60°, dissolves in its own weight of water *. It does not deliquesce in the air; but when exposed to a strong light, it becomes brown, and the silver is partly reduced. It is soluble in alcohol †. When heated, it readily melts, swells up, and then remains liquid. When allowed to cool, it forms a grey-coloured mass, crystallized internally in needles. In that state it is cast in moulds by apothecaries, and formed into small cylinders, often employed by surgeons under the names of *lapis infernalis* and *lunar caustic*, to open ulcers and destroy fungous excrescences.

Lunar caustic.

When this salt is exposed to a red heat, as when it is put upon burning coals, it detonates, and the silver remains pure, attached to the surface of the coal. The same reduction takes place when the salt is distilled in a retort, and nitrous gas, oxygen gas, and azotic gas are disengaged.

Action of combustibles.

Mrs Fulhame has shown, that when this salt is dissolved in water, it is decomposed, and the silver reduced

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* Wenzel. *Verwandtschaft*, p. 308.

† Kunkel, *Phil. Trans.* 1684, vol. xv. 896.

by means of hydrogen gas and phosphorus. A bit of silk moistened with this solution, and exposed to the action of hydrogen gas, is almost immediately covered with a thin layer of silver, which adheres strongly. The same effect is produced by phosphorus and by sulphurous acid gas.

This salt, both in crystals and after being melted, has the property of fulminating violently when mixed with phosphorus, and struck smartly with a hammer. This was first observed by Brugnatelli. To the same ingenious chemist we are indebted for the two following facts: When three grains of sulphur and nine grains of nitrate of silver, mixed together, are struck with a cold hammer, the sulphur inflames, but no detonation takes place; whereas if the hammer be hot, the mixture detonates, and the silver is reduced. If charcoal be substituted for sulphur, only a faint detonation is heard though the hammer be hot *.

The silver is precipitated from the solution of this salt in water in a metallic state by the greater number of the metals, especially by mercury and copper, which at the same time combine with it.

This salt is decomposed by all the alkalies and alkaline earths, and by the sulphuric, sulphurous, muriatic, phosphoric, fluoric acids, and their salts.

Mr Proust has shown, that when silver is dissolved in nitric acid a small portion of the metal is volatilized by the ebullition. From his experiments it does not appear that oxynitrate of silver contains any water of crystallization. He found it composed of

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* *Ann. de Chim.* xxvii. 72.

69 or	70	peroxide of silver
31	30	nitric acid
100	100*	

2. *Nitrate.* This salt may be obtained by the following process: Put a quantity of pure powder of silver into a solution of nitric acid already saturated with silver, and boil the mixture for an hour after nitrous gas has ceased to be evolved; then draw off the clear liquor with a bulbed siphon. The solution is of a pale yellow colour, and it may be concentrated much more than the solution of oxynitrate, as the nitrate which it affords is much more soluble. When it is in the proportion of 240 to 100 of water, it is still far enough from crystallizing, and sometimes it remains fluid for several days; but if it be poured into a phial, it congeals so suddenly, that the last portions from the mouth of the retort become solid like icicles from the eaves of a house, and a great deal of heat is evolved. It is difficult to bring it to a regular crystallization, because it has a much greater tendency to congeal than to separate into crystals. If it congeal, it cannot be redissolved without the separation of a yellow powder, which is a subnitrate of silver. Hence it appears that the portion dissolved takes a portion of acid from this yellow powder.

When the solution of nitrate of silver is kept in the open air, it soon absorbs oxygen, loses its colour, and deposites crystals of oxynitrate. The same change is produced immediately by the adition of nitric acid. Hence a few drops of that acid occasion the immediate deposition of large scales of oxynitrate.

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* Nicholson's *Jour.* xv. 375.

When the solution of nitrate of silver is mixed with the infusion of litmus, a blue lake precipitates. Oxynitrate produces no effect upon this infusion. From the solution of cochineal the nitrate throws down a deep violet lake; the oxynitrate produces a scarlet powder. When the oxynitrate is dropt into sulphate of indigo, no change is produced; the nitrate instantly deprives it of colour, while the silver is reduced. Ammonia precipitates a black powder from the nitrate of silver. This black powder is silver reduced. What is dissolved by the ammonia is in the state of oxynitrate. Pure potash throws down a brown precipitate, as it does from oxynitrate. If this oxide be dried, it absorbs oxygen, and is converted into peroxide. Alcohol acts on nitrate of silver precisely as water does. A portion of subnitrate precipitates, and a supernitrate is dissolved. If the alcoholic solution be distilled, it leaves behind a portion of oxynitrate and of silver reduced. When a little nitrate of silver is dropt into boiling water, it is decomposed, a portion of the silver is reduced, and precipitated in the state of a black powder, and the rest of the salt is converted into oxynitrate.

When the nitrate of silver is concentrated in a retort, it grows thick, gives out a little nitrous gas, enters into fusion, and affords a yellow sublimate which lines the sides of the retort. If the melted mass be dissolved, a yellow powder mixed with a little reduced silver precipitates*.

Sp. 2. *Hyperoxymuriate of Silver.*

THIS salt was discovered by Mr Chenevix. It may

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* Proust, Nicholson's *Jour.* xv. 376.

be formed by boiling phosphate of silver in hyperoxymuriate of alumina, or by passing a current of oxymuriatic acid through water in which the oxide of silver is suspended. It is soluble in about two parts of warm water; but as the solution cools, it crystallizes in small rhomboids, opaque and dull, like nitrate of lead or barytes. It is soluble in alcohol. Muriatic acid decomposes it, as does nitric, and even acetic acid. But the hyperoxymuriatic acid is decomposed, and the muriate of silver remains behind.

When this salt is exposed to a moderate heat, it melts, oxygen is given out, and muriate of silver remains behind. When mixed with half its weight of sulphur, and struck slightly, it detonates with prodigious violence. The flash is white and vivid, and accompanied by a sharp and quick noise, and the silver is reduced and volatilized *.

II. INCOMBUSTIBLE SALTS.

Sp. 3. *Muriate of Silver.*

MURIATIC ACID does not attack silver, even when assisted by heat; but the muriate of silver is easily formed by dropping muriatic acid, or any of its combinations with alkalies or earths, into the solution of silver in nitric acid. A white flaky precipitate immediately forms, which is muriate of silver, or *hornsilver* as it was formerly called.

Properties.

This salt is one of the most insoluble known: Ac-

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[*] Chenevix *On the Oxygenized and Hyperoxygenized Muriatic Acids*, p. 39.

Book II. Division III.

cording to Monnet, it requires no less than 3072 parts of water to dissolve it. When exposed to the air, it gradually acquires a purple colour, owing to the escape of part of its acid, and the consequent reduction of part of the oxide of silver. When exposed to a heat of about 500°, it melts, and assumes, on cooling, the form of a grey-coloured semitransparent mass, having some resemblance to horn, and for that reason called *luna cornea*. A strong heat sublimes it, as Margraf ascertained [*]. When heated strongly in an earthen crucible, it passes through altogether, and is lost in the fire; but when mixed with about four times its weight of fixed alkali, formed into a ball with a little water, and melted rapidly in a crucible well lined with alkali, the silver is reduced, and obtained in a state of purity. Considerable caution is necessary in conducting this experiment. The easiest way of obtaining the silver is, by boiling the muriate in an iron pot with water and pieces of iron.

The muriate of silver is soluble in ammonia. The alkaline carbonates decompose it, but not the pure alkalies: neither is it decomposed by any of the acids. Several of the metals, when fused along with it, separate the silver in its metallic state; but it is always alloyed with a little of the metal employed. Copper, iron, lead, tin, zinc, antimony, and bismuth, have been used for that purpose [†]. If the solution of this salt in ammonia be mixed with running mercury, the silver gradually separates, combines with the mercury, and

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[*] *Opusc.* i. 265. Proust affirms that this sublimation stops after the salt is in complete fusion.

[†] Margraf, Ibid.

forms the crystals usually distinguished by the name of *arbor Dianæ*. Margraf recommends this amalgamation as the best method of procuring pure silver. This salt dissolves in muriatic acid, and by that means may be obtained in octahedral crystals. When the ammoniacal solution of this salt is heated, fulminating silver is precipitated *.

Considerable pains have been taken to ascertain the constituents of this salt correctly, because it is by means of it that the different muriates are analysed. The following Table exhibits the result of the most accurate trials hitherto made:

	†	‡	§	‖	¶
Acid	16.54	17	17·7	18	18·28
Base	83·46	83	82·3	82	81·72
Total	100	100	100	100	100

These analyses correspond very closely with each other. The result of Bergman's ** experiments, as well as those of Wenzel ††, differ very little from the preceding. We may consider 100 parts of dry muriate of silver as containining 75·6 parts by weight of pure silver.

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* Proust, Nicholson's *Jour.* xv. 369.

† Kirwan, Nicholson's *Quarto Jour.* iii. 215. The salt was dried at 130°. The oxygen in the base he states at 8·46.

‡ Chenevix *On Hyperoxygenized Muriatic Acid*, p. 12.

§ Zaboada, *Jour. de Phys.* lx. 379.

‖ Proust, *Jour. de Phys.* xlix. 221.

¶ Rose, Gehlen's *Jour.* vi. 29.

** *Opusc.* ii. 391.

†† *Verwandtschaft*, p. 123.

Muriate of silver is formed also when silver is exposed to the action of oxymuriatic acid.

Sp. 4. Sulphate of Silver.

Sulphuric acid does not act on silver while cold; but when boiled upon that metal in the state of powder, an effervescence is produced, occasioned by the escape of sulphurous acid gas, and the silver is reduced to a white mass soluble in diluted sulphuric acid. This solution is limpid and colourless, and yields on evaporation crystals of sulphate of silver. These crystals are white and brilliant, and have the form of very fine prisms.

Properties.

This salt, according to Wenzel, requires 87¼th parts of water to dissolve it; hence the reason that it is generally precipitated in the state of a white powder when sulphuric acid is dropt into a solution containing silver. It is soluble in nitric acid without decomposition[*]. When heated, it melts, and in a dry heat is decomposed: the silver is reduced, and sulphurous acid and oxygen gas are disengaged. When exposed to the light, it is slowly decomposed. It is decomposed also by the following bodies:

1. Alkalies and alkaline earths, and their carbonates.
2. Muriates, phosphates, fluates.

According to Bergman[†], 100 parts of silver, precipitated from its solution by sulphuric acid, yield 134 of sulphate. Now allowing, with Proust, 10·6 parts of the increase for oxygen, this would give us the component parts of sulphate of silver as follows:

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[*] Klaproth.

[†] *Opusc.* ii. 391.

17·4	acid
82·6	oxide of silver
100·0	

This would make the proportions of sulphate nearly the same as those of the muriate.

Sp. 5. Sulphite of Silver.

Sulphurous acid does not attack silver, but it combines readily with its oxide. The sulphite assumes the form of small brilliant white grains. It has an acrid metallic taste. Water dissolves only a very minute portion of it: accordingly sulphurous acid occasions a white precipitate of sulphite in solutions of silver. When exposed to the light, it assumes a brown colour. When strongly heated the silver is reduced, and sulphurous and sulphuric acids exhaled.

This salt may be obtained also by mixing together the solutions of sulphite of ammonia and nitrate of silver; but if too much sulphite of ammonia be added, the salt is redissolved, and a triple salt formed, composed of sulphurous acid, oxide of silver, and ammonia. The fixed alkalies are also capable of dissolving the sulphite of silver, and forming with it triple salts[*].

Sp. 6. Phosphate of Silver.

Phosphoric acid does not act upon silver, but it combines readily with its oxide. Phosphate of silver is precipitated in the state of a white powder when phosphoric acid is poured into liquid nitrate of silver. It is

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[*] Fourcroy, vi. 323.

insoluble in water, but soluble in an excess of phosphoric acid. When heated strongly in a crucible, a little phosphorus comes over, and phosphuret of silver remains in the retort [*]. This salt is soluble in nitric acid [†]. Mr Chenevix has shown, that when boiled with a solution of an earthy muriate in proper proportions, muriate of silver and phosphate of the earth, both insoluble, are formed, so that the liquid is deprived of the whole of its saline part.

Sp. 7. *Carbonate of Silver.*

Carbonic Acid has no action whatever upon silver; but it is absorbed readily by the oxide of that metal. The carbonate may be obtained by precipitating silver from its acid solutions by means of a carbonated alkali. A white insoluble powder is obtained, which is carbonate of silver. This salt becomes black when exposed to the light; and, when heated, the acid is driven off, and the silver reduced. According to Bergman, when this salt is obtained by precipitating 100 parts of silver from its solution, by means of carbonate of soda, it weighs 129 [‡]. According to this experiment, if we allow, with Proust, 10·6 parts of the increase of weight to be oxygen, carbonate of silver is composed of about

14·2	acid
85·8	oxide of silver
100·0	

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[*] Fourcroy, vi. 340.

[†] Darracq, *Ann. de Chim.* xl. 178.

[‡] Bergman, ii. 391.

Sp. 8. *Fluate of Silver.*

Fluoric acid does not attack silver; but its oxide is partly dissolved by that acid, and partly forms with it an insoluble salt[*]. This acid precipitates the fluate of silver from the liquid nitrate in the form of a white heavy powder, which is supposed by some to resemble the muriate of silver. This salt is decomposed by the sulphuric acid.

Sp. 9. *Borate of Silver.*

Boracic acid has no action on silver whatever; but the borate may be formed by pouring a solution of borax into liquid nitrate of silver. The salt falls to the bottom in the form of an insoluble white powder, which has not been examined.

III. Combustible Salts.

Sp. 10. *Acetate of Silver.*

Acetic acid has no action whatever on silver; but it readily dissolves its oxide, and forms with it acetate of silver. The properties of this salt are but imperfectly known. It may be formed easily by putting acetate of potash into a solution of nitrate of silver, or by saturating hot acetic acid with the oxide of silver. On cooling, the solution yields, according to Margraf, small prismatic crystals of an acrid metallic taste, and easily dissolved in water[†]. When heated, it swells up,

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[*] Scheele, i. 32.

[†] *Opusc.* i. 106. This has been denied by Monnet, but found accurate by Kirwan. The saturated solution, filtered while hot, yielded him

the acid is dissipated, and the oxide of silver remains behind.

Sp. 11. *Benzoate of Silver.*

Benzoic acid does not attack silver, but it dissolves its oxide, and forms with it a salt easily soluble in water, but in a very small proportion in alcohol. It does not deliquesce in the air; but when exposed to the rays of the sun, it becomes brown. Heat volatilizes the acid and revives the silver *.

Sp. 12. *Succinate of Silver.*

The succinic acid does not act on silver, but it dissolves its oxide, and forms with it a salt which crystallizes in thin oblong radiated prisms †.

Sp. 13. *Oxalate of Silver.*

Oxalic acid does not attack silver, but it dissolves a small portion of its oxide. The oxalate of silver, which was first examined by Bergman, may be formed by pouring oxalic acid into a solution of nitrate of silver. It is a white powder scarcely soluble in water, and not at all in alcohol; but soluble in nitric acid. It becomes black by being exposed to the air, owing to the reduction of the oxide ‡.

Sp. 14. *Tartrate of Silver.*

Tartaric acid does not attack silver; but tartar

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very speedily acicular crystals. He supposes that Monnet failed by evaporating the solution.—Kirwan on *Mineral Waters*, p. 81.

* Trommsdorf, *Ann. de Chim.* xi. 313.

† Wenzel's *Verwand*, p. 245.

‡ Bergman, i. 386.

dissolves its oxide, and forms with it a saline mass, which becomes black by exposure to the air[*]. Tartaric acid does not occasion a precipitate in liquid nitrate of silver.

Sp. 15. *Mellate of Silver.*

MELLITIC ACID occasions no precipitate in nitrate of silver[†].

Sp. 16. *Citrate of Silver.*

SILVER is not attacked by the citric acid; but its oxide combines with it, and forms with it a salt insoluble in water, of a harsh metallic taste, which blackens when exposed to the light, and yields, when distilled, acetic acid, while the silver is revived. This salt is decomposed by nitric acid. According to Vauquelin, to whom we are indebted for these facts, it is composed of

36 acid
64 oxide of silver

100[‡]

Sp. 17. *Saccolate of Silver.*

SACLACTIC ACID occasions a white precipitate when dropt into nitrate of silver[§].

Sp. 18. *Malate of Silver.*

SCHEELE ascertained, that malic acid occasions a pre-

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[*] Wenzel's *Verwand.* p. 218.

[†] Klaproth's *Beitrage*, iii. 131.

[‡] Fourcroy, vii. 209.

[§] Scheele, ii. 80.

Book II. Division III.

cipitate in nitrate of silver. But the nature of that precipitate has not been examined *.

IV. METALLIC SALTS.

Sp. 19. *Arseniate of Silver.*

FOR the only account of this salt hitherto given we are indebted to Scheele, the discoverer of arsenic acid. This acid does not attack silver at the common temperature; but when the two bodies are heated together pretty strongly, arsenic is sublimed, the silver oxidized, and the mixture melts into a transparent glass. Water carries off from this glass arsenic acid, holding silver in solution, and leaves a brown insoluble powder, which is arseniate of silver. When this salt is exposed to a heat sufficient to melt the silver, that metal is reduced.

The arseniate of silver may be obtained also by dropping arsenic acid into a solution of silver in nitric acid. The salt precipitates in the state of a brown powder. It may be obtained equally by using, instead of arsenic acid, the alkaline arseniates †.

Scheele has observed, that a mixture of arsenic and muriatic acids oxidizes the silver in a digesting heat, and converts it into muriate, though neither of these acids has any effect on it separately. During the process the arsenic acid loses its oxygen, and is converted into arsenic ‡.

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* Crell's *Annals*, ii. 11. Engl. Transl.

† Scheele, i. 167.

‡ Ibid. p. 169.

Chap. III.

Sp. 20. *Chromate of Silver.*

When chromate of potash is dropt into liquid nitrate of silver, a powder precipitates of a beautiful crimson, which becomes purple when exposed to the action of light. This powder is chromate of silver. When heated, it melts and becomes blackish. Before the blowpipe, when exposed to the action of the blue flame of the candle, it acquires a green colour, and the silver is reduced*.

Sp. 21. *Molybdate of Silver.*

When molybdic acid is added to a nitrate of silver, a white flaky precipitate falls†.

V. Triple Salts of Silver.

Sp. 22. *Tartrate of Potash-and-Silver.*

Thenard has shown, that when tartar is poured into liquid nitrate of silver, a triple salt is formed, composed of tartaric acid, potash, and oxide of silver. This salt is decomposed by the alkalies and their carbonates, and by the sulphates and muriates‡.

Genus IV. Salts of Mercury.

There is no genus of metallic salts which has been subjected to a longer or more varied examination than

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* Vauquelin.

† Scheele, i. 146.

‡ *Ann. de Chim.* xxviii. 36.

this. Mercury was the metal from which the alchymists conceived the greatest hopes, and which they exposed to every possible torture during their researches after the philosopher's stone. The introduction of mercurial salts into medicine occasioned a scrutiny no less varied and obstinate, after the paroxysm of the alchymists was over. The important cures performed by their means, especially in cases of the venereal disease, were early seen by physicians: but the energy with which they acted, and the ravages which they sometimes made on the constitutions of those who used them, were equally visible. These deleterious effects were ascribed to a certain acrid *something* which was supposed to constitute a component part of mercury. The object of chemical physicians was long directed towards discovering a method of removing, neutralizing, or destroying this acrid something, without impairing the good effects of the medicine. Hence the numerous preparations of mercury which were one after another introduced into practise; some of which have in a great measure answered the purposes for which they were intended; while the greater number, after continuing fashionable for a time, have gone one after another out of use.

Mercurial salts have lately engaged the attention of philosophical chemists, because, from the peculiar nature of the metal, the changes which take place during their formation are more easily traced. To them we are indebted for the discovery of the composition of sulphuric acid, of metallic oxides, and for the first decisive proofs of the non-existence of phlogiston; to them we owe the discovery of oxygen gas, and perhaps also of nitrous gas.

Mercurial salts are distinguished by the following properties

Characters.

1. When strongly heated, they are volatilized and dissipated; and traces of mercury may be sometimes observed.

2. Triple prussiate of potash or lime occasions a whitish precipitate, which becomes yellow when exposed to the air.

3. Hydrosulphuret of potash occasions a black precipitate.

4. Muriatic acid, when poured into their solution in water, often occasions a white precipitate.

5. Gallic acid, or the infusion of nutgalls, occasions an orange-yellow precipitate.

6. A plate of copper plunged into a liquid mercurial salt gradually precipitates running mercury.

There are two well authenticated oxides of mercury, and every acid seems capable of combining with both. Of course every species is divisible into two varieties, distinguished by the simple name, and by prefixing to it the epithet *oxygenized*. Many of these varieties are capable of existing in the state of *sub* and *super* salts. This gives rise to another set of varieties still more numerous.

The oxides of mercury are thrown down from their solution in acids by most of the alkalies and alkaline earths, but in different states. When lime is used, Proust has shown that a portion of the acid is retained, and that the precipitate combines with about $\frac{1}{100}$th part of its weight of lime. When ammonia is used, Bayen has ascertained that the precipitate retains a considerable portion of that alkali. But from Berthollet's experiments we learn that the fixed alkalies throw down a sub-salt of mercury not contaminated with any of the precipitating body.

I. DETONATING SALTS.

Sp. 1. *Nitrated Mercury.*

THE action of nitric acid on mercury has been long known to chemists, and indeed is described minutely even by the alchymists: but it was Bergman who first pointed out the different compounds which that acid forms with the mercurial oxides *. These are two in number; namely, the *nitrate* and *oxynitrate;* the last of which contains mercury oxidized to a maximum. Both of them seem capable of existing with an excess of base and an excess of acid. So that we have no fewer than six varieties of nitrated mercury.

Action of nitric acid on mercury.

1. *Nitrate of Mercury.* When nitric acid is poured upon mercury, an effervescence takes place, and nitrous gas is disengaged; the metal is gradually oxidized, and dissolved in that portion of the acid which remains undecomposed. Nitric acid, without the assistance of heat, is capable of dissolving almost its own weight of mercury, and the solution is colourless, very heavy, and exceedingly caustic. It tinges the skin indelibly black, and gives the same colour to almost all animal substances. By spontaneous evaporation it yields transparent crystals, composed of two four-sided pyramids

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* *Opusc.* i. 102.

applied base to base, having their apexes and the four solid angles at their bases truncated. This solution does not yield a precipitate when water is poured into it, and the crystals of nitrate of mercury are soluble without decomposition. But if nitric acid be boiled upon mercury till it refuses to dissolve any more, the first portion is oxidized at the expence of the acid, nitrous gas is disengaged, and oxynitrate formed; the second portion is oxidized at the expence of the oxide, no gas is disengaged, and almost the whole is in the state of nitrate; but the acid holds a much greater proportion of oxide in solution than in the former case. If water be poured into this solution, the salt immediately divides itself into two portions: The first, containing an excess of base, falls down in the state of a white insoluble powder; it is a *subnitrate* of mercury: The second, containing an excess of acid, remains in solution; it is a *supernitrate* of mercury *.

Varieties of nitrate.

Mr Zaboada has shown, that if mercury be dissolved in dilute nitric acid without the assistance of heat, the crystals that form spontaneously in the solution (supposing some running mercury present, which the acid was incapable of dissolving) consist of pure nitrate of mercury †.

When a current of sulphureted hydrogen gas is passed through a solution of nitrate of mercury, the oxide is gradually reduced, and the metal separates in combination with sulphur. Muriate of tin, when mixed with

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* See Berthollet, *Mem. de l' Instit.* iii. 233.

† *Jour. de Phys.* lx. 386.

the solution of this salt, throws down the base in the state of running mercury *.

When the nitrate of mercury is placed upon burning coals, it detonates feebly, emitting a lively white flame. When mixed with a little phosphorus, and struck with a hot hammer, it detonates violently, and the mercury is reduced †.

2. *Oxynitrate of Mercury.* When nitric acid is made to dissolve mercury with the assistance of heat, it acts with much more energy, a much greater quantity of nitrous gas is emitted, and the metal combines with a greater proportion of oxygen; and if the heat be continued, it passes at last into a yellow coloured crystalline mass. In this solution the acid is combined with mercury oxidized nearly to a maximum. It is more acrid than the first solution; and when diluted with water, a precipitate appears, consisting of the salt combined with a great excess of base. This precipitate is white if the solution be diluted with cold water, bu yellow or greenish-yellow if hot water be used. This salt is capable, like the nitrate, of existing both in the state of a superoxynitrate and suboxynitrate. The yellow precipitate obtained by hot water is in fact a suboxynitrate. The crystals always turn blue colours red, and of course contain an excess of acid.

The yellow coloured precipitate obtained from this salt by hot water has been called *nitrous turpeth.* Ac-

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* Zaboada, Ibid.

† Brugnatelli, *Ann. de Chim.* xxvii. 74.

cording to the analysis of Messrs Braamcamp and Siqueira-Oliva, it is composed of

12 acid
88 peroxide

100 *

When a current of sulphureted hydrogen gas is passed through a solution of oxynitrate of mercury, the salt is gradually converted into nitrate, and precipitates in the state of a white powder, which is a combination of nitrate of mercury and sulphur. Muriate of tin likewise reduces the base to the state of protoxide. The protoxide thus formed combines with the acid of the muriate of tin. Hence muriate of mercury may be obtained by subliming the mixture †.

Sp. 2. Hyperoxymuriate of Mercury.

THIS singular salt was discovered by Mr Chenevix. When oxymuriatic acid is made to pass through water in which there is mixed red oxide of mercury, the oxide acquires a dark brown colour, and part of it is dissolved. By evaporating to dryness, a salt was obtained; which, as usual, was a mixture of the oxide combined with muriatic and hyperoxymuriatic acid. By carefully separating the last formed crystals, Mr Chenevix obtained some hyperoxymuriate, which he purified by a second crystallization. This salt is soluble in about four parts of water. When sulphuric, or even weaker acids, are poured on it, hyperoxymuriatic acid

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* *Ann. de Chim.* liv. 125.

† Zaboada, *Jour. de Phys.* lx. 58c.

Book II. Division III.

is disengaged in the usual way. The other properties of this salt have not been examined*.

II. Incombustible Salts.

Sp. 3. *Muriated Mercury.*

The compounds formed by the combination of muriatic acid with the oxides of mercury have, on account of their very great importance, attracted the peculiar attention of chemical philosophers. There is scarcely a single writer on the science who has not either attempted to vary the processes for making them, or to ascertain their properties, or to explain their nature and composition. In 1769 Bergman published a treatise on the mercurial muriates, in which he collected the more important labours of his predecessors, and gave us also his own experiments †; but that illustrious philosopher failed in his attempts to explain the cause of the different properties exhibited by these salts. It was only after the discovery of the oxymuriatic acid, and of the nature of the different oxides of mercury, that this difficult problem could receive a satisfactory solution: and for the first complete solution we are indebted to Berthollet. His conclusions have been decisively confirmed by the experiments of Chenevix.

There are two mercurial muriates; one of them is composed of muriatic acid and mercury combined with a maximum of oxygen; it is of course an *oxymuriate*; the other, containing mercury oxidized to a less degree, is only a *muriate*.

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* Chenevix *on Oxygenized and Hyperoxygenized Muriatic Acids, Phil. Trans.* 1802.

† *Opusc.* iv. 279.

Muriatic acid has no action whatever upon mercury; but it combines very readily with its oxides, and its affinity for these bodies is so strong that it separates them from the sulphuric and nitric acids. It will be proper first to describe the oxymuriate of mercury, because it is usually employed in the manufacture of the muriate.

History.

1. *Oxymuriate of mercury.* This salt is usually denominated *corrosive sublimate,* or *corrosive muriate of mercury.* The original discoverer of it is unknown. It is mentioned by Avicenna, who died before the middle of the eleventh century; and was even known to Rhases, who lived in the century before him. The Chinese have been acquainted with it also for a long time *. The alchymists appear all to have been acquainted with it, and to have reckoned it among their secrets; and some of them, Albertus Magnus for instance, describe it with a good deal of precision. Bergman has enumerated no less than 14 different processes recommended by chemists for preparing this salt; and since that time several new methods have been proposed.

Preparation.

The process most commonly followed is to mix together equal parts of dry oxynitrate of mercury, decrepitated common salt, and calcined sulphate of iron. One-third of a matrass is filled with this mixture; the vessel is placed in a sand-bath, and gradually heated to redness. When the apparatus is cold, oxymuriate of mercury is found sublimed in the upper part of the matrass. The theory of this process is obvious. The heat expels the sulphuric acid from the sulphate, which in its

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* Bergman, iv. 281.

Book II.
Division III.

turn decomposes the common salt, and leaves the muriatic acid at liberty to act upon the mercurial oxynitrate, from which it separates the oxide, and sublimes with it in the state of oxymuriate. Another process, first proposed by Kunkel, is to expose, in a similar vessel, a mixture of equal parts of oxysulphate of mercury and dry common salt to a strong heat: oxymuriate of mercury is equally sublimed. It may be formed likewise by passing oxymuriatic acid into a solution of nitrate of mercury, and evaporating the solution till the salt crystallizes *. But it would be tiresome and useless to enumerate all the different processes. By far the most simple, and certainly the best for chemical purposes, is to dissolve the red oxide of mercury in muriatic acid. The solution takes place readily, and without the disengagement of any gas; and the salt crystallizes spontaneously †.

Properties.

Oxymuriate of mercury, when obtained by sublimation, is in the form of a beautiful white semi-transparent mass, composed of very small prismatic needles. By evaporation, it yields cubes or rhomboidal prisms, or more commonly quadrangular prisms with their sides alternately narrower, and terminated by dihedral summits ‡. Its specific gravity is 5·1398 §. Its taste is excessively acrid and caustic, and it leaves for a long time a very disagreeable styptic metallic impression on the tongue. When swallowed, it is one of the most virulent poisons known, producing violent pain, nausea, and vomiting, and corroding in a very short time the

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* Fourcroy, v. 337.

† Berthollet, *Mem. de l'Instit.* iii. 136.

‡ Bergman, iv. 295.

§ Hassenfratz, *Ann. de Chim.* xxviii. 12.

stomach and intestines[*]. It is soluble in about 20 parts of cold water. Boiling water, according to Macquer, dissolves half its weight of it. According to Wenzel, water when boiled over this salt dissolves very nearly $\frac{1}{3}$d of its weight of it[†]. Alcohol, according to Macquer, at the temperature of 70°, dissolves $\frac{3}{8}$ths of its weight, and 100 parts of boiling alcohol dissolve 88 parts of it. It is not altered by exposure to the air. When heated, it sublimes very readily; and while in the state of vapour, it is exceedingly dangerous to those who are obliged to breathe it.

It is soluble in sulphuric, nitric, and muriatic acids; and may be obtained again by evaporation unaltered. It is decomposed by the fixed alkalies, and its oxide precipitated of a yellow colour, which soon becomes brick-red. This decomposition renders oxymuriate of mercury a useful test for ascertaining the presence of alkalies in solution. If liquid oxymuriate of mercury be dropt into a solution containing the smallest portion of alkali, the brick-red precipitate appears. The alkaline earths also decompose this salt, and ammonia forms with it a triple compound. Several of the metals, or their sulphurets, decompose it also by the assistance of heat. This is the case in particular with arsenic, bismuth, antimony, and tin. These metals are oxidized and combined with muriatic acid, while the mercury is reduced, and combined with sulphur if it be present.

The constituents of this salt were first clearly ascertained by Mr Chenevix. Since that time the subject

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[*] Hence it was called by the alchymists the *dragon*.

[†] *Verwandtschaft*, p. 310.

Book II. Division III.

has been examined by Zaboada. The following Table exhibits the result of the different analyses hitherto made:

	*	†	‡	§
Acid	18	18·5	18·8	19·5
Peroxide	82	81·5	81·2	80·5
Total	100	100	100	100

According to Chenevix, the oxide contains about 17·6 of oxygen; but Zaboada has rendered it probable that the proportion of oxygen does not exceed 10 *per cent*. This last chemist has shown that 100 grains of oxymuriate of mercury, when reduced by means of muriate of tin, yield 71 grains of mercury. According to Chenevix, 69·6 grains of mercury yield very nearly 100 grains of corrosive sublimate; a result which differs but little from the preceding. According to Rose, 100 parts of corrosive sublimate contain 74 of mercury.

History.

2. *Muriate of mercury*. The discoverer of this important salt, commonly known in this country by the names of *calomel* and *mercurius dulcis*, is altogether unknown. It seems to have been prepared by the alchymists; yet Crollius, so late as the beginning of the 17th century, speaks of it as a grand secret and mystery: But Beguin made the process public in 1608 in

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* Chenevix. † Rose, Gehlen's *Jour.* vi. 28.

‡ Braamcamp aud Siqueira-Oliva, *Ann. de Chim.* liv. 124.

§ Zaboada, *Jour. de Phys.* lx. 383.

his *Tirocinium Chemicum*, in which he describes the salt under the name of *draco mitigatus* *.

Preparation.

The processes for preparing it, which are numerous, have been described by Bergman. The most usual is to triturate four parts of oxymuriate of mercury with three parts of running mercury in a glass mortar, till the mercury is *killed*, as the apothecaries term it; that is to say, till no globules of the metal can be perceived; and the whole is converted into a homogeneous mass. This mixture is put into a matrass, and exposed to a sufficient heat in a sand bath. The muriate is sublimed; mixed, however, usually with a little oxymuriate, which is either removed by repeated sublimations and triturations, or by washing the salt well with water.

It may be prepared also in the humid way, by a process first suggested by Scheele, but lately corrected by Mr Chenevix.

Scheele's method is to form a nitrate of mercury by dissolving as much mercury as possible in a given quantity of boiling nitric acid. A quantity of common salt, equal to half the weight of the mercury used, is then dissolved in boiling water, and the boiling nitrate is cautiously poured into it. A white precipitate falls, which is to be edulcorated with water till the liquid comes off without any taste, and then dried upon a filter †.

We have seen formerly, that the nitrate of mercury, formed as Scheele prescribes, contains an unusual proportion of oxide. When water is added to its solution,

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* It has been known also by a variety of other names; such as, *sublimatum dulce, aquila alba, aquila mitigata, manna metallorum, panchymogogum minerale, panchymogogus quercetanus.*

† Scheele, i. 221.

it immediately separates into two portions; supernitrate, which remains in solution; and subnitrate, which precipitates in the state of a white insoluble powder. When the solution of common salt is added to the solution, a portion only of the oxide will have time to combine with the muriatic acid; another portion must be precipitated by the water in the state of subnitrate. Scheele's precipitate then is not muriate of mercury, but a mixture of muriate and subnitrate. To obtain pure muriate, the nitrate must be prepared without heat; in which case no excess of base is present: or if it be prepared by means of heat, the solution of muriate of soda must be mixed with some muriatic acid. In the first case, no subnitrate is precipitated; in the second, it is decomposed by the muriatic acid present *.

The theory of the formation of this salt is obvious. By the first process, the mercury, combined with the oxymuriate, which amounts to $\frac{3}{4}$ths of its weight, deprives the oxide of part of its oxygen, and of course the salt is converted into a muriate, which combines at the same time with an additional dose of oxide. In Scheele's process, the mercury is not oxidized to a maximum, or only a small portion of it is so; and the oxymuriate formed is mostly dissolved by the solution of common salt, which is added in excess on purpose, and afterwards completely removed by the water with which the muriate is washed.

Properties.

Muriate of mercury is usually in the state of a dull white mass; but when slowly sublimed, it crystallizes

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* Chenevix *On the Oxygenized and Hyperoxygenized Muriatic Acids*, p. 39.

in four-sided prisms, terminated by pyramids. It has very little taste, is not poisonous, but only slightly purgative. Its specific gravity is 7·1758 *. It is scarcely soluble, requiring, according to Rouelle, 1152 parts of boiling water to dissolve it.

When exposed to the air, it gradually becomes deeper coloured. When rubbed in the dark, it phosphoresces, as Scheele discovered. A stronger heat is required to sublime it than is necessary for the sublimation of oxymuriate. Oxymuriatic acid converts it into oxymuriate of mercury; and the same change is produced by subliming it with one part of common salt and two parts of sulphate of iron. Nitric acid dissolves it readily, and much nitrous gas is evolved, as Berthollet has shown, and the salt is converted into oxymuriate.

Mr Chenevix employed the following method to ascertain the composition of this salt. He dissolved 100 parts of it in nitric acid, and precipitated the acid by nitrate of silver. The precipitate indicated 11·5 muriatic acid. The oxide obtained was 88 5. Zaboada followed nearly the same plan. The precipitate, by means of nitrate of silver, indicated 10·6 of muriatic acid. Muriate of tin threw down 85 grains of pure mercury. Hence he concluded that the oxide contained 5 *per cent.* of oxygen. Whereas Chenevix's experiments indicated 10·7 *per cent.* of oxygen. The following is the result of the analyses of these two chemists:

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* Hasschfratz, *Ann. de Chim.* xxviii. 12.

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Acid	10·6	11·5
Protoxide	89·4	88·5
Total	100	100

Sp. 4. *Sulphated Mercury.*

THE action of sulphuric acid on mercury had been observed by chemists in the very infancy of the science; but the phenomena of that action were first explained by Lavoisier in 1777 [‡], and the different compounds obtained were first examined with precision by Fourcroy in 1791 [§]. Sulphuric, like other acids, combines with two oxides of mercury, and forms a *sulphate* and *oxysulphate*; and each of these is capable of combining with an excess of acid and of base. We have therefore no less than six varieties at least of sulphated mercury. These are,

Varieties.

1. Sulphate
2. Supersulphate
3. Subsulphate
4. Oxysulphate
5. Superoxysulphate
6. Suboxysulphate.

Sulphate.

1. *Sulphate of Mercury.* Sulphuric acid has no action on mercury while cold; but when heat is applied, an effervescence ensues, and sulphurous acid gas is emitted. This indeed is the method usually followed for obtaining that gas in a state of purity. At the same time the mercury is gradually oxidized and converted

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* Zaboada. † Chenevix.

[‡] *Mem. Par.* 1777. [§] *Ann. de Chim.* x. 293.

into a white mass; the nature of which differs according to the proportion of the ingredients and the degree of heat employed; but it is usually a mixture of supersulphate and superoxysulphate. Sulphate of mercury may be formed by boiling over mercury a quantity of sulphuric acid diluted with its own weight of water. Very little sulphurous acid gas is disengaged *. By proper evaporation this salt is obtained in small prismatic crystals. It is soluble without decomposition in 500 parts of cold water, and in 287 parts boiling water. It is not altered by exposure to the air; but heat decomposes it. According to Fourcroy, it is composed of..................12 acid

Composition.

83 oxide of mercury
5 water

100

The alkalies and lime-water precipitate the mercury in the state of black oxide, or rather *subsulphate*, as it retains a small portion of acid. Sulphuric acid combines with it, and converts it into supersulphate of mercury †.

Supersulphate.

This last variety may be obtained at once. If sulphuric acid be boiled on mercury, and the process be stopped before the whole of the sulphuric acid is evaporated to dryness, the white mass obtained, after being washed with a little water, is *supersulphate of mercury*. This salt has an acrid taste, it reddens vegetable blues, and does not become yellow when exposed to the air. As it contains different proportions of acid, according to the process, its solubility of course is different,

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* Berthollet, *Mem. de l' Instit.* iii. 230.

† Fourcroy, *Ann. de Chim.* x. 299.

When the excess of acid amounts to about the twelfth of its weight, it is soluble in 157 parts of cold water, and in about 33 parts of boiling water *.

Oxysulphate.

2. *Oxysulphate of Mercury.* When three parts of sulphuric acid are boiled upon two parts of mercury, the whole is gradually converted into supersulphate. If the heat be continued, the excess of acid is slowly decomposed, sulphurous acid gas is disengaged, the mercury combines with an additional dose of oxygen, and there remains oxysulphate of mercury. This salt crystallizes in small prisms. Its colour is a dirty white when perfectly neutral; but when obtained at once in a dry mass, it is of a fine white colour, and always contains an excess of acid. It undergoes no alteration by being exposed to the air, unless it has been allowed to retain an excess of acid; but in that case it deliquesces. It is composed, according to the experiments of Messrs Braamcamp and Siqueira-Oliva, of

31·8	acid
63·8	peroxide
4·4	water
100·0 †	

When water is poured upon this salt, it is immediately separated into two portions; namely, *superoxysulphate* and *suboxysulphate:* The superoxysulphate, with a great excess of acid, is dissolved by the water; and the suboxysulphate remains in the state of a beautiful yellow powder, known formerly by the name of *turpeth mineral.* That it is oxysulphate with an excess of base was

Suboxysulphate

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* Fourcroy, *Ann. de Chim.* x. 298.

† *Ann. de Chim.* liv. 123.

first proved by Rouelle. Its specific gravity is 6·444 *. It is soluble in 2000 parts of cold water, and in 600 parts of boiling water. The solution is colourless †.

Turpeth mineral.

The name *turpeth mineral* seems to have been given to this salt by Crollius, who boasted of its medicinal virtues, but kept the preparation a secret. He attempted to moderate the violent action of this substance by a long digestion, but without success. The process for preparing it was afterwards made public. Kunkel published a set of experiments on it in 1700, in his *Laboratorium Chymicum*. The name *turpeth* was no doubt given from some resemblance which it was supposed to have either in its colour or effects to the root of the *convolvolus turpethum*, a plant formerly used in medicine.

According to the experiments of the Portuguese chemists above quoted, *turpeth mineral* is composed of

15·0 acid
84·7 peroxide
0·3 water

100·0 ‡

Sp. 5. *Phosphated Mercury.*

Phosphoric acid does not act on mercury: but it combines with its oxide, and forms phosphate of mercury. This salt is formed most conveniently by mixing together the solutions of nitrate of mercury and phosphate of soda. The salt immediately precipitates

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* Watson's *Chemical Essays*, v. 68.

† Fourcroy, *Ann. de Chim.* x. 298.

‡ *Ann. de Chim.* liv. 123.

in the state of a white powder. This salt has been lately introduced into medicine, and seems to answer equally well with the other mercurial preparations. It phosphoresces when rubbed in the dark; and when distilled, it yields phosphorus, like the other metallic phosphates. Its specific gravity is 4·9835 *. This salt is in fact an oxyphosphate of mercury. Its constituents are

	28·5 acid
	71·5 peroxide
	100·0 †

Phosphited Mercury. Messrs Braamcamp and Siqueira have shown, that phosphurous acid decomposes all the oxides and salts of mercury, separating the base in the metallic state. Hence it is not probable that *phosphite of mercury* can exist ‡.

Sp. 6. *Carbonate of Mercury.*

Carbonic acid does not attack mercury, but it may be combined with its oxide by pouring an alkaline carbonate into nitrate of mercury. The precipitate in that case is a white powder, composed, according to Bergman, of

	90·9 mercury
	9·1 oxygen and acid
	100·0 §

Sp. 7. *Fluate of Mercury.*

Fluoric acid has no action on mercury; but it

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* Hassenfratz, *Ann. de Chim.* xxviii. 12.

† Braamcamp and Siqueira, *Ann. de Chim.* liv. 125.

‡ *Ann. de Chim.* Ibid.

§ Bergman, ii. 391.

combines with its oxide, and forms a white insoluble fluate of mercury *. The same salt is precipitated when the alkaline fluates are mixed with the nitrate of mercury.

Sp. 8. *Borate of Mercury.*

Boracic acid has no action on mercury; but borate of soda, poured into a solution of that metal in nitric acid, occasions a precipitate of borate of mercury in the state of a yellow powder, first described by Monnet. Its specific gravity is 2·266 †.

III. Combustible Salts.

Sp. 9. *Acetated Mercury.*

Acetic acid does not act sensibly on mercury; but it dissolves its oxides, especially when hot. The first accurate set of experiments on these solutions was made by Margraf, who procured from them a salt in crystals ‡. With the protoxide of mercury acetic acid forms an *acetate*, and with the red oxide an *oxacetate;* salts which were first properly distinguished from each other by Mr Proust §.

1. *Acetate of Mercury.* This salt may be formed by dissolving in acetic acid the precipitate obtained from nitrate of mercury by means of alkalies. As the solution cools, thin brilliant plates of acetate of mercury are deposited, resembling boracic acid. It may be prepared also by mixing together solutions of nitrate of

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* Scheele, i. 32.

† Hassenfratz, *Ann. de Chim.* xxviii. 12.

‡ *Opusc.* i. 119.

§ *Jour. de Phys.* lvi. 205.

Crystals.

mercury and acetate of potash. Large flat crystals of acetate of mercury, of a silvery whiteness, soon make their appearance. This salt has an acrid taste, is insoluble in alcohol, and scarcely soluble in water. In alkalies it blackens. The proportion of the constituents of this salt has not been ascertained. It is employed in medicine.

2. *Oxacetate of Mercury.* This salt is obtained by dissolving the red oxide of mercury in acetic acid. It does not crystallize; but when evaporated to dryness, forms a yellow mass, which soon deliquesces. It dissolves readily in alcohol; but water divides it into two salts, a *superoxacetate*, which remains dissolved in the water, in consequence of its great excess of acid; and a *suboxacetate*, in the same state of a yellow powder, insoluble in water. When the solution of red oxide of mercury in acetic acid is heated, some crystals of acetate are obtained; because a part of the oxygen of the oxide is separated at the expence of the acid, a portion of which is decomposed [*].

Varieties.

Sp. 10. *Succinate of Mercury.*

When succinic acid is digested with the oxide of mercury, it forms with it a shapeless mass containing some crystals, and soluble in water; from which the oxide is precipitated by alkalies and hydrosulphurets [†].

Sp. 11. *Benzoate of Mercury.*

Benzoic acid dissolves the oxide of mercury, and

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[*] Proust, *Jour. de Phys.* lvi. 205.

[†] Wenzel's *Verwandtschaft*, p. 245.

forms with it a white powder, not altered by exposure to the air. It is insoluble in water, and very sparingly soluble in alcohol. A moderate heat sublimes this salt, and a strong heat decomposes it. It is decomposed by lime, by sulphuric acid and muriatic acids, and by sulphur [*].

Sp. 12. *Oxalate of Mercury.*

Oxalic acid does not act on mercury; but it dissolves its oxide, and forms with it an oxalate in the state of a white powder, scarcely soluble in water. When exposed to the light, it very soon becomes black. The same salt is precipitated when oxalic acid is poured into the sulphate or nitrate of mercury [†]. Klaproth first discovered that this salt has the property of detonating when heated [‡]: the same observation was afterwards made by Von Packen [§]. Howard's fulminating powder consists partly of this salt.

Sp. 13. *Mellate of Mercury.*

Mellitio acid occasions a white precipitate in nitrate of mercury, which is redissolved on the addition of nitric acid [||].

Sp. 14. *Tartrate of Mercury.*

Tartaric acid does not attack mercury; but it dissolves its protoxide, and forms with it an insoluble white salt, which soon becomes yellow when exposed

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[*] Trommsdorf, *Ann. de Chim.* xi. 316.

[†] Bergman, i. 266.

[‡] Westrumb's *Kl. Ph. Chim. Abh.* i. 228.

[§] *De Sale Acid Tartari*, 1779.

[||] Klaproth's *Beitrage*, iii. 131.

to the light. This salt precipitates also when tartaric acid is poured into nitrate of mercury.

Sp. 15. *Citrate of Mercury.*

THIS salt has been examined by Vauquelin. Citric acid does not attack mercury; but when poured upon its red oxide, an effervescence takes place, and the oxide becomes white and unites into one mass. The citrate thus formed has a mercurial taste, but is scarcely soluble in water. Nitric acid decomposes it. When distilled, there comes over acetic and carbonic acids, and the mercury is reduced*.

Sp. 16. *and* 17. *Saccolate and Malate of Mercury.*

WHEN saclactic acid or malic acid is dropt into nitrate of mercury, a white precipitate appears†.

Sp. 18. *Prussiate of Mercury.*

THIS salt, which was first formed by Scheele, is composed of the prussic acid combined with the red oxide of mercury. It may be formed by boiling the red oxide of mercury with prussian blue. It crystallizes in tetrahedral prisms, terminated by quadrangular pyramids, the sides of which correspond with the angles of the prism. Its specific gravity is 2·7612‡.

This salt is capable of combining with sulphuric and muriatic acids, and forming triple salts, which have not yet been examined §.

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* Fourcroy, vii. 209.

† Scheele, ii. 80. and Crell's *Annals*, ii. 11. Eng. Trans.

‡ Hassenfratz, *Ann. de Chim.* xxviii. 15.

§ Berthollet, Ibid. i. 33.

IV. METALLIC SALTS.

Sp. 19. *Arseniate of Mercury.*

WHEN arsenic acid and mercury are heated in a retort, white oxide of arsenic, mercury, and oxide of mercury of a yellow colour, are driven over, and there remains a yellow-coloured insoluble mass, consisting of arseniate of mercury. The same salt is precipitated in the form of a yellow powder when arsenic acid is poured into the liquid nitrate or sulphate of mercury †.

Sp. 20. *Molybdate of Mercury.*

MOLYBDIC ACID precipitates mercury from nitric acid in the form of a white flaky powder ‡; but it occasions no precipitate in the solution of oxymuriate of mercury §.

Sp. 21. *Tungstate of Mercury.*

TUNGSTIC ACID forms with the oxide of mercury an insoluble powder, which has not been examined.

Sp. 22. *Chromate of Mercury.*

THIS salt may be formed by mixing together the solutions of an alkaline chromate and a mercurial nitrate. It is an insoluble powder of a fine purple colour ||.

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† Bergman, ii. 391.

‡ Hatchett.

§ Scheele, i. 247.

|| Vauquelin.

V. TRIPLE SALTS.

Sp. 23. *Nitroxymuriate of Mercury-and-Soda.*

THIS triple, or rather quadruple salt, was first noticed by Mr Berthollet. When a solution of muriate of soda is poured into oxynitrate of mercury diluted with water, scarcely any precipitate appears; but by proper evaporation rhomboidal crystals are obtained, whose faces are channelled. These, according to Berthollet, are composed of nitrate of soda and oxymuriate of mercury. When heated in a crucible, oxymuriate of mercury sublimes, and nitrate of soda with a little muriatic acid remains behind *.

Sp. 24. *Oxymuriate of Soda-and-Mercury.*

WHEN four parts of oxymuriate of mercury and one part of muriate of soda are mixed, they form a triple salt more soluble than corrosive sublimate †.

Sp. 25. *Suboxymuriate of Ammonia-and-Mercury.*

WHEN ammonia is poured into a solution of oxymuriate of mercury, a white precipitate falls, consisting of the oxymuriate of mercury-and-ammonia with excess of base. It has a taste at first earthy, afterwards metallic. It is scarcely soluble in water. According to Fourcroy, it is composed of

16 acid
81 oxide
3 ammonia

100

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* *Mem. de l' Instit.* iii. 235.

† Berthollet, Ibid. p. 236.

Sulphuric and nitric acids decompose it, and convert it into oxymuriate of mercury and sulphate of ammonia-and-mercury, or nitrate of ammonia-and-mercury, according to the acid. The addition of muriatic acid renders it soluble in water *. In this last state it has been long known by the names of *sal alembroth* and *salt of wisdom*. It was formed by dissolving oxymuriate of mercury in a solution of sal ammoniac in water, or by subliming the two salts together. When potash is poured into this solution, a precipitate falls, which sublimes in the state of calomel †.

Sp. 26. *Tartrate of Potash-and-Mercury.*

THIS salt, first described by Monnet, may be formed by boiling in water six parts of tartar and one part of oxide of mercury. The liquid, when evaporated, yields small crystals of tartrate of potash-and mercury. Thenard has ascertained, that the same triple salt may be formed by mixing together the solutions of tartar and mercurial nitrate. This salt is decomposed by the alkalies, the alkaline carbonates, the hydrosulphurets, the sulphates, and the muriates ‡.

GENUS V. SALTS OF PALLADIUM.

PALLADIUM has been so recently discovered, and is so scarce and difficult to procure in a state of purity, that an exact knowledge of the salts which it forms cannot be expected. To Dr Wollaston and Mr Chenevix we are indebted for all the facts respecting them

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* *Ann. de Chim.* xiv. 47.

† Berthollet, *Statique Chimique*, ii. 419.

‡ *Ann. de Chim.* xxxviii. 36.

hitherto published. They may be distinguished by the following properties:

Characters.

1. They are almost all insoluble in water, and the colour of the solution is a fine red.

2. Prussiate of potash occasions an olive, or rather a dirty yellowish brown precipitate.

3. Hydrosulphuret of potash occasions a blackish-brown precipitate.

4. The alkalies occasion an orange-coloured precipitate.

5. Mercury and sulphate of iron throw down the palladium in the metallic state.

6. Muriate of tin renders the solution opaque by throwing down a brown precipitate; but if the solution be sufficiently diluted, it assumes a fine emerald green colour.

Neither nitrate of potash nor sal ammoniac occasions any precipitate.

Sp. 1. *Nitrate of Palladium.*

When palladium is put into a strong colourless nitric acid, the liquid gradually acquires a red colour; but the action of the acid is extremely slow, no nitrous gas whatever being extricated. This fact, hitherto unique in the history of the action of metals on nitric acid, explains in some measure the slowness of the action of the acid; and that circulation of the fluid which takes place during the solution of other metals is wanting. When the acid contains nitrous gas the action is more rapid *. The nitrate of palladium, thus formed, is of a

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* Wollaston *on the Discovery of Palladium*, *Phil. Trans.* 1805.

dark red colour; by evaporation it yields a red matter, which is probably in the state of a subnitrate.

Sp. 2. *Muriate of Palladium.*

MURIATIC ACID acts slowly upon palladium when assisted by heat, and assumes a fine red colour; but the true solvent of this metal is nitro-muriatic acid, which attacks it with great violence, and forms a beautiful red solution [*]. The properties of the salt thus formed have not been examined.

Sp. 3. *Sulphate of Palladium.*

SULPHURIC ACID boiled upon palladium acquires a beautiful red colour, and dissolves a portion of the substance; but the action of this acid is not very powerful [†]. The properties of the sulphate thus formed have not been examined.

Sp. 4. *Muriate of Palladium-and-Soda.*

WHEN a solution of common salt or of soda is poured into muriate of palladium, no precipitate is separated, and by evaporation a triple salt is obtained, which is soda-muriate of palladium. This salt deliquesces when exposed to the air, a property which sufficiently distinguishes it from soda-muriate of platinum; for this last salt forms permanent crystals [‡].

Sp. 5. *Muriate of Palladium-and-Potash.*

WHEN nitrate of potash is dissolved in muriatic acid,

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[*] Chenevix *on Palladium*, *Phil. Trans.* 1803. [†] Chenevix, Ibid.

[‡] Wollaston on a New Metal found in Crude Platina. *Phil. Trans.* 1804.

a liquid is formed, which acts readily upon palladium, but not upon platinum; because the muriate of platinum-and-potash is scarcely soluble in water, whereas the muriate of palladium-and potash is remarkable for its solubility. The proportion which Dr Wollaston, to whom we are indebted for the discovery found to answer best, was five parts of acid diluted with its bulk of water and one part of nitre. The solution of palladium thus formed, which is of a deep red, by evaporation yields crystals of muriate of palladium-and-potash. They are very soluble in water, but insoluble in alcohol. They are in the form of four-sided prisms, and present a curious contrast of colour. When viewed transversely they are of a bright green; but when viewed in the direction of their axes, their colour is the same as that of the solution: on account of its extreme intensity, however, this colour is with difficulty distinguished in fragments that exceed $\frac{1}{100}$th of an inch in thickness. When the crystal is viewed obliquely it is of a dull brown, arising from a mixture of the red and green *.

Sp. 6. *Muriate of Palladium-and-Ammonia.*

THIS triple salt, like the last species, is very soluble in water, which distinguishes it sufficiently from the muriate of platinum-and-ammonia. Hence palladium is not thrown down from its solutions by sal-ammoniac. This salt, according to Dr Wollaston, resembles the last species in every respect.

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* Wollaston on a New Metal from Crude Platina.

Sp. 7. *Prussiate of Palladium.*

When prussiate of mercury is poured into any neutral solution containing palladium, a flocculent precipitate of a pale yellow colour is gradually thrown down. This precipitate is prussiate of palladium. It is insoluble in water, and differs somewhat in its properties in different circumstances. In general, it is affected by heat, like other prussiates; but when the palladium has been dissolved in nitric acid, and precipitated from such a neutral solution by prussiate of mercury, the precipitate thus formed has the property of detonating when heated. The noise is similar to that occasioned by firing an equal quantity of gunpowder, and accordingly the explosion is attended with no marks of violence unless occasioned by close confinement. The heat requisite for the purpose is barely sufficient to melt bismuth. The light produced is feeble, and can be seen only in the absence of all other light *.

GENUS VI. SALTS OF RHODIUM.

The properties of the salts belonging to this genus are too imperfectly known to admit of a detailed description. Dr Wollaston alone has examined them, and only so far as to show that their base is the oxide of a peculiar metal. They may be distinguished by the following properties:

1. The solution of them in water is red.
2. Prussiate of potash occasions no precipitate.

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* Wollaston on the Discovery of Palladium.

3. Neither is any precipitate produced by hydrosulphuret of potash.

4. Neither sal ammoniac nor the alkaline carbonates occasion any precipitate; but the pure alkalies throw down a yellow powder soluble in an excess of alkali.

Sp. 1. *Nitrate of Rhodium.*

THE oxide of rhodium dissolved in nitric acid forms a red solution which does not crystallize.

Sp. 2. *Muriate of Rhodium.*

THE oxide of rhodium forms a rose-coloured solution in muriatic acid. It does not crystallize, but the residuum is soluble in alcohol. Sal ammoniac, nitre, and common salt, cause no precipitation, but form triple salts which are insoluble in alcohol.

Sp. 3. *Soda-Muriate of Rhodium.*

THIS triple salt, which has the taste of sulphate of soda, forms rhomboidal crystals, of which the acute angle is about 75°. They have a very dark red colour, are not altered by exposure to the air. They dissolve readily in 1½ part of water, but not in alcohol.

GENUS VII. SALTS OF IRIDIUM.

THIS genus of salts is still less known than the former. We are indebted to the French chemists, and to Mr Tennant, for all the facts hitherto detailed.

1. The salts of iridium appear to be soluble in water, and to have a colour at first green, but which changes to red by concentrating the solution in an open vessel.

2. Neither prussiate of potash nor the infusion of nutgalls occasions any precipitate; but both render the solution colourless.

2. They appear to be partially precipitated by sal-ammoniac; since Descotils has shown that the red colour which the muriate of platinum-and-ammonia sometimes assumes, is to be ascribed to the presence of iridium.

The only salt of iridium hitherto examined is the muriate. The solution of iridium in muriatic acid by slow evaporation yielded an imperfectly crystallized mass, which being dried on bloating paper and redissolved, formed by evaporation octahedral crystals of a red colour. These crystals dissolved in water, and formed a deep red solution inclining to orange.

GENUS VIII. SALTS OF OSMIUM.

THIS genus of salts is entirely unknown. It has not been even proved that the oxide of osmium has the property of combining with acids. It seems more inclined to unite with alkaline and earthy bases, and from its solubility in water, and other properties, obviously approaches in its nature to an acid.

No acid hitherto tried, not even the nitro-muriatic, has any effect upon osmium in the metallic state.

GENUS IX. SALTS OF COPPER.

THESE salts, in consequence of the facility with which copper absorbs oxygen, are in general more easily formed, and of course may be more readily examined than the preceding genera. Hence no doubt the reason that some of them have been so long known and so generally employed. The alchymists and the earlier chemists distinguished them by the name of *salts of Venus,* because Venus was the term which they gave to copper. They are the class of metallic salts with the composition of which we are at present best acquainted, in consequence of the accurate analysis to which they have been subjected by the celebrated Proust *, and the important additions lately made to that analysis by Mr Chenevix †.

The cupreous salts may be distinguished by the following properties:

Characters.

1. They are almost all soluble in water, or at least become so by the addition of an acid. This solution has either a blue or a green colour, or it acquires that colour after being for some time exposed to the air.

2. When ammonia is poured into this solution, it assumes a deep blue colour.

3. Triple prussiate of potash occasions a greenish-yellow precipitate when poured into a cupreous solution.

4. Hydrosulphuret of potash occasions a black precipitate.

5. Gallic acid occasions a brown precipitate.

6. A plate of iron, when plunged into a liquid salt of copper, precipitates the copper in the metallic state.

Almost all the acids, as far as is known, combine only with copper oxidized to a maximum; so that, strictly speaking, all the salts of copper are oxygenized. To this general rule, however, there is one exception; the

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* *Ann. de Chim.* xxxii. 26.

† *Phil. Trans.* 1802, p. 193.

muriatic acid combines with both oxides of this metal, so that there is both a muriate and an oxymuriate of copper. It can scarcely be doubted, that similar salts will be discovered composed of the other acids and protoxide of copper.

I. DETONATING SALTS.

Sp. 1. *Nitrate of Copper.*

NITRIC ACID attacks copper with considerable violence; nitrous gas is emitted in great purity, while the metal is oxidized and dissolved. The solution is of a fine blue colour; and when slowly evaporated yields regular crystals of nitrate of copper.

Properties.

These crystals are long parallelopipeds. Their specific gravity is 2·174*. They have a fine blue colour; their taste is acrid and metallic; and they are exceedingly caustic, corroding the skin with great energy. They are very soluble in water; and when exposed to the air, gradually attract moisture, and deliquesce. At a heat not exceeding 100° they undergo the watery fusion; and if the heat be increased, they lose their water and part of their acid. On burning coals they detonate feebly. These crystals detonate also when mixed with phosphorus and struck with a hammer, as Brugnatelli first observed. When a quantity of them, moistened with water, is wrapt up in a sheet of tinfoil, they act with amazing energy upon that metal, nitrous gas is emitted, a strong heat is produced, the tinfoil is burst open in every direction, and very often it takes

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[*] Hassenfratz, *Ann. de Chim.* xxviii. 12.

fire. This curious experiment was first made by Dr Higgins [*].

Subnitre.

When potash is poured into a solution of nitrate of copper, a blue precipitate appears, which soon becomes green by agitation, provided the quantity of potash be insufficient to decompose the whole of the nitrate. Mr Proust has proved, that this green precipitate is a *subnitrate* of copper. It may be obtained also by distilling nitrate of copper in a retort. At a particular period of this process the salt becomes thick, and encrusts the retort in the state of a green lamellar concretion. It is then converted into subnitrate. This salt is completely insoluble in water. Sulphuric acid separates its acid; and the same separation may be effected also by distillation. According to Proust, it is composed of

Composition.

16	acid
67	oxide
17	water
100 [†]	

Nitric acid does not seem to combine with protoxide of copper. When concentrated, it oxidizes the metal to a maximum, and then dissolves it: when diluted, one part of the metal attracts oxygen from the other: Blue nitrate is formed, and a red powder precipitates, which is copper reduced [‡].

Sp. 2. Hyperoxymuriate of Copper.

WHEN a current of oxymuriatic acid gas is passed through the oxide of copper suspended in water, the ox-

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[*] *Phil. Trans.* lxiii. 137.

[†] *Ann. de Chim.* xxxii. 26.

[‡] *Jour. de Phys.* li. 182.

ide is speedily dissolved: But Mr Chenevix, to whom we are indebted for this experiment, has not examined the properties of the hyperoxymuriate which is formed during the process.

II. Incombustible Salts.

Sp. 3. *Muriated Copper.*

Muriatic acid, while cold, does not act on copper in close vessels, though in an open vessel it gradually corrodes and dissolves it. When heated it readily oxidizes and dissolves the metal, while at the same time hydrogen gas is evolved, and part of the acid volatilized. By this process the copper is oxidized to a maximum. But muriatic acid is also capable of combining with the first oxide of copper, and of forming another salt, first discovered by Mr Proust, and afterwards more precisely examined by Mr Chenevix. Let us distinguish these salts, by calling the first *oxymuriate* of copper, because the metal contained in it is oxidized to a maximum, and giving the name of *muriate* to the salt discovered by Mr Proust.

1. *Oxymuriate of copper.* This salt may be obtained either by dissolving copper in muriatic acid by the assistance of heat, or by throwing the oxide of copper into that acid cold. The solution, which is of a fine green colour, yields, when sufficiently concentrated, and allowed to cool slowly, crystals of oxymuriate of copper, in the form of rectangular parallelopipeds of a fine grass-green colour.

This salt is exceedingly acrid and caustic. Its specific gravity is 1·6775 *. It is very soluble in water;

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* Hassenfratz, *Ann. de Chim.* xxviii. 12.

and when exposed to the air, very soon attracts moisture, and is converted into a liquid of the consistence of oil. At a moderate heat it melts, and assumes a solid form when cold. According to Proust, it is composed of..........24 acid
40 peroxide
36 water

100 [*]

This salt may be distilled to dryness without alteration; but if the heat be increased, oxymuriatic acid passes over, the copper loses part of its oxygen, and there remains behind muriate of copper. When potash is poured into the solution of oxymuriate of copper, a green powder is precipitated, which is a suboxymuriate, containing 72 parts in the hundred of brown oxide of copper. When copper is dissolved in nitromuriatic acid, a similar green powder separates, composed, according to Proust, of......12·5 acid
79·0 oxide
8·5 water

100·0 [†]

Muriate of copper is not decomposed by sulphuric or nitric acid; but the alkalies and alkaline earths precipitate the oxide in the state of a subsalt, if the muriate of copper predominate; and in the state of a hydrate if the alkalies predominate [‡].

2. *Muriate of copper*. This salt, which contains copper combined with a minimum of oxygen, was disco-

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[*] *Ann. de Chim.* xxxii. 47.

[†] Ibid.

[‡] Ibid.

vered by Mr Proust while engaged in his experiments on tin. He observed, that when the salts of copper were mixed with the muriate of tin, that last salt deprived the copper of part of its oxygen, and formed a salt of a white colour, not acted on by sulphuric acid, but soluble in muriatic acid. This solution yielded him a colourless salt, which on examination proved to be a muriate of copper *.

Formation.

Mr Chenevix has discovered a very simple process for obtaining this salt. He mixed together, in a mortar, 57·5 parts of the black oxide of copper, and 50 parts of copper in the state of a fine powder, obtained by precipitating that metal from its solution in muriatic acid by means of a plate of iron. The mixture was put along with muriatic acid into a well-stopped phial. A violent disengagement of caloric took place, the liquor became of a red orange colour, and the whole was dissolved except 7·5 of metallic copper. The solution consisted entirely of muriate of copper †.

It may be obtained also, as Proust has shown, by distilling oxymuriate of copper. After the greatest part of the water has passed over, the acid attracts oxygen from the metal, and passes over partly in the state of oxymuriatic acid ; a grey mass remains in the retort, which is muriate of copper. The salt may be obtained also by keeping a plate of copper plunged in a bottle filled with muriatic acid. Crystals of muriate gradually form upon the plate ; and when the colourless acid is diluted with water, muriate of copper precipitates in the state of a white powder ‡.

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* *Ann. de Chim.* xxviii. 218.

† *Phil. Trans.* 1801, p. 237.

‡ *Jour. de Phys.* li. 181.

This salt crystallizes in tetrahedrons. When its concentrated solution is diluted with water, the salt precipitates in the state of a white powder, being no doubt deprived of the excess of acid which held it in solution. When repeatedly washed with water, its acid is carried off, and the orange oxide of copper only remains *. From the experiments of Proust, compared with those of Chenevix, this salt seems to be composed of about

Composition.

24·75	acid
70·25	protoxide
5·00	water
100·00	

When this salt is exposed to the air, it very speedily attracts oxygen, and is converted into oxymuriate of copper. The sulphate of iron, when dropt into a solution containing it, precipitates the copper in the metallic state, while it passes itself to the state of oxysulphate †.

It dissolves in ammonia, and forms a colourless solution, which gradually attracts oxygen when exposed to the air, and at the same time acquires a fine blue colour ‡.

Sp. 4. Sulphate of Copper.

Sulphuric acid does not attack copper while cold; but at a boiling heat part of the acid is decomposed, the copper is oxidized, and combines with the remainder of the acid. But recourse is seldom had to this process,

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* Chenevix, *Phil. Trans.* 1801, p. 230.

† Proust, *Ann. de Chim.* xxviii. 220.

‡ Id. *Jour. de Phys.* li. 182.

as the sulphate of copper is found native abundantly, dissolved in mineral waters connected with copper mines. From these waters it is often obtained by evaporation; or it is formed by burning native sulphuret of copper, or by moistening that substance and exposing it to the air. By either of these methods the sulphur is acidified, and the sulphate of copper formed. This salt appears to have been known to the ancients. In commerce it is distinguished by the name of *blue vitriol*, and sometimes by that of *blue copperas*. It is in fact an oxysulphate. There are three varieties of this salt known, namely, *supersulphate*, *sulphate*, and *subsulphate*.

Properties.

1. *Supersulphate*. This is the variety which occurs in commerce, and which is formed by the usual processes. It renders vegetable blues red, and therefore contains an excess of acid. It has a deep blue colour. The primitive form of its crystals, according to Hauy, is an oblique parallelopiped, whose sides are inclined to each other at angles of 124° 1′ and 55° 59′; and whose base makes, with one of the sides, an angle of 109° 21′, and with the opposite side an angle of 70° 39′. It sometimes passes into the octahedron and decahedron, and the edges at the bases are often truncated.

It has a strong styptic metallic taste, and indeed is employed as a caustic. Its specific gravity is 2·1943 *. It is soluble in about four parts of water at the temperature of 60°, and in 1·6 parts of water at the temperature of 144° †. When exposed to the air, it undergoes a very slight efflorescence, and its surface is covered with

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* Hassenfratz, *Ann. de Chim.* xxviii. 12. According to Dr Watson, 2·230 (*Chemical Essays*, v. 69.)

† Wenzel's *Verwandtschaft*, p. 309.

a greenish white powder. When heated, it loses its water, and is converted into a bluish white powder: if the heat be increased, the acid is driven off, and the black oxide of copper remains behind.

Composition.

This salt, according to the analysis of Mr Proust, is composed of ....33 acid
32 oxide
35 water

100[*]

But part of this water is intimately combined with the oxide in the state of hydrate of copper, as Mr Chenevix has observed. We may therefore consider the salt as composed of ....33 acid
42 hydrate of copper
25 water

100

This salt is decomposed by the alkalies and earths, the alkaline carbonates, borates, and phosphates, and by those metallic salts whose base forms with sulphuric acid a salt nearly insoluble, as the salts of lead.

It seems to have the property of forming a quadruple salt with muriate of ammonia. When equal parts of the two salts dissolved in water are mixed together, the

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[*] *Ann. de Chim.* xxxii. 33.—According to Kirwan, it is composed of
31 acid
40 oxide
29 water

100

This agrees almost exactly with the experiments of Proust, if we suppose Mr Kirwan's oxide was in the state of a hydrate.

solution has a yellow colour while warm, but becomes green on cooling. This solution forms a sympathetic ink. Lines drawn with it on paper are invisible while cold; but when the paper is heated they assume a yellow colour, which disappears again when the paper cools [*].

2. *Sulphate.* This salt possesses nearly the properties of the first variety, but it crystallizes in four-sided pyramids separated by quadrangular prisms [†]. It may be obtained by saturating the excess of acid in the supersulphate with the oxide of copper.

3. *Subsulphate.* When a small quantity of pure potash is poured into a solution of sulphate of copper, a green-coloured powder appears, which swims in the solution. It may be separated by filtration; and when sufficiently edulcorated is insoluble in water. This powder was first examined by Mr Proust. He has ascertained it to be a subsulphate of copper, and to be

composed of............18 acid Composition.
68 oxide
14 water
100 [‡]

The experiments of Proust render it probable that sulphuric acid does not combine with the protoxide of copper; for when that acid is poured upon this oxide, one part of the metal attracts oxygen from the other. The consequence is, the formation of blue sul-

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[*] Gillet Laumont, *Phil. Mag.* xiv. 76.

[†] Leblanc, *Jour. de Phys*, lv. 301.

[‡] *Ann. de Chim.* xxxii. 34.

phate of copper, and the precipitation of a red powder, which is copper reduced *.

Sp. 5. *Sulphite of Copper.*

Sulphurous acid does not attack copper; but it dissolves its oxide with facility, and forms with it a sulphite of copper. This salt has been hitherto examined by Fourcroy and Vauquelin only. It may be formed by mixing together the solutions of sulphite of soda and sulphate of copper. An orange-coloured precipitate immediately falls, and afterwards small whitish-green crystals are deposited; the colour of which becomes deeper by exposure to the air. The first of these, in the form of an orange-coloured powder, is a *subsulphite*; the second, in the form of crystals, is a *sulphite* of copper.

When these salts are heated, they melt, and acquire a leaden grey colour. The subsulphite is insoluble in water; but that liquid dissolves the sulphite, though sparingly. Nitric acid converts them into sulphate of copper; sulphuric acid separates the acid from the sulphite, and part of the oxide is reduced to the metallic state †.

Sp. 6. *Phosphate of Copper.*

Phosphoric acid does not attack copper immediately; but when allowed to remain long upon that metal, oxidation at length takes place, and the phosphate of copper is formed. This salt may be obtained with great facility by pouring phosphate of soda into a

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* *Jour. de Phys.* li. 182.

† Fourcroy, vi. 272.

solution of nitrate of copper. A bluish-green powder immediately precipitates, which is phosphate of copper. This salt is insoluble in water. Its specific gravity, according to Hassenfratz, is 1·4158 *. When exposed to a red heat, it loses its water, and acquires a brown colour. When violently heated, phosphureted copper comes over. According to the analysis of Mr Chenevix, it is composed of

Brown oxide	49·5	hydrate of copper	61·5
Water	12		
Acid...........................			35·0
Water			3·5
			100·0 †

Sp. 7. Carbonate of Copper.

CARBONIC ACID does not attack copper ; but it combines readily with its oxide, or with the hydrate of copper, when that compound is mixed with water, and a current of carbonic acid gas made to pass through it. Or the carbonate may be formed by precipitating a solution of nitrate of copper with a fixed alkaline carbonate ‡. To give the carbonate all its lustre, the solution should be mixed with boiling water, and the precipitate should be washed with great care, and exposed to the light of the sun. It has then a fine apple-green colour, and it is found often native in its greatest beauty. The native carbonate is known among mineralogists by

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* *Ann. de Chim.* xxviii. 12.

† *Phil. Trans.* 1801, p. 206.

‡ Mr Chenevix has shown that the alkaline carbonates have the property of dissolving a portion of the oxide of copper, and of forming with it a triple salt.

Book II.
Division III.

the name of *malachite*. It is insoluble in water, and is entirely decomposed and reduced to the state of black oxide by the action of heat. According to the analysis of Proust, it is composed of 25·0 acid
69·5 peroxide
5·5 water

100·0

A hundred parts of copper, dissolved in sulphuric or nitric acid, and precipitated by the carbonate of potash or soda, give 180 parts of carbonate of copper, which, being deprived of its acid and water by distillation, leaves 125 parts of oxide of copper *.

Sp. 8. *Fluate of Copper.*

Fluoric acid dissolves a small portion of copper when assisted by heat; and it dissolves its oxide with facility. The solution is gelatinous, and yields, when evaporated, blue crystals of fluate of copper, in the form of cubes or oblongs †.

Sp. 9. *Borate of Copper.*

When borax is poured into a solution of sulphate of copper, borate of copper is precipitated in the form of a pale light-green jelly, which when dried is with great difficulty soluble in water. It easily melts into a dark-red vitreous substance ‡. According to Palm, by long trituration of filings of copper and boracic acid in water, and then digesting the mixture, it dissolves, and crystals may be obtained from it.

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* Proust, *Ann. de Chim.* xxxii. 28.

† Scheele, i. 33.

‡ Bergman.

III. COMBUSTIBLE SALTS.

Sp. 10. *Acetate of Copper.*

ACETIC ACID attacks copper very slowly in open vessels, converts it into an oxide, and dissolves it: but in close vessels no action takes place. This acid readily combines with the oxide of copper, and forms with it an acetate. This salt was known to the ancients, and various ways of preparing it are described by Pliny [*]. It is usually obtained by exposing plates of copper to the action of vinegar till they are converted to a bluish-green powder called *verdegris*, and then dissolving this powder in acetic acid, and crystallizing it.

Properties.

Acetate of copper crystallizes in four-sided truncated pyramids. It has a beautiful bluish-green colour. Its specific gravity is 1·779 [†]. Its taste is disagreeably metallic, and, like all the compounds into which copper enters, it is poisonous. It is sparingly soluble in cold water. When that liquid is boiled upon the salt, it takes up, according to Wenzel, $\frac{1}{5}$th of its weight of it [‡]. Alcohol likewise dissolves it. When exposed to the air, it effloresces. By distillation it gives out acetic acid. Proust first remarked that acetous acid and acetic acid form the same salt with copper; and hence concluded that there is no difference between the two acids [§]. When sulphureted hydrogen gas is made to pass through a solution of this salt in water, the copper is deoxidized, and precipitates in the state of a blue sulphuret, and

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[*] Lib. xxxiv. c. 11.

[†] Hassenfratz, *Ann. de Chim.* xxviii. 12.

[‡] *Verwandtschaft*, p. 310.

[§] *Jour. de Phys.* lvi. 211.

there remains behind an acid which possesses the properties of the acetic *.

According to Proust, the acetate of copper is composed of..................61 acid and water
39 oxide
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100

When the verdegris of commerce is put into water, 0·56 parts of it are dissolved, and there remains 0·44 parts in the state of a fine green powder, which remains long suspended in the solution. Mr Proust has ascertained that this powder is a *subacetate* of copper. It is decomposed by sulphuric acid, by potash, and by distillation. According to the analysis of Proust, it is composed of.............. 37 acid and water
63 oxide
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100

Thus it appears, from the experiments of this philosopher, that the verdegris of commerce is composed of two different acetates of copper; the one soluble in water, the other insoluble. It is much used as a paint; and crystallized acetate of copper is a frequent ingredient in dyeing compounds. Verdegris is formed in great quantities at Montpelier. A particular account of the processes followed in that place has been published by Mr Chaptal †.

Sp. 11. *Succinate of Copper.*

Succinic acid dissolves copper with difficulty, and

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* *Ann. de Chim.* xxxii. 36.

† Ibid. xxv. 305.

only when assisted by a long digestion. The solution is green, and yielded Wenzel small green crystals, the properties of which have not been examined. From the experiments of the same chemist we learn, that there are two varieties of this salt, a *supersuccinate* and a *subsuccinate*. He digested 10 grains of carbonate of copper in succinic acid: An effervescence took place; one portion was dissolved, but another remained at the bottom of the vessel. This portion weighed 17 grains. It had lost its carbonic acid, and evidently contained succinic acid. The solutions contained a portion of copper, which was not separated by an alkali, but by a hydrosulphuret, and zinc threw it down *.

Sp. 12. *Benzoate of Copper.*

BENZOIC ACID does not act upon copper, but it combines readily with the oxide of that metal. The salt formed is in small crystals of a deep green colour, sparingly soluble in water, and insoluble in alcohol. When heated, the acid evaporates and leaves the oxide. The alkalies and the carbonates of lime and barytes decompose it †.

Sp. 13. *Oxalate of Copper.*

OXALIC ACID is capable of attacking copper, and forming with it needle-shaped crystals of a green colour, not altered by exposure to the air ‡. It combines with great facility with its oxide. The oxalate formed

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* Wenzel's *Lehre von der Verwandtschaft der Korper.* Grindel's edit. p. 242.

† Trommsdorf, *Ann. de Chim.* xi. 315.

‡ Wenzel, Ibid. p. 229.

is in the state of a bluish-green powder, scarcely soluble in water unless with excess of acid. According to Bergman, to whom we are indebted for all that is yet known of this salt, 21 parts of copper require 29 parts of acid to dissolve them. Oxalic acid precipitates this salt from liquid sulphate, nitrate, muriate, and acetate of copper [*].

Sp. 14. *Mellate of Copper.*

MELLITIC ACID, when dropt into acetate of copper, throws down a precipitate of a Spanish green colour, but produces no change on muriate of copper [†].

Sp. 15. *Tartrate of Copper.*

TARTARIC ACID has little action on copper; but it dissolves the metal at last by the assistance of the air, which converts it into an oxide, and the solution shoots into dark bluish green crystals [‡]. When this acid is poured into the sulphate or muriate of copper, it precipitates a tartrate of that metal in the form of blue crystals [§].

Sp. 16. *Citrate of copper.*

CITRIC ACID scarcely acts on copper; but it dissolves its oxide when assisted by a boiling heat, and the solution yields light green crystals [||].

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[*] Bergman, i. 267.

[†] Klaproth's *Beitrage*, iii. 132.

[‡] Grindel, Wenzel's *Verwandtschaft der Korper*, p. 214.

[§] Bergman, iii. 456.

[||] Wenzel, Ibid. p. 185.

Sp. 17. *Saccolate of Copper.*

Sulphate of copper is not precipitated by saclactic acid [*].

Sp. 18. *Lactate of Copper.*

When lactic acid is digested on copper, it assumes first a blue colour, and then a green, which passes into a dark brown; but the solution does not crystallize [†].

Sp. 19. *Suberate of Copper.*

Suberic acid gives a green colour to nitrate of copper, but occasions no precipitate [‡].

Sp. 20. *Prussiate of Copper.*

The triple prussiates precipitate copper from its solutions of various shades of brown, some of which are remarkably beautiful. Mr Hatchett has lately recommended this prussiate as an excellent pigment; and when tried by artists, both in oil and water, it was found to excel, in beauty and durability, every brown paint known. The method of preparing this paint recommended by Mr Hatchett is the following: Dissolve oxymuriate of copper in ten parts of water, and precipitate with triple prussiate of lime till the whole is thrown down. Wash the precipitate, and dry it without heat [§].

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[*] Scheele, ii. 80.

[†] Ibid. p. 66.

[‡] Bouillon Lagrange, *Ann. de Chim.* xxiii. 48.

[§] *Journal of the Royal Institution*, i. 306.

IV. METALLIC SALTS.

Sp. 21. *Arseniated Copper.*

WHEN arsenic acid is digested on copper, the metal is oxidized and dissolved, and a bluish white powder is formed, which consists of the arseniate of copper. This salt may be formed also by pouring arsenic acid into acetate of copper, or by precipitating nitrate of copper by means of an alkaline arseniate *.

Varieties.

Arseniate of copper has been lately found native in considerable quantities in the mine of Huel Gorland in the parish of Gwennap in Cornwall; and a very interesting description and analysis of it have been published by the Count de Bournon and Mr Chenevix in the Philosophical Transactions for 1801. From the experiments and observations of these celebrated philosophers, it appears that there are no less than five varieties of arseniated copper, differing from each other in the proportion of oxide, acid, and water, which they contain. In general they are insoluble in water, if we except one variety, which seems to be a superarseniate, and which hitherto has not been found native. Their colour varies from a deep blue to green, and even to brown, yellow, and black. This variation seems to depend upon the proportion of water which they contain, the blue and the green containing most, and the brown least water.

Variety 1. *Obtuse octahedral Arseniate.* This variety is crystallized in obtuse octahedrons, composed of two

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* Scheele, i. 175.

Chap. III.

four-sided pyramids applied base to base, the faces of which are isosceles triangles; and two of them which are opposite are more inclined than the others. These meet at the apex at an angle of 130°, and at the base at an angle of 50°. The pyramids often terminate in ridges. These crystals are commonly a deep sky-blue, and sometimes a fine grass green. Their specific gravity is 2·881 *. They are composed, according to the analysis of Chenevix, of 14·3 acid
50·0 brown oxide
35·7 water

100·0

Variety 2. *Hexahedral Arseniate.* This variety is commonly found in very fine six-sided laminæ, and is divisible into thin scales like mica. It is of a deep emerald green colour; and its specific gravity is 2·548 †.
It is composed of.........43 acid
39 oxide
18 water

100 ‡

This variety precipitates in the form of very small blue crystals when arseniate of ammonia is poured into nitrate of copper §.

Variety 3. *Acute octahedral Arseniate.* This variety is composed of two four-sided pyramids applied base to base; two of the faces, which are more inclined, meet at the apex at an angle of 84°, and at the base at one

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* Bournon. † Id.

‡ Vauquelin, *Jour. de Min.* x. 562.

§ Chenevix.

of 96°. The other two form at the apex and base angles of 68° and 112°. The apex of the pyramids is often a ridge. Very frequently it assumes the form of a rhomboidal prism, terminated by dihedral summits, and in many cases the angles of 96° are truncated. Its usual colour is brown or dark bottle-green. Its specific gravity is 4·280*. It is composed of 29 acid
50 oxide
21 water

100

But sometimes it is destitute of water altogether†.

Variety 4. *Trihedral Arseniate.* The primitive form of this variety is a trihedral prism, whose bases are equilateral triangles; but it occurs crystallized in a great variety of figures, which have been described with great accuracy by the Count de Bournon. They are usually of a fine bluish-green colour, and of the same specific gravity as the last species. When opaque, they are sometimes nearly black. They are composed, according to the analysis of Chenevix, of 30 acid
54 oxide
16 water

100

Variety 5. *Superarseniate.* This salt has not been found native; but it has been formed by Mr Chenevix by the following process: Arseniate of ammonia was poured into the nitrate of copper, and occasioned a precipitate, which was the second variety described above.

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* Bournon.

† Chenevix.

The solution, which retained its blue colour, was partially evaporated, and then alcohol was poured into it. Another precipitation took place, and increased considerably on allowing the solution to stand. This precipitate consisted of rhomboidal crystals of a blue colour *. They were composed of 40·1 acid
35·5 oxide
24·4 water

100·0

Perhaps a more precise idea may be formed of the composition of these varieties from the following Table, which exhibits the proportion of oxide and water combined in each with 1·00 of acid, according to the analysis of Chenevix:

Composition.

	Acid.	Oxide.	Water.
Variety 1st,	1·00	3·70	2·50
2d,	1·00	2·76	1·00
3d,	1·00	1·72	0·70
4th,	1·00	1·80	0·53
5th,	1·00	0·88	0·60 †

The white oxide of arsenic is capable also of combining with copper. It forms with the oxide of that metal an *arsenite*, usually distinguished by the name of *Scheele's green*, because Mr Scheele first examined it, and proposed it as a paint. It may be formed by dissolving two parts of sulphate of copper in 44 parts of water, and likewise two parts of potash of commerce

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* *Phil. Trans.* 1801, p. 207.

† See Hauy's remarks on this analysis, *Jour. de Min.* xiii. 425.

and nearly one part of the white oxide of arsenic pulverised in 44 parts of water by the assistance of heat. The solution of copper is gradually added while hot to the arsenite of potash, and the whole is often stirred during the mixture. The mixture, on standing, gradually deposites the arsenite of copper in the form of a fine green powder. It is to be washed well with water and then dried *.

Sp. 22. *Molybdate of Copper.*

MOLYBDIC ACID throws down a green precipitate from nitrate of copper †.

Sp. 23. *and* 24. *Tungstate and Chromate of Copper.*

TUNGSTIC ACID and its compounds occasion a white precipitate when poured into the salts of copper: and when chromic acid is dropt into nitrate of copper, a red precipitate falls ‡.

V. TRIPLE SALTS.

Sp. 25. *Tartrate of Potash and Copper.*

THIS salt may be formed by boiling together oxide of copper and tartar in water. The solution yields by evaporation blue crystals, which have a sweetish taste, and contain a great proportion of metal §. When tartar and copper, or its oxides, are boiled together, they dissolve; and by evaporating to dryness, a bluish-green powder is obtained, which, according to Leonhardi,

Brunswick green.

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* Scheele, i. 261.

† Hatchett.

‡ Scheele and Vauquelin.

§ Thenard, *Ann. de Chim.* xxxviii. 36.

constitutes the better kind of the pigment called *Brunswick green* *.

The oxides of copper are capable of entering into several other triple compounds, both with the metalline, and earthy and alkaline salts; but the properties of these compounds have not been examined with precision, if we except the solutions obtained by pouring ammonia on most of the salts of copper.

GENUS X. SALTS OF IRON.

THE compounds which the acids form with the oxides of iron were formerly distinguished in chemistry by the epithet *martial,* because Mars was the title given by the alchymists to iron. The most important of these salts have been long known. No metal attracts oxygen and combines with acids with more facility than iron; many of its salts therefore are found ready formed, or at least are often formed during the multiplicity of operations to which this very useful metal is exposed. Some of these salts have been long of great importance in manufactures. They form the basis of writing ink and of the black dye, and are employed also to communicate several other colours to cloth.

Iron is capable of combining with two doses of oxygen, and several of the acids unite with each of its oxides. There are therefore two sets of salts which have iron for their bases; one set containing the black oxide, the other the red. The last of these sets was scarcely attended to by chemists till Mr Proust published his

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* Gren's *Handbuch der Chemie,* iii. 331.

Researches on Prussian Blue in 1797; in which he described the properties of the salt composed of the red oxide of iron and sulphuric acid; which, according to the rule formerly laid down, I shall call *oxysulphate of iron.* Since that time Mr Davy has ascertained the existence of several more of these salts.

The salts of iron may be distinguished by the following properties:

Characters.

1. The greater number are soluble in water; and in general the solution has a greenish or yellowish red colour, and an astringent taste.

2. The triple prussiates occasion in these solutions a precipitate of a deep blue, or at least which acquires that colour on exposure to the atmosphere.

3. Hydrosulphuret of potash occasions a black precipitate.

4. Sulphureted hydrogen renders the solution nearly colourless, but occasions no precipitate *.

5. Gallic acid, or the infusion of nutgalls, occasions a black or purple precipitate, at least if the solution has been for some time exposed to the air.

I. Detonating Salts.

Sp. 1. *Nitrated Iron.*

Nitric acid, when as strongly concentrated as possible, does not act rapidly on iron; but when the acid is of a moderate strength, the action is very violent, a

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* From this rule the oxygenized salts of iron must be excepted. In them sulphureted hydrogen occasions a precipitate. This precipitate is sulphur, thrown down by the decomposition of the sulphureted hydrogen; at the same time the salt loses a portion of its oxygen.

prodigious torrent of gas is extricated, which Dr Priestley found to be a mixture of nitrous oxide and nitric oxide. During this action the iron is oxidized to a maximum, and a red powder precipitates, consisting probably of oxynitrate with excess of base. These phenomena have been long known; but it was not till after Mr Proust's *Researches on the Prussiates of Iron* that the existence of two salts consisting of this acid, combined with each of the oxides of iron, was well understood by chemists. It is the *oxynitrate* of iron which is obtained by the usual process. Mr Proust merely announced the existence of the simple nitrate, but it has since been examined by Mr Davy.

Formation.

1. *Nitrate of Iron*. When nitric acid of the specific gravity 1·16 is poured upon iron, it acts upon the metal but slowly, no gas being given out for some time. The solution becomes of a dark olive brown in consequence of the nitrous gas which it holds in solution; but when exposed to the air, it becomes pale, because that gas combines with oxygen and is converted into nitric acid. When alkalies are poured into it, a pale green precipitate falls, consisting of iron oxidized to a minimum. This solution absorbs nitrous gas. It cannot be concentrated, nor even heated, without being converted into oxynitrate *.

2. *Oxynitrate of Iron*. This is the salt obtained when iron is treated with strong nitric acid, or when the nitrate is heated or left exposed to the air. The solution is of a brown colour, and does not yield crystals. When evaporated, it lets fall a red powder, not afterwards so-

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* Davy's *Researches*, p. 187.

Properties.

luble in nitric acid; and sometimes when concentrated assumes the form of a jelly. When strongly heated, the acid is disengaged, and the oxide remains in the form of a fine red powder. Hence solution in nitric acid, evaporating to dryness, and digesting the residuum in water, is the method recommended by Bergman, and formerly practised by chemists, to separate iron from earths. The iron and earths are first dissolved together in nitric acid; by the evaporation to dryness, and a strong heat, the nitrate of iron is decomposed, while the earthy nitrates remain unaltered. They are of course dissolved by the water, but the red oxide of iron is left untouched.

Crystals.

Vauquelin has lately discovered a method of obtaining the oxynitrate of iron in crystals. When concentrated nitric acid is kept for some months in contact with the black oxide of iron, solution slowly takes place, and crystals nearly colourless are formed, which have the figure of rectangular four-sided prisms, terminated by dihedral ridges. These crystals have an acrid and inky taste, and are very deliquescent. Their solution in water has a red colour, and the alkalies precipitate from it red oxide of iron [*].

Sp. 2. Hyperoxymuriate of Iron.

WHEN a current of oxymuriatic acid is made to pass through water having red oxide of iron diffused through it, the oxide is dissolved, though with considerable difficulty. But Mr Chenevix, to whom we are indebted for this experiment, has not examined the properties of

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[*] Fourcroy, vi. 205.

the hyperoxymuriate which must be formed during the process.

II. INCOMBUSTIBLE.

Sp. 3. *Muriated Iron.*

MURIATIC ACID attacks iron with great rapidity; hydrogen gas is emitted in consequence of the decomposition of water, and the iron is oxidized and dissolved. This acid dissolves likewise the oxides of iron much more readily than any other, and for that reason it is usually employed to take out iron-marks from linen, and to remove particles of rust, which often adhere with great obstinacy to glass vessels. Muriatic acid combines both with the black and red oxides of iron, and forms with each of them a peculiar salt, the properties of which have been lately described by Mr Davy. Their existence had been previously pointed out by Proust. The common muriate of iron, usually obtained by dissolving iron or its oxides in muriatic acid, is a mixture of these two salts.

1. *Muriate of Iron.* When iron-filings are dissolved in muriatic acid, the solution, provided it be excluded from the air, is of a pale green colour, and yields, when evaporated, crystals of muriate of iron of a pale green, which are extremely soluble in water, and soluble also, according to Davy, in alcohol. The solution attracts oxygen from the air and from nitric acid. It absorbs nitrous gas even in greater quantity than sulphate of iron, and acquires, when saturated, a dark brown colour, and a much more astringent taste than muriate of iron in its usual state. When heated, the greatest part of the gas is driven off, some red oxide of iron is precipitated, and some ammonia formed, precisely as hap-

Properties.

pens to a solution of sulphate of iron impregnated with nitrous gas *. This salt may be formed very readily by dissolving sulphuret of iron in muriatic acid; the sulphureted hydrogen gas evolved preventing the absorption of oxygen from the atmosphere †.

2. *Oxymuriate of Iron.* This salt may be formed by dissolving the red oxide of iron in muriatic acid, by treating the muriate of iron with nitric acid, or simply by exposing it in solution to the air. The solution of this salt is of a deep brown; its odour is peculiar, and its taste, even when much diluted with water, is exceedingly astringent. When evaporated to dryness, it yields an uncrystallizable orange-coloured mass, which deliquesces in the air, and is soluble in alcohol. This salt gives a yellow tinge to animal and vegetable substances, as is the case with oxymuriatic acid. When sulphuric acid is poured upon it, the odour of oxymuriatic acid is perceptible. This salt does not absorb nitrous gas. When sulphureted hydrogen gas is made to pass through it, part of the oxygen is abstracted, and the salt is converted into muriate of iron ‡.

Properties.

When this salt is distilled, oxymuriatic acid passes over, and the iron is reduced to the state of black oxide. This acid is also formed and exhaled during the solution of red oxide of iron in muriatic acid, at least if the solution be promoted by the application of heat.

If the heat be increased after the oxymuriate of iron is evaporated to dryness, the whole salt sublimes, not however in the state of oxymuriate, but of simple muriate, which is capable of crystallizing. The whole of

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* Davy, p. 180.

† Davy, *Journal of the Royal Institution*, i. 308.

‡ Ibid. p. 181.

these changes are easily explained. Oxymuriate of iron contains more acid than muriate. This excess flies off, and carries with it the second dose of oxygen of the oxide. The iron thus reduced to the state of black oxide, sublimes in combination with the rest of the muriatic acid *.

Sp. 4. *Sulphated Iron.*

CONCENTRATED sulphuric acid acts but very slowly upon iron, unless it be assisted by heat. In that case the metal is oxidized, and sulphurous acid gas exhaled. But diluted sulphuric acid dissolves iron with great rapidity, and abundance of hydrogen gas is emitted. In this case the water is decomposed; its oxygen combines with the iron, while its hydrogen is emitted. The solution has a green colour, and when evaporated immediately, yields crystals of *sulphate* of iron; but if allowed to remain exposed to the atmosphere, it gradually attracts more oxygen, and is converted into *oxysulphate*, unless it contains an excess of acid; which retards, and, when sufficiently abundant, prevents the change.

History. 1. *Sulphate of Iron.* This salt was known to the ancients, and is mentioned by Pliny under the names of *misy*, *sory*, and *calchantum* †. In commerce it is usually denominated *green vitriol* or *copperas*. It is not prepared by dissolving iron in sulphuric acid, but by moistening the pyrites which are found native in abundance, and exposing them to the open air. They are slowly covered with a crust of sulphate of iron, which is dis-

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* See on this subject the experiments of the Duc d'Ayen.

† Lib. xxxiv. c. 12.

solved in water, and afterwards obtained in crystals by evaporation. Sometimes the salt is found ready formed, either in a state of solution in water or mixed with decayed pyrites. In some cases it is found necessary to roast the pyrites before they can be made to undergo spontaneous decomposition. This is most probably owing to the compact state of the pyrites in these cases, and the absence of all uncombined iron. Pyrites is in fact a supersulphurate of iron. The roasting reduces it to the state of sulphuret, which decomposes very readily. The solution always contains an excess of acid. Hence it is necessary, in order to obtain the salt in crystals, to throw into it a quantity of old iron.

Properties. Sulphate of iron has a fine green colour. Its crystals are transparent rhomboidal prisms, the faces of which are rhombs with angles of 79° 50′ and 100° 10′, inclined to each other at angles of 98° 37′ and 81° 23′[*]. It has a very strong styptic taste, and always reddens vegetable blues. Its specific gravity is 1·8399[†]. It is soluble in about two parts of cold water, and in $\frac{3}{4}$ths of its weight of boiling water. It is insoluble in alcohol. When exposed to the air, its surface gradually becomes opaque, and is covered with a yellow powder; because it absorbs oxygen, and is partially converted into oxysulphate. This change takes place much more rapidly and completely if the salt be moistened with water. The cause of these phenomena was first explained by Scheele.

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[*] Hauy, *Jour. de Min.* An. v. 542.

[†] Hassenfratz, *Ann. de Chim.* xxviii. 12. According to Wallerius, the specific gravity is 1 880 (*Chemiæ*, p. 266.); according to Dr Watson, 1·812 (*Essays*, v. 67.); when calcined to whiteness, its specific gravity becomes 2·636 (Watson, Ibid.)

When heated it melts, gradually loses its water of crystallization, and by a strong heat sulphuric acid is driven off, and there remains behind a red powder, formerly known by the name of *colcothar of vitriol*, which is either a mixture of red oxide of iron and oxysulphate, or pure oxide, according to the heat applied. When this salt is distilled, there comes over first water slightly acidulated with sulphuric acid, and afterwards a very strong fuming acid, formerly known by the name of *glacial oil of vitriol*, and which is now known to be a compound of sulphuric and sulphurous acids. The residuum is the same mixture of oxide and oxysulphate which is obtained by calcination in the open air. This decomposition, which sulphate of iron undergoes when heated, enables it in many cases, in a high temperature, to act nearly the same part as sulphuric acid. Hence it is often employed by manufacturers to disengage the weaker acids from their bases.

Composition.

This salt, according to the best analyses hitherto made, is composed of the following proportions :

	*	‡	†
Acid	26	26·7	39
Base	28	28·3	23
Water	46	45·0	38
Total	100	100	100

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* Kirwan *on Mineral Waters*, Table IV.

‡ By my analysis.

† Bergman, *Opusc.* i. 37.

Hydrate of iron.

It cannot be doubted, I think, that the black oxide of iron is capable of combining intimately with water, and of forming a *hydrate*, as well as the oxide of copper. The colour of this hydrate is *green*; hence the reason that the black oxide of iron, when precipitated from acids by means of alkalies, has a green colour. It is in the state of hydrate. When the water is driven off by heat, the oxide assumes its natural black colour. The oxide, which constitutes a part of the sulphate of iron, is also combined with water, and in the state of a hydrate. Mr Kirwan, therefore, has, with great propriety, distinguished between the water of crystallization and that part which is a necessary constituent of the salt.

When the crystals of sulphate of iron are moderately heated, they assume at first a white colour; the same change of colour is observed when the salt, in the state of powder, is infused in alcohol. Hence we see the separation of the water changes the colour from green to white; and if water be now poured on the white powder, it becomes again green.

The sulphate of iron is decomposed by the alkaline phosphates and borates, and by the greater number of those salts whose base forms an insoluble compound with the sulphuric acid, as nitrate of silver, of lead, of barytes, &c.

Thenard has lately published a number of experiments on this salt. The crystals of copperas are sometimes of a dark green colour, sometimes of a light emerald green. Dyers prefer the first variety, and dislike the light green crystals, alledging that they do not answer so well for their processes. According to Thenard, the dark coloured crystals consist of sulphate of iron, the light coloured ones of supersulphate of iron. The excess of acid in the latter prevents them from parting so easily with the oxide, and therefore renders them less useful as a dye stuff*. This explanation appears plausible; but upon analysing specimens of both varieties, I found the difference of acid hardly to exceed 1 *per cent*. The excess was in the light coloured crystals, but it appears a great deal too small to account for the different appearances which the salt assumes.

According to Thenard, besides the sulphate and supersulphate, there are other two salts of iron, containing the metal in a higher degree of oxidizement. The first is neutral, has a brown colour, does not crystallize, and is not easily changed by exposure to the air. Iron converts it into sulphate. This salt he considers as a combination of sulphuric acid and green oxide of iron; but the existence of this oxide has not been established in a satisfactory manner. The other salt crystallizes; the crystals have an emerald green colour, and are not altered by exposure to the air. This is a supersalt, and, according to Thenard, is composed of the same green oxide and sulphuric acid.

2. *Oxysulphate*. This salt exists ready formed in what is called the *mother water of vitriol*, or the brown liquid which remains after all the sulphate of iron has been extracted by crystallization from those waters which contain it. The properties of this salt were first accurately described by Mr Proust. It may be formed by exposing the solution of sulphate of iron to the open

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[*] *Ann. de Chim.* lvi. 59.

air for some time, or by pouring into it nitric acid, and applying heat*.

This salt has a yellowish red colour. It does not afford crystals; and when evaporated to dryness, soon attracts moisture, and becomes again liquid. It is exceedingly soluble in water, and also in alcohol. By this last liquid it may be separated from the sulphate of iron, with which it is always mixed in the *vitriol* of commerce. When exposed to the air, it gradually deposites red oxide, or rather oxysulphate with excess of base.

A great number of substances have the property of depriving this salt of its excess of oxygen, and of converting it into sulphate of iron. This is the case with iron. When the solution of oxysulphate is mixed with iron filings, and kept for some time in a well-covered vessel, part of the iron is dissolved by abstracting the second dose of oxygen from the oxide, and the whole is converted into sulphate. The same change is produced by tin, and probably also by all the salts of tin which contain that metal combined with a minimum of oxygen. Sulphureted hydrogen produces that change instantaneously when made to pass through a solution of oxysulphate †. That gas has the property of reducing the oxides of iron to a minimum of oxygen; but it does not bring them to the metallic state. Hence the reason that it does not precipitate iron from its solution in acids.

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* During this change a quantity of ammonia is also formed. Hence not only the nitric acid but some water also is decomposed. See Davy's *Researches*, p. 157.

† Proust, *Ann. de Chim.* xxiii. 23.

On the other hand, all those bodies which part with oxygen very readily, convert the sulphate of iron into oxysulphate. Hence this change is produced by the nitric and oxymuriatic acids, by the oxymuriates, the muriate of gold, &c.

Absorbs nitrous gas.

The solution of sulphate of iron has the property of absorbing a great quantity of nitrous gas, and at the same time it acquires a yellowish colour. When this solution is heated without being exposed to the air, the greatest part of the nitrous gas is driven off unchanged; but a small portion of it is decomposed, a little red oxide of iron is precipitated, and some ammonia formed, owing to the decomposition of a little of the water of the solution, and the combination of its hydrogen with the azote of the nitrous gas. From the experiments of Mr Davy, it appears that 910 parts of a solution of sulphate of iron, of the specific gravity 1·4, absorb 5·72 parts of nitrous gas; 4·28 of these are emitted unaltered on the application of heat, and 1·44 are decomposed. This ingenious gentleman calculates that one part of water was also decomposed; that the oxygen furnished by these two bodies amounted to 1·65, and that it combined with 4·1 parts of black oxide, and occasioned the precipitation of 5·75 parts of brown oxide, which was doubtless in the state of oxysulphate with excess of base. Hence the ammonia formed must have amounted to about 0·8 [*]. The oxysulphate of iron has not the property of absorbing nitrous gas [†].

The sulphate of iron has the property of uniting with many other metalline sulphates, and forming a variety

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[*] Davy's *Researches*, p. 170.

[†] Ibid.

of triple salts not easily decomposed. The most remarkable are the following:

1. Sulphate of iron-and-copper
2. Sulphate of iron-and-zinc
3. Sulphate of iron-and-nickel.

In some cases it combines with two sulphates at once, and forms a kind of quadruple salt. Linke has noticed the following:

1. Sulphate of iron-zinc-and-nickel
2. Sulphate of iron-copper-and-nickel.

It combines also with alkaline bases, and forms another kind of triple salts. The following has been noticed:

1. Sulphate of iron-and-potash.

Sp. 5. Sulphite of Iron.

Sulphurous acid attacks iron with rapidity, much heat is produced, and the solution assumes at first a brown colour, which gradually passes into a green. During this solution no hydrogen gas is emitted except a few bubbles at first. The iron is oxidized at the expence of the acid, part of which is decomposed; its oxygen combines with the iron, and converts it into black oxide, while its sulphur combines with the sulphite of iron as it forms. The salt, therefore, which is obtained by this process, is not pure sulphite of iron, but that salt combined with sulphur. These phenomena were first described by Berthollet[*]. When sulphuric acid or muriatic acid is poured into this solution, the sulphurous acid is disengaged with effervescence; and if these

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[*] *Ann. de Chim.* ii. 58.

acids be added in sufficient quantity, a portion of sulphur is precipitated.

Varieties.

When the solution is exposed to the air, crystals of sulphite of iron are formed, and at the same time a red powder is deposited, probably consisting of *oxysulphite* of iron with excess of base, and combined with sulphur. The crystals dissolved in water and exposed to the air are gradually converted into sulphate of iron *.

Thus there are two varieties of sulphited iron, *simple sulphite* and *sulphureted sulphite*. The first of these is insoluble in alcohol; but that liquid dissolves the second: the first, when exposed to the air, is converted into sulphate, but the second remains unaltered †.

Sp. 6. Phosphated Iron.

Phosphoric acid has but little action upon iron. However, if that metal remain exposed to the contact of phosphoric acid, or even to the solutions of salts which contain that acid, it is gradually oxidized, and converted into phosphate of iron. The properties of phosphated iron have not been examined with attention. Scheele has shown that the acid combines with both oxides, and forms of course both a *phosphate* and *oxyphosphate* af iron. Fourcroy and Vauquelin have lately ascertained that there are two varieties of this last salt; one which had been already described by Bergman, Meyer, Klaproth, and Scheele, and another with excess of base, and consequently a *suboxyphosphate*, which these philosophers first observed.

Varieties.

1. *Phosphate of Iron.* When sulphate of iron dis-

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* Fourcroy, vi. 200. † Ibid.

solved in water is mixed with a solution of phosphate of potash, a blue powder precipitates, which is phosphate of iron. This powder is insoluble in water, and does not lose its colour when exposed to the air *. This salt is found native, and constitutes the colouring matter of a blue mineral called *native prussian blue*, found in bogs, and first analysed by Klaproth. *Native prussian blue*, as it is called, when dry out of the earth, is at first often colourless; but when exposed to the air, it becomes blue. The cause of this change has not been ascertained.

This salt has been lately found native in small prismatic crystals. Specimens of it have been brought from Brazil and the Isle of France. Its colour is a light blue; it is partly transparent and partly opaque. Before the blow-pipe it runs into a metalline globule. When heated, it assumes the red colour of peroxide of iron. It dissolves readily in nitric acid. Its specific gravity is 2·6. By the analysis of Laugier, as confirmed by Fourcroy and Vauquelin, it is composed of

21 acid
45 protoxide
34 water

100 †

2. *Oxyphosphate of Iron.* This salt may be readily procured by mixing together the solutions of oxymuriate of iron and phosphate of potash or soda. A white powder immediately falls, which is oxyphosphate of iron.

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* Scheele, Crell's *Annals*, i. 115. Eng. Trans.

† *Ann. de Chim.* l. 214.

This salt, like almost all the phosphates, is soluble in acids, but precipitated undecomposed by ammonia. It is almost insoluble in water, as it requires more than 1500 parts of that liquid to dissolve one part of oxyphosphate. When heated violently, it melts into an ash-coloured globule *. When mixed with charcoal, and heated to redness, it is converted into phosphuret of iron.

3. *Suboxyphosphate of Iron.* When the oxyphosphate of iron is treated with the pure fixed alkalies, a red, or rather brownish-red, powder is separated, while the alkali combines with phosphoric acid. This powder was examined by Fourcroy and Vauquelin, and found by them still to contain a portion of acid. It is therefore merely oxyphosphate with excess of base. This salt is scarcely soluble in acids or in water; but it dissolves readily in the white of an egg, or in the serum of blood, and communicates to these liquids a brown or red colour. Its solubility is increased, and its colour heightened, by the presence of a portion of fixed alkali †. This is the salt which is supposed to give a red colour to the blood.

Sp. 7. *Carbonated Iron.*

LIQUID carbonic acid, when kept in contact with iron, attacks it slowly, and dissolves a sufficient quantity of it to acquire a sensibly chalybeate taste. When exposed to the air, the iron is gradually precipitated in the state of oxide ‡; and by boiling it is deposited in the form of a yellow ochre, still retaining a portion of acid. This carbonate often exists native in mineral waters.

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* Bergman, iii. 118. † Fourcroy, ix. 152. ‡ Bergman, i. 33.

It may be obtained also by precipitating the sulphate of iron by means of an alkaline carbonate. In that case it is always in the form of a green mass, or hydrate, which gradually becomes black if the contact of air be excluded.

The carbonate of iron has been found native crystallized in rhombs at Eulenloh in Bareuth, a mineral lately described and analysed by Bucholz. It is somewhat transparent, has a greenish-yellow colour, is brittle, easily pounded, and of the specific gravity 3·333. It dissolves slowly in acids. Its constituents, as ascertained by Bucholz, are

36·0	acid
59·5	protoxide
2·0	water
97·5	

This mineral has the curious property of becoming a permanent magnet when it is heated red hot *.

Rust.

Rust may be considered as a carbonate of iron ; for it consists of the oxide of that metal combined with carbonic acid. Hence it dissolves in acids with effervescence, and when heated gives out carbonic acid gas : the residuum in that case is black oxide of iron †. Its brown colour seems to be owing to the presence of water. There is likewise a subcarbonate of iron which, from the experiments of Bergman, seems to be composed of about

24	acid
76	oxide
100 ‡	

The liquid known by the name of Stahl's tincture of Mars, because it was discovered by that illustrious che-

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* Bucholz, Gehlen's *Jour.* i. 231.

† Fourcroy, vi. 215.

‡ Bergman, ii. 392.

Stahl's tincture of Mars.

mist, has not been examined by modern chemists; but it appears to be a triple, or rather quadruple saline compound. It is formed by pouring a solution of oxynitrate of iron into liquid carbonate of potash: a red powder first precipitates, which is redissolved by agitating the mixture. The liquid of course is an *oxynitrocarbonate of potash and iron*. But the combination is not permanent; for the liquid soon deposites a red powder.

Sp. 8. *Fluate of Iron.*

FLUORIC ACID attacks iron with violence; hydrogen gas is emitted, and the metal oxidized and dissolved. The solution has an inky taste; and when evaporated does not crystallize, but assumes the form of a jelly. In this state it is undoubtedly an *oxyfluate* of iron. Heat decomposes it by expelling the acid. The same effect is produced by sulphuric acid. Fluoric acid also dissolves the red oxide of iron, and forms the same salt *.

Sp. 9. *Borate of Iron.*

BORACIC ACID acts very feebly upon iron: but borate of iron may be obtained very readily by pouring liquid borate of soda into a solution of sulphate of iron. A pale yellow powder immediately precipitates, which is the salt required. This salt is insoluble in water. Before the blow-pipe it melts readily into a globule of glass †.

III. COMBUSTIBLE SALTS.

Sp. 10. *Acetated Iron.*

THE acetic acid dissolves iron with rapidity, produ-

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* Scheele, i. 34.

† Id. Crell's *Annals*, i. 114. Eng. Transl.

cing an effervescence, and, like the other acids, it forms a salt with each of the oxides of that metal; but the properties of these salts have not been examined with attention.

1. *Acetate of Iron.* This salt, as Mr Davy affirms, may be easily procured by dissolving sulphuret of iron in acetic acid *. It yields by evaporation crystals of a green colour, in the form of small prisms. It has a sweetish styptic taste, and its specific gravity is 1·368 †. By exposure to the air, or by the application of heat, it is converted into *oxacetate*.

2. *Oxacetate of Iron* is a reddish-brown solution, incapable of yielding crystals, and assumes the form of a jelly when evaporated. It is deliquescent. This salt is much employed by calicoe printers, because it is more easily decomposed than any other of the oxygenized salts of iron. They prepare it either by mixing together sulphate of iron and acetate of lead, and leaving the solution exposed to the air, or by dissolving iron in an impure acetic acid, obtained by distilling wood.

The acetates of iron are decomposed by heat, and the iron left in the state of red or black oxide, according to the temperature.

Sp. 11. *Succinate of Iron.*

Succinic acid dissolves the oxide of iron, and yields by evaporation small brown transparent radiated crystals ‡. This salt is insoluble in water. Succinic acid accordingly separates iron from all other solutions. When succinate of soda is dropt into solutions contain-

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* *Journal of the Royal Institution*, i. 308.

† Hassenfratz, *Ann. de Chim.* xxviii. 12.

‡ Wenzel's *Verwandtschaft*, p. 240. Grindel's Edit.

ing iron, a brownish red precipitate falls in light flakes, which is succinate of iron. This salt is composed of

61·5 acid and water
38·5 oxide

100·0 *

Gehlen has shown, that by means of succinate of soda iron may be very completely separated from manganese. To succeed, the solution must be neutral, and the iron oxidized to a maximum †.

Sp. 12. *Benzoate of Iron.*

THIS salt forms yellow crystals. It has a sweet taste. It is soluble in water and alcohol. It effloresces in the air. Heat disengages the acid ‡.

Sp. 13. *Oxalated Iron.*

OXALIC ACID attacks iron rapidly, and dissolves it with effervescence, and forms a peculiar salt with each of its oxides.

1. *Oxalate* is obtained by dissolving iron or its black oxide in that acid, and evaporating the solution. Prismatic crystals, of a green colour and sweet astringent taste, are formed, very soluble in water with an excess of acid, which fall to powder when heated. They are composed of ....55 acid
45 oxide

100

2. *Oxygenized Oxalate* may be obtained by dissolving red oxide of iron in oxalic acid, or by exposing the first salt to the air in a digesting heat. It has the form of

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* Gehlen, Klaproth's *Beitrage*, iii. 63.

† Bucholz, Gehlen's *Jour.* ii. 515.

‡ Trommsdorf, *Ann. de Chim.* xi. 314.

a yellow powder scarcely soluble in water, and incapable of crystallizing *.

Oxalic acid readily dissolves the oxides of iron even when combined with gallic acid. Hence it is often used to take spots of ink out of linen; and superoxalate of potash is usually sold in this country for that purpose, under the name of *essential salt of lemons.*

Sp. 14. *Mellate of Iron.*

Mellitic acid precipitates iron from nitric acid in the state of an Isabella yellow powder, which is redissolved by the addition of muriatic acid †.

Sp. 15. *Tartrated Iron.*

Tartaric acid dissolves iron with effervescence, and combines with each of its oxides.

1. *Tartrate of Iron* may be formed, according to Retzius, by pouring tartaric acid into sulphate of iron, and applying heat to the solution. Lamellar crystals are formed, sparingly soluble in water, which possess the properties of tartrate of iron.

2. *Oxytartrate* is usually formed when iron is dissolved in tartaric acid, and heat applied to the solution. It has a red colour, does not crystallize, but assumes the form of a jelly when evaporated.

Sp. 16. *Citrate of Iron.*

This salt has only been examined by Vauquelin. Citric acid dissolves iron slowly; the solution has a brown colour, and deposites small crystals of citrate of

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* Bergman, i. 268.

† Klaproth's *Beitrage*, iii. 131.

iron. When evaporated, it becomes black like ink, ductile while hot, but brittle while cold. This mass is evidently oxycitrate of iron. It is astringent, and very soluble in water.

Sp. 17. *Saccolate of Iron.*

Saclactic acid does not precipitate iron from sulphuric acid *.

Sp. 18. *Malate of Iron.*

Malic acid forms with iron a brown solution, which does not yield crystals †.

Sp. 19. *Lactate of Iron.*

Lactic acid dissolves iron, and forms with it a brown liquid not capable of crystallizing ‡.

Sp. 20. *Suberate of Iron.*

Suberic acid gives a deep yellow colour to sulphate of iron, but occasions no precipitate §.

Sp. 21. *Gallate of Iron.*

Mr Proust first observed, that the gallic acid does not occasion any precipitate when poured into salts of iron containing that metal in the state of black oxide. Hence it follows that the gallate of iron, if it be formed in these cases, is very soluble in water and without colour; but when gallic acid is poured into the oxygenized salts of iron, the solution becomes black, and a black precipitate, composed of gallic acid and red oxide of

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* Scheele, ii. 80.

† Scheele, Crell's *Annals*, ii. 10. Eng. Trans.

‡ Scheele, ii. 65.

§ Bouillon Lagrange, *Ann. de Chim.* xxiii. 48.

iron, immediately begins to fall: But it is so very fine and light, that the greater part of it remains long suspended; and if a quantity of mucilage or syrup be mixed with the solution, the precipitate remains suspended altogether. It is this solution which constitutes writing *ink*. But ink is usually made by mixing the sulphate of iron of commerce with a saturated solution of nutgalls. Now the sulphate of commerce is a mixture of sulphate and oxysulphate of iron. That part of the iron which is in the state of sulphate forms at first a colourless solution; but by attracting oxygen from the atmosphere, it gradually becomes black. Hence the reason that ink is often pale at first, but becomes black when the writing dries, in consequence of the absorption of oxygen.

Writing ink.

Gallate of iron is soluble in acids without decomposition, but it loses its colour in very strong acids. Hence the reason that these acids destroy the colour of writing.

Sp. 22. Prussiated Iron.

The combination formed between the prussic acid and iron has been the object of a great many researches, and has given occasion to several curious and important discoveries. We are indebted to Mr Proust for the fact, that the prussic acid, like all other acids hitherto tried, is capable of forming a peculiar salt with each of the oxides of iron.

1. *Prussiate of Iron.* This salt may be formed by pouring triple prussiate of potash into a solution of sulphate of iron. The salt precipitates in the form of a white powder. It is not altered by sulphuric and muriatic acids. When exposed to the air it absorbs oxy-

gen with great rapidity, and passes to the state of oxyprussiate. Oxymuriatic and nitric acids produce the same change.

2. *Oxyprussiate of Iron.* This salt is formed when triple prussiate of potash is poured into oxysulphate of iron, or into the solution of any oxygenized salt of iron. A beautiful blue precipitate appears, which is the salt. It is not altered by the acids. Sulphureted hydrogen gas converts it into prussiate by absorbing oxygen. When it is mixed with iron-filings, and kept in water in a close vessel, it is also converted into prussiate, the iron absorbing the second dose of oxygen from the red oxide *.

IV. METALLIC SALTS.

Sp. 23. *Arseniated Iron.*

ARSENIC ACID dissolves iron when assisted by a digesting heat; and if the experiment be made in an open vessel, the solution at last assumes the form of a jelly; but in a close vessel this does not happen. When one part of iron-filings and four parts of arsenic acid are distilled together to dryness, inflammation takes place, and at the same time both arsenic and white oxide of arsenic are sublimed †. Arsenic acid, as we see from these facts, is capable, like other acids, of combining with both the oxides of iron, and of forming *arseniate* of iron and *oxarseniate* of iron. Both of these salts have been found native in Cornwall, and have been lately described and analysed with great accuracy by Bournon and Chenevix.

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* Proust, *Ann. de Chim.* xxii. 88.

† Scheele, i. 177.

Book II.
Division III.

1. *Arseniate of Iron.* This salt may be formed by pouring arseniate of ammonia into sulphate of iron. The salt precipitates in the state of a powder, insoluble in water. It exists native crystallized in cubes, which in some instances have their alternate angles truncated. Their colour is usually dark green, and their specific gravity 3 *. When heated, the iron attracts oxygen from the acid, and passes to the state of red oxide, while white oxide of arsenic sublimes. This native salt is usually contaminated with a little copper. The artificial arseniate, according to the analysis of Chenevix, is composed of......38 acid

43 oxide
19 water

100

The native (abstracting the impurities) was found by the same accurate chemist to be composed of about

36 acid
52 oxide
12 water

100 †

2. *Oxarseniate of Iron.* This salt may be formed by precipitating oxysulphate of iron with arseniate of ammonia, or by boiling the arseniate of iron in nitric acid. The native arseniate is sometimes found converted into this salt, in consequence of the absorption of oxygen from the air. It has then a brownish-red colour. According to the analysis of Chenevix, the artificial oxarseniate is composed of

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* Bournon, *Phil. Trans.* 1801, p. 190.

† Ibid. p. 220.

42·4 acid
37·2 oxide
20·4 water

100·0 *

Sp. 24. *Tungstate of Iron.*

This salt exists native, and is known to mineralogists by the name of *Wolfram*. It may be formed by precipitating sulphate of iron by means of the tungstates. It is an insoluble powder, possessing properties similar to native tungstate of iron. As this native salt contains also manganese, and is not therefore a pure tungstate of iron, it will be proper to defer the description of it to the Second Part of this Work.

Sp. 25. *Molybdate of Iron.*

The alkaline molybdates precipitate iron brown from its solution in acids †.

Sp. 26. *Columbate of Iron.*

This compound occurs native in North America, though only a single specimen is at present known; the specimen from which Mr Hatchett extracted columbic acid. This specimen had a dark brownish-grey colour, a lamellated structure, a vitreous lustre, and a specific gravity of 5·918; was moderately hard and very brittle. It was decomposed by repeated fusions with potash, which abstracted its acid; and digestions in mu-

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* *Phil. Trans.* 1801, p. 225.

† Scheele, i. 248.

riatic acid, which dissolved its iron. Its component parts, according to Mr Hatchett's analysis, are

21·0 oxide of iron
77·5 columbic acid

98·5 *

V. TRIPLE SALTS.

Sp. 27. *Tartrate of Potash-and-Iron.*

THIS triple salt was formerly called *tartarised tincture of Mars*, *chalybeated tartar*, and *tartarised iron*. It may be formed by boiling two parts of tartar and one of iron-filings, previously made into a paste, in a proper quantity of water. The liquor by evaporation deposites crystals which form the salt wanted.

Sp. 28. *Sulphate of Potash-and-Iron.*

THIS salt may be formed by boiling together supersulphate of potash and iron-filings, and crystallizing the solution. It has been described by Link. The crystals resemble those of green vitriol. They effloresce in the air †.

Sp. 29. *Muriate of Ammonia-and-Iron.*

THIS salt, which has been long known, is obtained by dissolving in water 16 parts of sal ammoniac, and one part of oxymuriate of iron, evaporating the solution to dryness, and subliming. The yellowish mass sublimed is the triple salt. Its properties have not been examined with care.

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* Hatchett, on a Mineral Substance from North America. *Phil. Trans.* 1802.

† Crell's *Annals*, 1796, i. 30.

Sp. 30. *Phosphate of Ammonia-and-Iron.*

Chap. III.

THIS triple salt has been lately mentioned by Fourcroy. It was obtained by dissolving the phosphate of iron in nitric acid, and precipitating by ammonia. An excess of that alkali redissolves the precipitate, but it appears again when the liquid is boiled for a sufficient length of time. It is a compound of phosphate of iron and ammonia *.

GENUS XI. SALTS OF TIN.

THOUGH several of the salts of tin are of great importance in the art of dyeing, and have been known to manufacturers ever since the discovery of the scarlet dye, of which the oxide of tin constitutes a necessary ingredient, it is only of late that the nature and constitution of these salts have been examined with any kind of precision, and that a satisfactory explanation has been given of the curious properties which some of them possess, and the great changes to which they are liable. For the progress which this branch of the science has made, we are chiefly indebted to Adet, Pelletier, and Proust.

Tin, like iron, combines with two doses of oxygen, and forms two distinct oxides, with each of which several of the acids are capable of combining; and those salts which contain the metal oxidized to a minimum are extremely ready to absorb oxygen, and to pass into the state of oxygenized salts. The salts of tin may be distinguished by the following properties:

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* *Ann. de Chim.* l. 200.

Characters.

1. Most of them are more or less soluble in water, and the solution has usually a yellowish or brownish tinge, but is sometimes colourless.

2. Triple prussiate of potash occasions a white precipitate when dropt into these solutions.

3. Hydrosulphuret of potash occasions a brown-black precipitate in the salts containing the protoxide of tin; a golden yellow precipitate in those that contain the peroxide.

4. Neither gallic acid nor the infusion of nutgalls occasions any precipitate.

5. Corrosive sublimate throws down a black precipitate from the salts of tin containing the protoxide, a white precipitate from those that contain the peroxide.

6. When a plate of lead is put into some solutions of tin, that last metal is separated either in the state of metal, or of white oxide: but this does not happen in every solution of tin.

7. When muriate of gold is poured into solutions containing tin combined with a minimum of oxygen, a purple-coloured precipitate falls.

The salts of tin were formerly distinguished by the epithet *Jovial,* because *Jupiter* was the name by which the alchymists distinguished that metal.

I. DETONATING SALTS.

Sp. 1. *Nitrated Tin.*

NITRIC ACID acts with amazing energy upon tin, and converts it into an oxide with the evolution of a great deal of heat; but there seems to be but a very feeble affinity between that acid and the oxides of tin. Hence the union which they form is but of transient duration, the oxides separating when any attempt is made to concentrate the solution. This has been long known to chemists, and has occasioned a variety of attempts to make the solution of tin in nitric acid more permanent; but these attempts, as might have been expected, have not been attended with success.

Action of nitric acid on tin.

When nitric acid of the specific gravity 1·114 is poured upon tin, the metal is dissolved rapidly with effervescence and a great elevation of temperature, which ought to be moderated by plunging the vessel containing the mixture in cold water. In this case the oxygen is chiefly furnished by the water, and the tin is only combined with a minimum of oxygen. The solution, therefore, which is of a yellow colour, is a real *nitrate* of tin. It becomes gradually opaque, and deposites a white powder, which is an oxide of tin with a minimum of oxygen, as Proust has demonstrated. This oxide separates in greater abundance if the solution be heated. During the solution of the tin a quantity of ammonia is formed. When potash is dropt into the liquid, this ammonia becomes sensible by its odour. Hence we see that, during the solution, both water and nitric acid have been decomposed; their oxygen combined with the tin, and the hydrogen of the one, uniting with the azote of the other, formed ammonia. If a little nitric acid be poured in and heat applied, the tin precipitates in the state of a peroxide *.

When nitric acid, of the specific gravity 1·25, is poured upon tin, a very violent action takes place, the metal is oxidized to a maximum, and the whole of it separates from the liquid. Hence we see that there is

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* Proust, *Jour. de Phys.* li. 173.

No oxynitrate.

no *oxynitrate* of tin; the peroxide of that metal, not being susceptible of entering into combination with nitric acid. When the liquid is evaporated, nitrate of ammonia is obtained. Morveau found, that one part of strong nitric acid and 1½ part of tin, when treated in a retort, gave out no gass, notwithstanding the violence of their action. Upon examining the liquid, he found that the ammonia formed amounted to $\frac{1}{20}$th of the weight of the whole[*]. Hence we see that during the oxydation, both the acid and the water are decomposed; and that they are decomposed in such proportions, that their hydrogen and azote combine, and form ammonia, while the whole of their oxygen unites with the tin.

II. INCOMBUSTIBLE.

Sp. 2. *Muriated Tin.*

MURIATIC ACID dissolves tin in considerable quantity when its action is assisted by heat. The water of the acid is decomposed, its oxygen combines with the tin, while the hydrogen is emitted in the form of gas. This gas has usually a fetid smell, owing, according to Mr Proust, to a quantity of arsenic which it holds in solution, and which is partly deposited on the sides of the jars in which the gas is kept. During the solution of the tin, the arsenic which it usually contains is precipitated in the metallic state in the form of a black powder; so that the quantity of arsenic contained in tin may be ascertained by dissolving it in muriatic acid, provided that portion which is carried off by the hydrogen gas be also taken into account[†]. Muriatic acid

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[*] *Encyc. Method. Chim.* i. 632.

[†] Proust, *Jour. de Phys.* li. 175.

combines with both the oxides of tin, and forms with them permanent salts.

1. *Muriate of Tin.* This is the salt obtained by dissolving tin in about four times its weight of muriatic acid. The solution has a brownish-yellow colour, and yields when evaporated small needle-shaped crystals, soluble in water, and somewhat deliquescent. Their specific gravity is 2·2932 *. Water, when poured on it in small quantity, readily decomposes it; a submuriate precipitates, while a supermuriate remains in solution.

Deoxidizes metals.

This salt has a strong affinity for oxygen, and absorbs it with avidity from the air, from oxymuriatic acid, and from nitric acid, and is converted into oxymuriate of tin, as Pelletier first observed. It absorbs oxygen also from arsenic acid, and the white oxide of arsenic. When these bodies are treated with muriate of tin, they are precipitated, completely deprived of oxygen, in the state of a black powder. Molybdic acid and yellow oxide of tungsten, or their combinations, when dropt into a solution of muriate of tin, immediately assume a blue colour, being changed into oxides with a minimum of oxygen. The red oxide of mercury, the black oxide of manganese, the white oxide of antimony, the oxides of zinc and of silver, are likewise deprived of their oxygen by this salt, and reduced to the metallic state. The oxygenized salts of iron and copper are also reduced to salts with a minimum of oxygen, and the muriate of gold occasions a purple precipitate, consisting of gold reduced to the state of purple oxide. For

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* Hassenfratz, *Ann. de Chim.* xxviii. 12.

these interesting results we are indebted to Pelletier and Proust. They afford a sufficient key to explain all the singular changes produced upon the greater number of metallic salts by this muriate *.

Smoking liquor of Libavius.

2. *Oxymuriate of Tin.* This salt may be formed very conveniently by the process first proposed by Pelletier, which consists in causing oxymuriatic acid gas to pass into a solution of muriate of tin till it be saturated, and then expelling the excess of acid by heat. But it was known long before this process was thought of, and was usually distinguished by the name of *smoking liquor of Libavius;* because Libavius, a chemist of the 16th century, was the discoverer of it. When equal parts of amalgam of tin † and oxymuriate of mercury are triturated together, and then distilled in a retort with a very moderate heat, there passes first a colourless liquid, consisting chiefly of water, and afterwards a white vapour rushes all of a sudden into the receiver. This vapour condenses into a transparent liquid, which exhales a heavy dense smoke when exposed to the air, but does not smoke when confined in close vessels. This is the fuming liquor of Libavius, or oxymuriate of tin. The proportions which answer best, according to the experiments of Sulze (assisted by a little calculation, however), are six parts of tin, one part of mercury, and 33 parts of corrosive sublimate ‡.

The theory of the process is obvious: The tin abstracts oxygen from the mercury, and at the same time combines with the muriatic acid. Muriates of mercury

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* Pelletier, *Ann. de Chim.* xii. 225.—Proust, *Jour. de Phys.* li. 573.

† Composed of two parts of tin and one of mercury.

‡ Gehlen's *Journal*, iv. 438.

and of tin are also formed, and line the neck of the retort, mixed with a quantity of pure mercury; and there remains behind an amalgam of tin, covered with a crust of muriate of tin[*]. It had been long known that this liquid contained muriatic acid and tin. Adet endeavoured to show that the acid was in the state of hyperoxymuriatic[†]. His experiments were afterwards confirmed by Pelletier[‡]; but Proust demonstrated the falsehood of his theory[§].

The white smoke constantly exhaled by this salt, prepared according to the process of Libavius, has also been accounted for by Adet. This salt is nearly destitute of water, and in this state it is exceedingly volatile. The vapour as it rises combines with the vapour of the atmosphere, and the smoke appears at the moment of the combination. When the salt is confined in a glass jar, either in moistened air or standing over water, it condenses gradually on the sides of the jar in the form of small crystals, having imbibed the water necessary for its crystallization from the air. When thrown into water, this substance produces heat, and at the same time dissolves if the quantity of water be sufficient. Adet ascertained, that when seven parts of water are mixed with 22 parts of fuming muriate, the mixture condenses into a solid mass. This mass melts like ice when exposed to heat, and condenses again when cooled and agitated.

Oxymuriate of tin is capable of dissolving an additional dose of tin without effervescence or the exhalation of gas, and by that means is converted into muriate

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[*] Rouelle.

[†] *Ann. de Chim.* i. 5.

[‡] Ibid. xii. 225.

[§] *Jour. de Phys.* lvi. 217.

of tin. The new portion of tin in this case deprives the tin of the oxymuriate of its second dose of oxygen. Adet, however, found that this solution did not succeed except in the oxymuriate, rendered solid by mixture with water, and then liquefied by heat *.

Liquid oxymuriate of tin yields by evaporation small crystals; and when heated sublimes in the same manner as fuming muriate. The crystals deliquesce when exposed to the open air, and dissolve readily in water. They have usually an excess of acid. The solution forms a white precipitate when dropt into the nitrates of mercury, lead, or silver; and into the sulphate of zinc, but does not alter salts of copper or arsenic.

Oxymuriate of tin is employed by dyers in great quantities, as it forms the basis of the scarlet dye. They usually prepare it by dissolving tin in nitro-muriatic acid; the consequence of which is, that the nature of the solution varies according to the proportion of the acids and the manner of dissolving the tin. In some cases it is merely a muriate; in others, an oxymuriate; and, generally, it consists of a mixture of the two. Hence the difficulty of which dyers complain, of forming with this solution the same shade of colour in different circumstances. This would be in a great measure removed by preparing the salt according to the process recommended by Pelletier †.

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* *Ann. de Chim.* i. 16.

† Bucholz has noticed a curious phenomenon. If more tin be put into muriatic acid than the acid is capable of dissolving, and if after the action of the acid has been assisted by heat, the solution be diluted with water and set aside, a great part of the dissolved tin separates in the metallic state (Gehlen's *Jour.* iii. 423.) On repeating the experi-

Sp. 3. *Sulphate of Tin.*

When a cylinder of tin is plunged into sulphuric acid, scarcely any action can be perceived for some time; but the metal is gradually converted into white flakes on the surface, which fall to the bottom, and remain in the state of a white powder; at the same time bubbles of sulphurous acid make their escape. The properties of the compounds which this acid forms with tin have not been examined with accuracy. Kunkel, Wallerius, and Monnet, the chemists who have paid the greatest attention to the action of sulphuric acid on tin, attempted the solution by means of heat. In that case the acid is decomposed, sulphurous acid exhaled, and even sulphur developed, if the heat be long enough continued. The metal is oxidized to a maximum, and the *oxysulphate* obtained is not crystallizable; but when evaporated assumes the form of a jelly; and when water is poured into the solution, the salt precipitates in the state of a white powder.

But if the action of the acid is not assisted by heat, or if tin combined with a maximum of oxygen be dissolved in sulphuric acid, in either of these cases a *sulphate* of tin is formed, which yields, when evaporated, crystals in the form of fine needles, as was observed long ago by Monnet. The simplest method of obtaining this salt is that which was pointed out by Berthollet

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ment it succeeded. The portion which continued in solution was in the state of oxymuriate. Hence we see that one part of the tin had given up the whole of its oxygen to another, as happens in some of the solutions of copper. It follows from this, that the best way of forming muriate of tin is to add the metal gradually to the acid as it dissolves.

junior. Pour sulphuric acid into muriate of tin; a white powder falls, which is the sulphate. It dissolves in water, and forms by evaporation small prismatic crystals. Alkalies decompose it imperfectly, throwing down a subsulphate of tin [*].

Sp. 4. *Sulphite of Tin.*

THE action of sulphurous acid upon tin has been examined lately by Fourcroy and Vauquelin, during their experiments on the combinations which that acid is capable of forming. When a plate of tin is plunged into liquid sulphurous acid, it assumes a yellow colour, and afterwards becomes black. A black powder is precipitated, which is sulphuret of tin. A portion of the acid is decomposed; the tin is partly oxidized, and combined with the remainder of the acid, and partly precipitated in the state of sulphuret combined with the sulphur of the decomposed acid. There remains in solution sulphite of tin combined with a portion of sulphur; for sulphur precipitates when sulphuric acid is added to the solution [†].

Sp. 5. *Phosphate of Tin.*

PHOSPHORIC ACID has scarcely any action on tin unless when it is exposed dry and mixed with that metal to the action of a strong heat. In that case, part of the acid is decomposed, its phosphorus combines with one portion of the tin and forms a phosphuret, while the oxide of tin unites with the undecomposed acid and forms a phosphate [‡]. This salt precipitates also when

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[*] *Statique Chimique*, ii. 464.

[†] Fourcroy, vi. 30.

[‡] Pelletier, *Ann. de Chim.* xiii. 16.

the alkaline phosphates are mixed with a solution of muriate of tin; and it may be formed by digesting oxide of tin in phosphoric acid. It is insoluble in water. Tin does not precipitate copper from muriatic acid. Phosphate of tin melts into a glass when heated [*].

Sp. 6. *Carbonate of Tin.*

As far as is known at present, the oxides of tin do not combine with carbonic acid. Bergman failed in his endeavours to form this combination; and when the oxides of tin are precipitated from their solution in acids by alkaline carbonates, he found that their weight receives scarcely a perceptible increase [†]. Nor have the attempts of Proust to combine these bodies with carbonic acid been attended with more success [‡].

Sp. 7. *Fluate of Tin.*

FLUORIC ACID does not attack tin; but it dissolves its oxide, and forms with it a gelatinous solution, which has a strong disagreeable taste [§]. This fluate may be formed also by mixing together an alkaline fluate and the muriate of tin.

Sp. 8. *Borate of Tin.*

BORACIC ACID does not attack tin; but borax produces a precipitate in the muriate of tin. The white powder which falls is insoluble in water: in a strong heat it melts into an opaque slag [‖].

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[*] Wenzel's *Verwandtschaft*, p. 175.

[†] *Opusc.* ii. 329.

[‡] *Jour. de Phys.* li. 167.

[§] Scheele, i. 34.

[‖] Wenzel's *Verwandtschaft*, p. 252.

III. COMBUSTIBLE SALTS.

Sp. 9. *Acetate of Tin.*

Action of vinegar on tin vessels.

ACETIC ACID attacks tin very slowly, even when assisted by heat, and oxidizes and dissolves only a small portion of it. The spontaneous action of this acid on tin vessels, when in the state of vinegar, has been lately examined by Vauquelin. The subject was of importance, because vinegar is usually measured out in tin vessels. Now, as these vessels contain always a little lead, and as the salts of lead are all poisonous, it was of consequence to determine whether the vinegar acted on the vessel, and if it did, whether its action was confined to the tin or extended also to the lead; because in this last case the vinegar would be converted into a poison. The result of this investigation was, that a small portion of tin was dissolved; and that when the lead exceeded the sixth part of the tin, a small portion of it was also dissolved at that part of the vessel only which was in contact both with the vinegar and the air *.

When acetic acid is boiled upon tin, the metal is gradually dissolved, combining with oxygen at the expence of the water. The solution has a whitish colour, and yields by evaporation small crystals. This fact, first mentioned by Lemery, had been denied by Monnet, Westendorf, and Wenzel, who could only obtain from it a gummy mass. But Morveau established the truth of Lemery's observation, by crystallizing acetate of tin by spontaneous evaporation †. It is easy to account for the different results obtained by these chemists.

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* *Ann. de Chim.* xxxii. 243.

† *Encycl. Method. Chim.* i. 23.

The crystals were no doubt *acetate* of tin, the gummy mass *oxacetate* of tin. The simplest method of obtaining the acetate of tin is to mix together the solutions of muriate of tin and acetate of lead.

Sp. 10. *Succinate of Tin.*

SUCCINIC ACID dissolves the oxide of tin when assisted by heat. The solution by evaporation yields thin, broad, transparent crystals[*]. Neither lead, iron, nor zinc, occasion any change in the solution of this salt[†].

Sp. 11. *Benzoate of Tin.*

NEITHER tin nor its oxide is soluble in benzoic acid; but when benzoate of potash is poured into a solution of tin in nitro-muriatic acid, benzoate of tin precipitates. It is soluble in water by the assistance of heat, but insoluble in alcohol, and decomposed by the action of heat[‡].

Sp. 12. *Oxalate of Tin.*

OXALIC ACID attacks tin when assisted by heat. The metal is first blackened, and is then covered with a white crust of oxide. The solution, which has an austere taste, by slow evaporation yields prismatic crystals; but when evaporated rapidly by means of a strong heat, it leaves a mass resembling horn[§].

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[*] Wenzel's *Verwand.* p. 241.

[†] Wenzel's *Verwandtschaft*, p. 252.

[‡] Trommsdorf, *Ann. de Chim.* xi. 315.

[§] Bergman, i. 269.

Sp. 13. *Tartrate of Tin.*

The tartrate of tin has never been examined by chemists. The acid does not attack the metal, but it dissolves the oxide of tin.

IV. Metallic Salts.

Sp. 14. *Arseniate of Tin.*

When tin is treated with arsenic acid in a digesting heat, it is slowly oxidized at the expence of the acid, and the solution at last assumes the form of a gelatinous mass. Arsenic acid precipitates tin from acetic acid, and the alkaline arseniates occasion a precipitate when poured into muriate of tin. The precipitate is arseniate of tin in the form of an insoluble powder, which hitherto has not been examined [*].

V. Triple Salts.

Sp. 15. *Tartrate of Potash-and-Tin.*

This triple salt may be formed by boiling together tartar and the oxide of tin in water. It is very soluble, and therefore its solution crystallizes with difficulty. No precipitate is produced in it by the alkalies or their carbonates [†].

Sp. 16. *Nitrate of Ammonia-and-Tin.*

The peroxide of tin is insoluble in nitric acid, but it dissolves when treated with nitric acid and ammonia. Hence the reason why a salt containing tin is often pro-

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[*] Scheele, i. 180.

[†] Thenard, *Ann. de Chim.* xxxviii. 35.

cured by the action of nitric acid on tin. Nitrate of ammonia is formed during the process *.

GENUS XII. SALTS OF LEAD.

THOUGH lead be one of the most abundant and useful metals, though it has been known from the earliest ages, and though it is without difficulty dissolved by the greater number of acids, its salts have not hitherto been much examined by chemists. This is to be regretted; because the various degrees of oxidizement of which it is susceptible, afford an excellent opportunity of ascertaining how many different salts it is capable of forming with each peculiar acid; and this once known, would probably lead to some general conclusions concerning the different classes of metallic salts. The salts of lead were formerly distinguished by the name of *saturn*, the title by which lead was known among the alchymists. They may be distinguished by the following properties:

Characters.

1. A considerable number of them are scarcely soluble in water without an excess of acid. These before the blow-pipe yield very readily a button of lead.

2. The solution of the soluble salts of lead in water is generally colourless and transparent.

3. They have almost all less or more of a sweet taste, accompanied with a certain degree of astringency.

4. Triple prussiate of potash occasions a white precipitate when poured into solutions containing salts of lead.

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* Thenard, *Ann. de Chim.* xlii. 218.

5. Hydrosulphuret of potash occasions a black precipitate. The same precipitate is produced by sulphureted hydrogen.

6. Gallic acid and the infusion of nutgalls occasion a white precipitate.

7. A plate of zinc kept in a solution of lead occasions either a white precipitate, or the lead appears in its metallic state.

Though lead is susceptible of combining with several doses of oxygen, it does not appear that each of its oxides is capable of combining with acids. As far as is known at present, it is only the first two oxides which possess this property, if we except the hyperoxymuriate, which contains the peroxide of lead. None of the attempts to combine the red oxide of lead with acids have been attended with success. The yellow oxide combines with all acids hitherto tried; the salts formed by means of that oxide alone have been hitherto examined: the combinations of the first oxide have been completely overlooked, except by Mr Proust.

I. DETONATING SALTS.

Sp. 1. *Nitrated Lead.*

Action of nitric acid on lead and its oxides.

NITRIC ACID acts upon lead with considerable energy, provided it be not too much concentrated; first converting it into a white powder, which is a suboxynitrate, and then dissolving it, especially when assisted by heat. The yellow oxide of lead is dissolved by nitric acid completely, and without effervescence; but the red oxide is rendered white; $\frac{6}{7}$ths of its weight are dissolved, and $\frac{1}{7}$th is converted into brown oxide, and remains undissolved*. Hence we see that it is the yellow oxide of lead only which combines with nitric acid. Six-sevenths of the red oxide are decomposed; the excess of oxygen combines with the remaining seventh, and converts it into brown oxide, while the base or yellow oxide combines with the acid. Thus we see that nitric acid does not combine with the red or brown oxide of lead, but it combines with the protoxide and yellow oxide, and forms with them two salts, which we shall distinguish, as usual, by the names of *nitrate* and *oxynitrate* of lead. The last has been long known; but the first has been pointed out within these few years by Mr Proust.

1. *Oxynitrate of Lead.* This salt is always formed when lead is dissolved in nitric acid, unless there be present an excess of lead, and a strong heat be applied. It is formed also by dissolving the deutoxide or white lead in nitric acid. The solution is transparent and colourless, and when sufficiently concentrated by evaporation, crystallizes on cooling. The crystals are usually tetrahedrons, having their apex truncated, and sometimes six-sided pyramids, according to Rouelle. They are opaque and white, and have a silvery lustre. Their taste is sweetish and harsh. They are not altered by exposure to the air. They are soluble in 7·6 parts of boiling water†. Their specific gravity is 4·068‡. When heated, they decrepitate, and then undergo a kind of detonation, emitting very brilliant sparks§. When they are triturated with sulphur in a hot mortar, a fee-

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* Proust.

† Wenzel's *Verwandtschaft*, p. 310.

‡ Hassenfratz, *Ann. de Chim.* xxviii. 12.

§ Bergman, ii. 470

ble detonation is produced, and the lead is reduced to the metallic state *.

My experiments give the constituents of this salt as follows:

Composition.

66 oxide
34 acid and water

100

The oxide of lead is thrown down by alkalies in the state of a yellow powder. Sulphuric, sulphurous, and muriatic acids combine with the oxide, and precipitate it in the state of a white powder. Iron occasions no precipitate though kept in the solution of oxynitrate of lead †.

2. *Nitrate of Lead.* This salt may be formed by boiling together a quantity of metallic lead and oxynitrate; a portion of the lead is dissolved at the expence of the deutoxide in the oxynitrate; and the whole is converted into the protoxide, which according to a very general law in chemistry, requires less acid to saturate it than the deutoxide. It may be formed also by boiling nitric acid on a greater quantity of lead than it is capable of dissolving. In that case the salt usually crystallizes in cooling, and the solution is yellow ‡. This salt crystallizes in brilliant scales of a yellow colour, and soluble in water §; or in small prisms. They have

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* Van Mons, *Ann. de Chim.* xxvii. 81.

† Wenzel's *Verwandtschaft*, p. 90.

‡ This experiment was made by Wenzel long ago; but it was impossible to draw the proper inference till the nature of the oxide was better understood. See his *Verwand.* p. 90.

§ Proust, *Jour. de Phys.* lvi. 206.

the same sweet astringent taste with nitrate of lead. By my analysis they are composed of

81·5 oxide
18·5 acid

100·0

Sp. 2. *Hyperoxymuriate of Lead.*

When the red oxide of lead is put into a Woulfe's bottle with water, and oxymuriatic acid gas is made to pass through it, the gas is absorbed, while the oxide acquires a brown colour, and is gradually dissolved. For this curious experiment we are indebted to Mr Proust. In this case the lead absorbs oxygen from the acid; and when the whole is oxidized to a maximum, a portion is dissolved, and hyperoxygenized muriate of lead formed. This salt is much more soluble than muriate of lead. It is very readily decomposed *.

II. Incombustible.

Sp. 3. *Muriate of Lead.*

Muriatic acid attacks lead when assisted by heat, and oxidizes and dissolves a portion of it; but its action is feeble and limited. It combines readily with the yellow oxide of lead. When poured upon the red oxide, it is converted partly into oxymuriatic acid by the assistance of heat, while the lead, reduced to the state of yellow oxide, combines with the remainder of the

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* Chenevix on Hyperoxygenized Muriatic Acid. *Phil. Trans.* 1802.

acid [*]. Thus we see that muriatic acid combines usually with yellow oxide of lead, and that it is incapable of combining with the red oxide of that metal; but in all probability it combines with the protoxide, though the experiment has not been tried. The compound of muriatic acid and lead at present known is in fact an oxymuriate. There are two varieties; the first neutral, long known; the second a submuriate.

1. *Muriate of Lead.* This salt may be formed readily by pouring muriatic acid or an alkaline muriate into a solution of nitrate of lead. The muriate precipitates in the state of a white powder. It has a sweetish taste. Its specific gravity is 1·8226 [†]. It is soluble in 22 parts of cold water, and this solubility is increased considerably by the presence of an acid [‡]. It is soluble in acetic acid; a property by which it may be readily distinguished from sulphate of lead. When its solution in boiling water is allowed to cool, the salt crystallizes in very small six-sided prisms of a white colour, and a brilliant appearance like satin. These crystals are not altered by exposure to the air. When heated they melt readily, and when cold assume the appearance of a semitransparent, greyish-white mass, formerly distinguished by the name of *plumbum corneum.* When exposed to a strong heat, they partly evaporate in a visible white smoke, and there remains behind a submuriate of lead; a substance which seems

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[*] Fabroni.

[†] Hassenfratz, *Ann. de Chim.* xxviii. 12.

[‡] Chenevix, Nicholson's *Jour.* iv. 223.—According to Wenzel, water, though boiled on muriate of lead, takes up only 1-30th of that salt, *Verwandtschaft*, p. 311.

to have been first examined by Bergman[*]. The constituents of this salt are, according to

Composition.

Klaproth.	Kirwan,	
	Crystals	Dried
13·5	18·23	17 acid
86·5	81·77	83 oxide
100·0[†]	100·00	100[‡]

According to Kirwan's estimate, we may consider 100 parts of crystallized salt as containing 76 parts of lead in the metallic state. This salt dissolves in nitric acid.

2. *Submuriate of Lead.* This salt may be procured either by treating muriate of lead with a pure alkali, or by decomposing common salt by means of four times its weight of litharge. In either case a white powder remains, which is the submuriate of lead. Vauquelin first pointed it out to the peculiar attention of chemists[§]. It had been previously mentioned by Bergman. It is insoluble in water. When heated, it assumes a fine yellow colour. Nitric acid dissolves the excess of oxide, and leaves muriate of lead in crystals. The fixed alkalies dissolve it without decomposition. This salt is employed as a yellow paint.

Sp. 4. *Sulphate of Lead.*

Sulphuric acid does not attack lead while cold; but at a boiling heat it communicates a portion of its oxygen, sulphurous acid gas is emitted, and the whole is converted into a thick white mass, which is sulphate

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[*] Bergman, ii. 470. and iii. 325.

[†] *Beitrage*, ii. 275.

[‡] On *Mineral Waters*, Table IV.

[§] *Ann. de Chim.* xxxi. 3.

of lead. It may be obtained readily by pouring sulphuric acid into acetate of lead, or by mixing this last salt with any of the alkaline sulphates. The sulphate of lead precipitates in the state of a white powder. This salt is tasteless. Its specific gravity is 1·8742 *. It is insoluble in alcohol and in nitric acid. According to Kirwan, it requires 1200 parts of water to dissolve it †; but when it contains an excess of acid, it is more soluble, and yields by evaporation small white crystals, which, according to Sage, have the form of tetrahedral prisms. It dissolves in strong muriatic acid when the action of the solvent is promoted by heat; the solution, on cooling, deposites many crystals of muriate of lead ‡. It is found native crystallized, according to Kirwan, in four-sided oblique angled prisms §; according to Hauy, in regular octahedrons ||. The native sulphate of lead found in Paris mountain, Anglesey, is crystallized in four-sided pyramids; the specimens found at Leadhills in Scotland are in transparent tables.

Composition.

According to the most accurate analyses hitherto made, the constituents of this salt are as follows:

	¶	**	††
Acid	23·37	24·72	26·5
Yellow oxide	75·00	75·28	73·5
Water	1·63		
Total	100	100	100

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* Hassenfratz, *Ann. de Chim.* xxviii. 12.

† *Mineralogy*, ii. 211.

‡ Descotils, Nicholson's *Jour.* xii. 221.

§ Kirwan's *Min.* ii. 211.

|| *Jour. de Min.* An. v. p. 508.

¶ Kirwan *on Mineral Waters*, Table IV.

** Bucholz, Gehlen's *Jour.* v. 262.

†† Klaproth's *Beitrage*, iii. 166.

A hundred parts of this salt, according to Kirwan, contain 71 parts of pure lead *.

In close vessels this salt endures a considerable heat without alteration. I find that, after being dried in the temperature of about 400°, it may be heated to redness in a platinum crucible without losing any weight. On charcoal it melts, and the lead is quickly reduced.

When this salt is treated with alkalies, it is deprived of the greater part of its acid ; but a portion still adheres. The white powder obtained by this process is therefore a subsulphate of lead.

Sp. 5. *Sulphite of Lead.*

SULPHUROUS ACID has no action whatever on lead. It absorbs oxygen from the red oxide of that metal, and is converted into sulphuric acid. But it combines with the deutoxide of lead, and forms with it a sulphite, which is in the state of a white powder, insoluble in water, and tasteless. Before the blowpipe on charcoal it melts, becomes yellow, and the lead is at last reduced †. Sulphite of lead, dried in a temperature of about 300°, is composed, according to my analysis, of

Composition.

74·5	oxide
25·5	acid
100·0	

When exposed to a red heat, it loses 5 *per cent.* of its weight; sulphurous acid exhales ; and there remains a blackish mass composed of sulphate of lead and sul-

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* *On Mineral Waters*, Table IV.

† Fourcroy and Vauquelin, *Connoissances Chimiques*, vi. 86.

phuret. When treated with nitric acid, the sulphuret is decomposed, and crystals of nitrate obtained.

Sp. 6. *Phosphate of Lead.*

PHOSPHORIC ACID has but little action on lead; however, when allowed to remain long in contact with it, the metal is partly oxidized and converted into an insoluble phosphate. The phosphate of lead may be easily formed by mixing the alkaline phosphates with nitrate of lead. The salt immediately precipitates in the state of an insoluble powder *.

The salt is found native in different parts of the world. Its colour is then usually green or yellow, and it is often crystallized in six-sided prisms. It is insoluble in water unless there be a considerable excess of acid; but it is soluble in pure soda, and probably forms with it a triple salt †. It dissolves readily in nitric acid, and likewise in concentrated muriatic acid when the action of the liquid is assisted by heat. As the solution cools, crystals of muriate of lead precipitate in abundance. Sulphuric acid, when assisted by heat, decomposes this salt, combining with the oxide, and leaving the acid in a state capable of dissolving in water. When heated, it melts, and assumes on cooling a regular polyhedral form. In a red heat it is decomposed by charcoal, which absorbs the oxygen from both of its component parts.

The yellow phosphate of lead, from Leadhills in Scot-

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* Margraf's *Opusc.* i. 171. Wenzel's *Verwandtschaft*, p. 174.

† Vauquelin, *Jour. de Min.* No. ix. p. 6.

land, is composed, according to my analysis (abstracting the impurities with which it is usually mixed), of

18	acid
82	yellow oxide
100	

With this analysis the constituents of the different varieties, as found by Klaproth, coincide almost exactly *.

Sp. 7. *Carbonate of Lead*.

Carbonic acid has no action whatever on lead, neither is it capable of dissolving its oxide; but it combines readily with the yellow oxide, and forms a carbonate. This salt is most easily obtained by precipitating lead from its solution in nitric acid by the alkaline carbonates. By that process it is obtained in the state of a white powder. It is tasteless and insoluble in water; but soluble in pure potash, in the same manner as the oxides of lead.

White lead.

The *white lead* of commerce (or *ceruse*), employed as a paint, is merely a carbonate of lead, as Bergman first observed †. It is prepared by exposing thin plates of lead to the hot vapours of acetic acid. The metal is gradually corroded and converted into a carbonate, probably at the expence of the acid.

This salt occurs native in abundance. In that state

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* *Beitrage*, iii. 146.

† *Opusc*. i. 39. Proust has lately shown the same thing. *Jour. de Phys*. lvi. 207. Scheele found that a little acetic acid was always separated from it when white lead was distilled with sulphuric acid. Crell's *Annals*, iii. 8. Engl. Trans.

it is usually white, and has a good deal of lustre. Its specific gravity is 7·2357 *. It is sometimes crystallized in six-sided prisms, terminated by six-sided pyramids, sometimes in regular octahedrons †, and sometimes in tables ‡. It is insoluble in water. When exposed to the action of the blowpipe upon charcoal, the lead is immediately reduced to the metallic state.

This salt has been analysed by some of the most expert chemists. The constituents, as determined by their experiments, may be seen in the following Table:

Composition.

	§	‖	¶	**
Acid	15.	16	16·15	16·33
Yellow oxide	85	84	83·85	83·67
Total	100	100	100	100

Sp. 8. *Fluate of Lead.*

Fluoric acid has no action on lead, though it dissolves a small proportion of the yellow oxide of that metal when there is an excess of acid; but the fluate of lead, formed by saturating the acid, is an insoluble powder, which melts easily before the blowpipe, and lets go its acid. The acid is driven off also by sulphuric acid ††.

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* Bournon, Nicholson's *Jour.* iv. 220.

† Hauy, *Jour. de Min.* An. v. 502. ‡ As at Leadhills in Scotland.

§ Chenevix, Nicholson's *Quarto Jour* iv. 221.

‖ Bergman, *Opusc.* ii. 393. ¶ Proust, *Jour. de Phys.* lvi. 207.

** Klaproth, *Beitrage*, iii. 165. †† Scheele, i. 33.

Sp. 9. *Borate of Lead.*

Boracic acid has no action on lead; but borate of lead is precipitated in the state of white powder when borate of soda is mixed with nitrate of lead. Before the blowpipe it melts into a colourless glass [*]. When one part of boracic acid is melted with two parts of red oxide of lead, the product, according to Reuss, is a greenish-yellow, transparent, hard, insoluble glass [†].

III. Combustible Salts.

Sp. 10. *Acetate of Lead.*

Acetic acid, as Scheele [‡] first, and Vauquelin afterwards showed, does not attack lead in close vessels; but it occasions its oxidizement when the lead is in contact both with the acid and the air, and the oxide is dissolved as it forms. It dissolves the yellow oxide very readily, and forms with it two salts; the first containing an excess of acid, the other neutral.

1. *Superacetate of Lead* has been long known. It is mentioned by Isaac Hollandus and Raymond Lully. It received formerly a great variety of names; such as, *sugar of lead, sugar of Saturn, salt of Saturn*, &c.

This salt is employed in considerable quantities by dyers and calico-printers. They mix it with alum or with sulphate of iron, and by that means compose acetate of alumina or of iron, according to the process; salts which answer much better as mordants for fixing their

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[*] Wenzel's *Verwandt.* p. 252.

[†] Reuss *de Sale Sedative.*

[‡] Crell's *Annals*, iii. 8. Engl. Trans.

colours than alum or green vitriol. It is prepared in considerable quantities both in this country and in Holland and France. The manufacturers distil their own acid in England and Holland from sour beer, and in France from sour wine. The different processes followed by manufacturers have been described by Weber * and Demachy †, and more lately by Pontier ‡.

Preparation.

These processes may be reduced to two; either lead in the metallic state is exposed to the action of the acetic acid, or the carbonate of lead is dissolved in it. In the first case, thin plates of lead are put into earthen vessels along with acetic acid. The portion of the lead near the surface, as soon as it is covered with a coat of oxide, is removed to the bottom of the vessel, and new plates are brought to the surface. These are incrusted in their turn, and removed to the bottom, where the oxide is dissolved. This change of place is continued daily till the acid has dissolved a sufficient quantity of lead. It is then filtered, and sufficiently concentrated by evaporation. As it cools, the acetate of lead precipitates in small crystals.

Other manufacturers dissolve the carbonate of lead, prepared by exposing the metal to the fumes of vinegar; or they make use of litharge in its stead, and the solution is evaporated in the usual way till the salt crystallizes. This process is considered as more expensive than the other: But might not native carbonate of lead, which is found abundantly in many places, be employed with advantage instead of these artificial oxides?

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* *Phys. Chem. Magazin.* i. 84.

† *Laborant in grossen*, ii. 194.

‡ *Ann. de Chim.* xxxvii. 268.

Properties.

Superacetate of lead is usually in the form of small needle-shaped crystals, which have a glossy appearance like satin, and are flat four-sided prisms, terminated by dihedral summits. Its taste is sweet and somewhat astringent. Its specific gravity is 2·345 *. When water is boiled upon this salt, it dissolves about ·29, and retains in solution when cold about ·27 of its weight of it †. When exposed to the air, it undergoes no change. Its constituents are easily separated. When it is dissolved in water, a small quantity of white powder usually falls. It is carbonate of lead, formed by the carbonic acid, which usually exists in water. When we blow through a solution of superacetate of lead, the same white powder precipitates ‡.

Products from its distillation.

This salt is decomposed by all those acids and their compounds which form with lead a salt nearly insoluble in water; as the sulphuric, phosphoric, muriatic, fluoric, oxalic, malic, &c. When heated, it is decomposed; and if it be distilled in a retort, very singular products are obtained. These products were first examined by Beccher; afterwards by Baumé, and more particularly by Pluvinet: But it is to Proust that we are indebted for the most precise information on the subject. By distilling 160 parts of sugar of lead, he obtained by a gentle heat 12 parts of water slightly acidulated with vinegar. Then by increasing the fire, there came over 72 parts of a yellow liquid, having the

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* Hassenfratz, *Ann. de Chim.* xxviii. 12.

† Bostock, Nicholson's *Jour.* xi. 79.—Wenzel affirms, that water at the temperature of 100° dissolves its own weight of this salt. *Verwandtschaft*, p. 308. But this is a mistake.

‡ Proust, *Jour. de Phys.* lvi. 207.

Book II. Division III.

odour of alcohol, strong and agreeable, though mixed with an empyreumatic smell. When lime is added to the liquid, ammonia is disengaged, which existed in the liquid, combined with a slight excess of acetic acid. When the liquid was saturated with potash, and allowed to remain for 24 hours, about $\frac{1}{3}$d of a part of oil separated and floated on its surface. This oil being separated by a syphon, was found to have a strong odour. The liquid was then distilled by means of a low heat. The first eight parts which came over were of the specific gravity 0·88. This liquid mixed with water exactly like alcohol. Its taste was strong, and its volatility scarcely inferior to that of ether. It burns rapidly, and with a large white flame, when brought near a lighted candle. It contained manifestly a considerable portion of water [*]. During the distillation abundance of carbonic acid gas is disengaged, but no sensible portion of any other elastic fluid.

The constituents of superacetate of lead are

26	acid
58	yellow oxide
16	water
100	

2. *Acetate.* The nature of this salt was first pointed out by Scheele [†]; but Thenard first investigated its properties with precision [‡]. It may be formed by boiling together in water 100 parts of the sugar of lead, and 150 parts of dry litharge deprived of carbonic acid. Its

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[*] Proust, *Jour. de Phys.* lvi. 209.

[†] Crell's *Annals*, iii. 8. English Transl.

[‡] Nicholson's *Journal*, vi. 223.

taste is less sweet; it is less soluble in water; and it crystallizes in plates. It is composed, according to Thenard, of the following proportions:

17	acid
78	oxide
5	water
100	

Goulard's extract.

The solution of the oxide of lead in acetic acid was strenuously recommended by Goulard, a surgeon in Montpelier, as an excellent application in cases of inflammation. It was prepared by boiling distilled vinegar on litharge till it refused to dissolve any more of the oxide. This preparation was distinguished by the names of *Goulard's extract* and *vinegar of lead.* Scheele first ascertained the nature of this substance, by showing that solution of sugar of lead in water is converted into Goulard's extract, by keeping in it a plate of lead for the space of a day; and by proving that the solution oxidized and dissolved a portion of the plate *. But subsequent writers had overlooked the observations of this chemist, till Dr Bostock examined Goulard's extract, and by comparing it with sugar of lead, showed that it is in reality a solution of *acetate of lead* in water †. It is precipitated in much greater proportion by carbonic acid than the superacetate; and it is a much more delicate test for mucilage or gum, as was known to chemists long before Mr John Hunter employed it as a reagent.

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* Crell's *Annals*, iii. 10. English Transl.

† Nicholson's *Jour.* xi. 75.

Sp 11. *Succinate of Lead.*

Succinic acid scarcely attacks lead, but it dissolves its yellow oxide; and the solution, according to Wenzel, yields long slender foliated crystals*, scarcely soluble in water, but soluble in nitric acid. Succinic acid does not precipitate lead from nitric or muriatic acid; but it occasions a precipitate in acetate of lead †.

Sp. 12. *Benzoate of Lead.*

Benzoic acid dissolves lead with difficulty. The solution yields by evaporation crystals of benzoate of lead of a brilliant white colour, soluble in alcohol and water; not altered by exposure to the air, but decomposed by heat, which drives off their acid. The sulphuric and muriatic acids separate the lead ‡.

Sp. 13. *Oxalate of Lead.*

Oxalic acid blackens lead, but it is scarcely capable of dissolving it; but it dissolves its deutoxide, and when nearly saturated deposites small crystalline grains of oxalate of lead. The same crystals are precipitated when oxalic acid is dropt into the nitrate, muriate, or acetate of lead dissolved in water. They are insoluble in alcohol, and scarcely soluble in water, unless they contain an excess of acid. They are composed, according to Bergman's analysis, of about

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* Wenzel's *Verwand.* p. 241.

† Stockar de Neuforn *de Succino*, § 33.; as quoted by Gren, *Handbuch*, iii. 281.

‡ Trommsdorf, *Ann. de Chim.* xi. 316.

41·2 acid
58·8 oxide

100·0 *

Sp. 14. *Mellate of Lead.*

Mellitic acid occasions a white precipitate when dropt into nitrate of lead; but the precipitate is redissolved by the addition of nitric acid †.

Sp. 15. *Tartrate of Lead.*

Tartaric acid has no action on lead; but it combines with its oxide, and precipitates tartrate of lead, in the state of a white powder, from the nitrate, muriate, and acetate of that metal. This salt is completely insoluble in water ‡. Its constituents, according to the respective analyses hitherto made, are as follows:

	§	‖	¶
Acid	34	37	37·44
Yellow oxide	66	63	62·56
Total	100	100	100

Sp. 16. *Citrate of Lead.*

Citric acid does not attack lead; but when dropt

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* Bergman, i. 267.

† Klaproth's *Beitrage*, iii. 132

‡ Bucholz, Gehlen's *Jour.* v. 269.

§ Thenard, *Ann. de Chim.* xxxviii. 37.

‖ Bucholz, Gehlen's *Jour.* v. 269.

¶ By my analysis.

into acetate of lead, a citrate precipitates in the state of a difficultly soluble powder [*].

Sp. 17. *Saccolate of Lead.*

SACLACTIC ACID occasions a white precipitate when dropt into nitrate of lead [†].

Sp. 18. *Malate of Lead.*

MALIC ACID does not attack lead; but when poured into a solution of lead in nitric or acetic acid, malate of lead is immediately precipitated [‡]; and likewise, as Vauquelin has observed, when acetate of lead is poured into a solution containing malate of lime. This precipitate is easily distinguished by the form of fine light flakes which it has, and by the facility with which it is dissolved by the acetic and weak nitric acids [§].

Sp. 19. *Lactate of Lead.*

LACTIC ACID, when digested upon lead for several days, dissolves it. The solution has a sweet and astringent taste, and does not crystallize [‖].

Sp. 20. *Suberate of Lead.*

SUBERIC ACID precipitates lead from the acetic and nitric acids [¶].

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[*] Wenzel's *Verwandtschaft*, p. 184.

[†] Scheele, ii. 80.

[‡] Scheele, Crell's *Annals*, ii. 7. Eng. Transl.

[§] *Ann. de Chim.* xxxv. 155.

[‖] Scheele, ii. 166.

[¶] Bouillon Lagrange, *Ann. de Chim.* xxiii. 48.

IV. Metallic Salts.

Sp. 21. *Arseniate of Lead.*

Arsenic acid attacks lead in a digesting heat, communicates a portion of its oxygen, and converts it into arseniate of lead in the state of an insoluble white powder. When arsenic acid is poured into the solution of lead in nitric, muriatic, or arsenic acids, arseniate of lead precipitates in powder. When this salt is heated it melts; and if charcoal be thrown into the mass while in fusion, arsenic is volatilized, and the lead is reduced; the charcoal abstracting the oxygen from both of the component parts of the salt.

Arseniate of lead is completely insoluble in water. It has been found native. According to the analysis of Chenevix and Thenard, its constituents are as follows:

	*	†
Acid	33	35·7
Yellow oxide	63	64·3
Water	4	
Total	100	100

Sp. 22. *Molybdate of Lead.*

The action of molybdic acid on lead has not been

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* Chenevix, *Phil. Trans.* 1801, p. 199.

† Thenard, *Ann. de Chim.* l. 123.

tried; but Scheele ascertained, that when dropt into the solution of lead in nitric or muriatic acid, molybdate of lead was immediately precipitated [*]. The precipitate from nitric acid is redissolved by adding nitric acid [†].

This salt occurs native in Carinthia. Its composition was first detected by Klaproth. It has a yellow colour, and is completely insoluble in water. Its specific gravity is 5·706 [‡]. Its crystals are cubic or rhomboidal plates. When heated, it decrepitates and melts into a yellowish mass. It is soluble in fixed alkalies and in nitric acid. Muriatic acid decomposes it by the assistance of heat, and carries off the lead. According to the analysis of Klaproth, it is composed of about

34·7	acid
65·3	oxide
100·0 [§]	

Sp. 23. *Tungstate of Lead.*

Nitrated tungstate of potash occasions a white precipitate in nitrate of lead [‖].

Sp. 24. *Chromate of Lead.*

This salt may be formed by mixing together the solutions of nitrate of lead and an alkaline chromate. The chromate of lead, in that case, precipitates in the state of a red powder; but it exists native, and is indeed the compound from which chromic acid is usually obtained.

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[*] Scheele, i. 246.

[†] Hatchett, *Phil. Trans.* 1796.

[‡] Ibid.

[§] *Beitrage*, ii. 275.

[‖] Scheele, ii.

Its colour is red with a shade of yellow; and its crystals are four-sided prisms, sometimes terminated by four-sided pyramids. Its specific gravity is about 6. It is insoluble in water, but soluble in the fixed alkalies without decomposition. Nitric acid also dissolves it; but muriatic and sulphuric acids decompose it, precipitating the lead in the state of muriate or sulphate. According to the analysis of Vauquelin, it is composed of

about................	34·9 acid
	65·1 oxide
	100·0 *

V. TRIPLE SALTS.

Sp. 25. *Tartrate of Potash-and-Lead.*

THIS triple salt may be formed by boiling tartar and oxide of lead together in water. Thenard informs us that it is insoluble, and that it is neither decomposed by alkalies nor by sulphates †.

Sp. 26. *Muriate of Ammonia-and-Lead.*

THIS triple salt may be formed by mixing together the solutions of muriate of ammonia and muriate of lead, or by boiling muriate of ammonia on oxide of lead. The solution yields no precipitate when mixed with sulphuric acid; but the alkaline carbonates throw down the lead ‡.

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* *Jour. de Min.* No. xxxiv. p. 790.

† Thenard, *Ann. de Chim.* xxxviii. 36.

‡ Ibid. xlii. 218.

Book II. Division III.

Sp. 27. *Muriate of Lead-and-Tin.*

THIS salt, first pointed out by Berthollet junior, may be obtained by digesting muriate of tin on the oxide of lead. It is formed also when muriate of tin is mixed with a greater proportion of acetate of lead than it is capable of dissolving. It crystallizes in thin scales of a pearly lustre, and so soft that they easily run together into a shapeless mass. This salt contains a greater proportion of lead than the muriate of that metal does *.

GENUS XIII. SALTS OF NICKEL.

THE scarcity of nickel, and the difficulty of obtaining it in a state of purity, have hitherto prevented the possibility of an accurate examination of the combinations which its oxide forms with acids. The salts of nickel, therefore, are at present but very imperfectly known. They may be distinguished by the following properties:

Characters.

1. Its salts are in general soluble in water, and the solution has a beautiful green colour.

2. Triple prussiate of potash, when dropt into these solutions, occasions a precipitate of a dull green colour.

3. The hydrosulphuret of potash occasions a black precipitate.

4. Sulphureted hydrogen gas occasions no precipitate.

5. Gallic acid, and the infusion of nutgalls, occasion a greyish white precipitate.

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* *Statique Chimique*, ii. 465.

Sp. 1. *Nitrate of Nickel.*

NITRIC ACID dissolves nickel or its oxide when assisted by heat. The solution has a green colour, and yields by evaporation nitrate of nickel in the form of rhomboidal crystals, which, on exposure to the air, at first deliquesce, but afterwards fall to powder, and gradually lose their acid, so that only the oxide of nickel remains behind *. The nitrate of nickel contains the protoxide of that metal. If it be distilled cautiously, a subnitrate may be obtained insoluble in water, and composed, according to the analysis of Proust, of

nickel	100	125
oxygen	25	
acid		17
		142 †

The nitrate of nickel, according to the same chemist, is composed of

55	acid
25	oxide
20	water
100	

Sp. 2. *Muriate of Nickel.*

MURIATIC ACID scarcely attacks pure nickel, especially if it has been hammered. The best solvent is nitromuriatic acid ‡. The solution, which has a green colour, yields when evaporated irregular crystals of mu-

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* Bergman, ii. 268.

† *Ann. de Chim.* lx. 273.

‡ Richter, Gehlen's *Jour.* iii. 257.

riate of nickel, which are decomposed by heat and by long exposure to the air, though at first they deliquesce like nitrate of nickel *.

The colour of this salt is apple-green. It stains paper yellow. When heated it loses 55 *per cent.* of water, and is converted into a yellow anhydrous muriate, which becomes green by absorbing water when exposed to the air. When heated sufficiently in a glass retort, that portion only which is in contact with the glass is decomposed; the rest sublimes in golden yellow flowers, which gradually absorb water and become green. Muriatic acid dissolves them with difficulty.

This salt, according to Proust, is composed of about

34	oxide
11	acid
55	water
100 †	

Sp. 3. *Sulphate of Nickel.*

Sulphuric acid scarcely attacks pure nickel, though it dissolves it when contaminated with other metals. The solution is of a beautiful green colour, and yields by evaporation long six-sided prismatic crystals of the sulphate, terminated by irregular pyramids. This salt is very soluble in water. The crystals effloresce in the air, and become opaque ‡. When strongly heated in a coated retort, it is partly reduced to the state of insolu-

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* Bergman, ii. 268.

† *Ann. de Chim.* lx. 273.

‡ Proust, *Jour. de Phys.* xlvii. 172.

ble subsulphate. According to the analysis of Proust, this salt is composed of 35 oxide

19 acid

46 water

100[*]

Sp. 4. *Phosphate of Nickel.*

Phosphoric acid is capable of dissolving only a very small portion of the oxide of nickel. The solution does not yield crystals, and has scarcely even a green colour[†]. Hence it would seem that the phosphate of nickel is nearly insoluble.

Sp. 5. *Carbonate of Nickel.*

It does not appear from the experiments of Bergman, that carbonic acid is capable of combining with nickel directly. When 100 parts of pure nickel are dissolved in nitric acid, and precipitated by carbonate of potash, the precipitate weighs when dried 293 parts; but when heated to redness it becomes 128. Hence carbonate of nickel must be composed of

56·4 acid and water

43·6 oxide

100·0[‡]

According to Proust the oxide amounts to 54 *per cent.* in this salt[§].

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[*] *Ann. de Chim.* lx. 274.

[†] Bergman, ii. 268.

[‡] Richter, Gehlen's *Jour.* iii. 258.

[§] *Ann. de Chim.* lx. 276.

Sp. 6. *and* 7. *Fluate and Borate of Nickel.*

Fluoric acid dissolves nickel with difficulty, and the solution yields light green-coloured crystals *.

Boracic acid can only be combined with nickel by mixing an alkaline borate with a solution of nickel in some acid.

Sp. 8. *Acetate of Nickel.*

Acetic acid dissolves nickel, and forms with its oxide rhomboidal crystals of a very green colour †.

Sp. 9. *Oxalate of Nickel.*

Oxalic acid attacks nickel at a digesting heat, and a greenish white powder is deposited, which is the oxalate of that metal. The same salt is precipitated when oxalic acid is dropt into the solution of nickel in sulphuric, nitric, or muriatic acids. It is scarcely soluble in water, and is composed, according to Bergman, of two parts of acid to one of metal ‡.

Sp. 10. *Tartrate of Nickel.*

Tartaric acid does not attack nickel §. The compound which it forms with its oxide has not been examined. Neither are we acquainted with any of the remaining species of the combustible salts of nickel.

Sp. 11. *Arseniate of Nickel.*

Arsenic acid does not appear capable of dissolving

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* Bergman, ii. 268.

† Ibid.

‡ Ibid. p. 269.

§ Ibid.

pure nickel. The arseniate of this metal is soluble in water. Hence nickel is not precipitated from its solutions either by arsenic acid or the arseniates*. This arseniate has an apple-green colour. When heated in a glass tube it loses its colour with its water and becomes hyacinth coloured and transparent. When heated to redness it becomes bright yellow and remains unaltered†.

Sp. 12. *Molybdate of Nickel.*

MOLYBDIC ACID precipitates nitrate of nickel white, provided there be no excess of nitric acid ‡.

Sp. 13. *Sulphate of Nickel-and-Potash.*

THIS salt was first described by Proust, who availed himself of its properties as a means to separate nickel and cobalt; a problem which has long occupied the attention of chemists §. It may be formed by dropping potash into a solution of sulphate of nickel. By evaporation the triple salt is obtained in crystals. It is sparingly soluble in water. The crystals are transparent rhomboids of a beautiful emerald colour. By dissolving this salt

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* The precipitates mentioned by Bergman and Scheele, as appearing when solutions of nickel were mixed with arseniate of potash, were doubtless arseniate of bismuth; for that metal is usually present in solutions of impure nickel.

† Proust, *Ann. de Chim.* lx. 278.

‡ Hatchett, *Phil. Trans.* 1796.

§ The most elegant method of separating these two metals seems to be that of Thenard. The mixture of the two metals is to be thrown down by an alkaline carbonate, and then treated with oxymuriate of lime. The cobalt is converted into a peroxide insoluble in ammonia, but the nickel is still soluble. Digest in ammonia. The nickel alone is taken up. Drive off the ammonia; dissolve the oxide in nitric acid, and crystallize. *Ann. de Chim.* l. 117.

in water, and crystallizing it repeatedly, the sulphate of cobalt is left behind in the mother water, being much less disposed to crystallize than the triple salt of nickel. The taste of the sulphate of nickel-and-potash is sweet like that of sugar of milk; but it leaves in the mouth a sensible acridity *.

When this salt is heated it loses 24 *per cent.* of water. It contains only 15 *per cent.* of oxide of nickel †.

Sp. 14. *Sulphate of Nickel-and-Ammonia.*

When ammonia is poured into the solution of sulphate of nickel, another triple salt is formed, which yields by evaporation crystals of a green colour, consisting of four-sided flat prisms terminated by four-sided pyramids ‡.

Sp. 15. *Sulphate of Nickel-and-Iron.*

This salt may be obtained by mixing together the solutions of nitrate of nickel and sulphate of iron, and evaporating the mixture; or by dissolving at once the oxides of nickel and iron in sulphuric acid. The salt crystallizes in tables; its colour is green: and it effloresces when exposed to the atmosphere §.

Sp. 16. *Nitrate of Nickel-and-Ammonia.*

This triple salt, first pointed out by Thenard, is obtained by adding ammonia in excess to the nitrate of nickel. By evaporation a green coloured salt is ob-

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* Proust, *Jour. de Phys.* xlvii. 169.

† Proust, *Ann. de Chim.* lx. 274.

‡ Link, Crell's *Annals*, 1796, i. 32.

§ Ibid. i. 31.

tained in crystals. The solution of this salt in water is not rendered turbid by alkalies; but the nickel is thrown down by hydrosulphurets [*].

Sp. 17. *Sulphate of Nickel-Copper-and-Iron.*

THIS salt is said by Link to be formed when the solution of nickel in nitric acid is mixed with sulphate of copper. It crystallizes, according to him, in blue-coloured prisms terminated by four-sided pyramids, and when exposed to the air falls to powder; but his experiments would require to be verified by repetition [†].

GENUS XIV. SALTS OF ZINC.

ALMOST all the acids act with energy on zinc, in consequence of the strong affinity which it has for oxygen. The salts of zinc, therefore, are very easily formed; and as the peroxide only seems to combine with acids, they are not liable to change their state, like the salts of iron and tin. They may be distinguished by the following properties:

Characters.

1. The greater number of them are soluble in water, and the solution is colourless and transparent.

2. Triple prussiate of potash occasions a white precipitate when dropt into these solutions.

3. Hydrosulphuret of potash and sulphureted hydrogen gas occasion a white precipitate.

4. Gallic acid and the infusion of nutgalls occasion no precipitate when dropt into these solutions.

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[*] *Ann. de Chim.* xlii. 217.

[†] Link, Crell's *Annals*, 1796. i. 31.

5. Alkalies occasion a white precipitate, which is readily dissolved by sulphuric or muriatic acid.

6. Zinc is not precipitated in the metallic form by any of the other metals.

I. Detonating Salts.

Sp. 1. *Nitrate of Zinc.*

Nitric acid attacks zinc with prodigious violence, and has been said even to inflame it. It is necessary to moderate its action by using it in a diluted state: even then considerable heat is evolved, and a strong effervescence is occasioned by the escape of nitrous oxide gas.

The solution is transparent and colourless, very caustic, and yields by evaporation flat striated tetrahedral prisms, terminated by four-sided pyramids. The specific gravity of these crystals is 2·096 *. They attract moisture when exposed to the air. They are soluble both in water and alcohol. When heated they melt and detonate on burning coals, emitting a red flame. When distilled, they emit red vapours of nitrous acid, and assume a gelatinous form. In a strong heat they are decomposed completely, giving out nitrous gas and oxygen gas.

II. Incombustible Salts.

Sp. 2. *Muriate of Zinc.*

Muriatic acid dissolves zinc rapidly, and with ef-

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* Hassenfratz, *Ann. de Chim.* xxviii. 12.

fervescence, owing to the emission of hydrogen gas. The solution is colourless; and, when evaporated, does not crystallize, but assumes the form of a jelly. When distilled, a little of its acid separates, and muriate of zinc remains behind in a solid mass, easily fusible. It was formerly known by the name of *butter of zinc*. When heated, it sublimes, and is obtained in a mass of a fine white colour, composed of small needles. Its specific gravity is 1·577[†]. It is very soluble in water; and when exposed to the air gradually attracts moisture, and assumes a gelatinous consistence. Sulphuric acid decomposes it, and the alkalies precipitate the oxide of zinc from its solution [‡].

Sp. 3. *Sulphate of Zinc.*

CONCENTRATED sulphuric acid scarcely acts upon zinc without the assistance of heat; but if it be sufficiently diluted with water, it attacks the metal with force; hydrogen gas is emitted, and the zinc is very speedily dissolved. In this case the water is decomposed; its oxygen combines with the metal, while its hydrogen is exhaled. When the solution is sufficiently concentrated by evaporation, it yields the sulphate of zinc in crystals.

History.

This salt, according to the best accounts, was discovered at Ramelsberg, in Germany, about the middle of the 16th century. Many ascribe the invention to Julius Duke of Brunswick. Henkel and Neumann were the first chemists who proved that it contained zinc; and Brandt first ascertained its composition com-

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[†] Hassenfratz, *Ann. de Chim.* xxviii. 13.

[‡] Fourcroy, v. 383.

pletely *. It is generally formed for commercial purposes from sulphureted zinc, or blende as it is called by mineralogists. This ore is roasted, which converts the sulphur into an acid; it is then dissolved in water, and concentrated so much that, on cooling, it crystallizes very rapidly, and forms a mass not unlike loaf-sugar. This salt is usually called *white vitriol.* It is almost always contaminated with iron, and often with copper and lead. Hence the yellow spots which are visible on it, and hence also the reason that its solution in water lets fall a dirty brown sediment; a circumstance very much complained of by surgeons when they use that solution in medicine. It may be easily purified by dissolving it in water, and putting into the solution a quantity of zinc filings; taking care to agitate it occasionally. The zinc precipitates the foreign metals, and takes their place. The solution is then to be filtered, and the sulphate of zinc may be obtained from it in crystals by proper evaporation.

Varieties.

There are two varieties of this salt, the *sulphate* and *supersulphate*. The sulphate crystallizes in rhomboids, differing very little from cubes †. It is colourless and perfectly transparent; its fracture is vitreous, and it resembles flint glass in its appearance. Its properties have scarcely been examined.

The supersulphate is the salt which usually occurs in commerce, and which has been described by chemists.

Its crystals are four-sided flat prisms, terminated by

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* Beckman's *History of Inventions*, art. *Zinc.*

† Leblanc, *Jour. de Phys.* lv. 301.

quadrangular pyramids. Two opposite edges of the prism are commonly replaced by small faces, which renders the prisms six-sided *. Its specific gravity when crystallized is 1·912; when in the state in which it commonly occurs in commerce, it is 1·3275 †. At the temperature of 60°, water dissolves 1·4 times its weight of it. Boiling water dissolves any quantity whatever. When heated, it melts and speedily loses its water of crystallization, and, in a high temperature, loses most part of its acid.

Composition.

The constituents of this salt are, according to

Bergman,	Kirwan,	
40	20·5	acid
20	40·0	oxide
40	39·5	water
100 ‡	100·0 §	

According to Mr Smithson, the salt deprived of its water, or the *arid* salt, as he terms it, is composed of

50	acid
50	oxide
100 ‖	

The great difference obvious in these different analyses is probably owing in part to chemists having hitherto confounded together the two varieties of this salt. A specimen of the pure supersulphate, analysed in my la-

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* Bergman, ii. 327.

† Hassenfratz, *Ann. de Chim.* xxviii. 12. According to Dr Watson 1·933, (*Essays*, v. 67.)

‡ Bergman, ii. 328.

§ Kirwan on *Mineral Waters*, Table IV.

‖ *Phil. Trans.* 1803, p. 21.

boratory, was found to approach in its composition to the supersulphate of Smithson. Its constituents were

28·2 oxide
25·8 acid
46·0 water

100·0

In this analysis the oxide and acid were separated and weighed; the first by means of an alkali; the second by muriate of barytes. The proportion of water was merely inferred. When the salt is heated to redness it loses 68·7 *per cent.* of its weight. Hence the residue contains very little acid.

When a solution of this salt is digested for a long time with filings of zinc, it is partly decomposed, and an abundant flesh coloured precipitate, consisting of protoxide of zinc, is obtained.

Sp. 4. *Sulphite of Zinc.*

HITHERTO the combinations which the sulphurous acid forms with metallic oxides have been examined only by Berthollet, and Fourcroy and Vauquelin. To these chemists we are indebted for the discovery, that the greater number of metallic sulphites are capable of combining with a quantity of sulphur, and of forming a *sulphureted sulphite.* This is the case in a remarkable degree with the sulphite of zinc.

1. *Sulphureted Sulphite.* Sulphurous acid attacks zinc with considerable violence, heat is produced, and sulphureted hydrogen gas is exhaled. The solution has an acrid, astringent, sulphureous taste. When exposed to the air, it becomes thick like honey, and deposites long slender crystals in the form of four-sided prisms,

terminated by four-sided pyramids. These are crystals of *sulphureted sulphite of zinc*, as Fourcroy and Vauquelin have proved. They are soluble in water and in alcohol. When exposed to the air they become white, and deposite a white insoluble powder. Before the blowpipe the salt swells, emits a brilliant light, and forms dendritical ramifications. When distilled, it yields water, sulphurous acid, sulphuric acid, and sulphur; and there remain behind oxide of zinc and a little sulphate of that metal. Sulphuric, nitric, and muriatic acids, when poured into its solution in water, drive off the sulphurous acid, while a quantity of sulphur precipitates. The theory of the formation of this salt is obvious. During the solution of the zinc, both water and sulphurous acid were decomposed; the oxygen of both combined with the metal; the hydrogen escapes combined with a portion of the sulphur of the decomposed acid, and the rest of the sulphur combines with the sulphite as it forms.

2. *Sulphite of Zinc.* Sulphurous acid dissolves the oxide of zinc with the evolution of heat, but without effervescence. The solution yields crystals of sulphite of zinc. These crystals have a less acrid, but more styptic taste than sulphureted sulphite. They are less soluble in water, and more easily crystallized. They are insoluble in alcohol. When exposed to the air, they are very soon changed into sulphate of zinc; whereas the sulphureted sulphite remains long unchanged.

When a mixture of sulphur and white oxide of zinc is treated with sulphurous acid, the product is a sulphureted sulphite *.

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* Fourcroy, v. 380.

Book II. Division III.

Sp. 5. Phosphate of Zinc.

PHOSPHORIC ACID attacks zinc with effervescence and dissolves it completely. The solution does not yield crystals, but leaves, when evaporated, a mass not unlike gum arabic, which before the blow-pipe melts into a transparent glass. The alkalies precipitate a white powder from this solution, which is a subphosphate of zinc, melting in a red heat to a semi-transparent glass*.

When phosphoric acid and zinc are melted together, the zinc is oxidized, and phosphorus evolved †.

Sp. 6. Carbonate of Zinc.

LIQUID CARBONIC ACID, confined in a vessel with zinc, or its oxide reduced to the state of a fine powder, dissolves a considerable portion of it; and the solution, when exposed to the air, is gradually covered with an iridescent pellicle of oxide of zinc ‡. The carbonate of zinc may be obtained in the state of a white powder, by precipitating zinc from its solution in acids by means of an alkaline carbonate.

Bergman first ascertained by analysis that this salt occurs native under the name of *calamine*; but his inferences were disputed by mineralogists, and considered by most as erroneous. Yet they have been lately fully confirmed by the precise analysis of Mr Smithson, who has demonstrated that different substances have been confounded under the name of calamine, and among others the carbonate of zinc.

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* Wenzel's *Verwandtschaft*, p. 172.

† Gren's *Handbuch*, iii. 600.

‡ Bergman, i. 35.

Composition.

According to the analysis of Bergman, native carbonate of zinc is composed of 28 acid
66 oxide
6 water

100[*]

From the analysis of Mr Smithson, it follows that *arid* carbonate is composed of 1 acid
2 oxide

3[†]

When water is present, the proportion of the other constituents still continues the same. Mr Smithson has shown, that the water in that case is combined with the oxide of zinc, constituting a hydrate, which is composed of..............................3 oxide
1 water

4[‡]

Sp. 7. *Fluate of Zinc.*

Fluoric acid attacks zinc with violence, hydrogen gas is emitted, and the metal is oxidized and dissolved. The properties of the fluate thus formed have scarcely been examined[§]. The salt is said not to crystallize.

Sp. 8. *Borate of Zinc.*

Boracic acid scarcely attacks zinc; but it combines with its oxide, and forms with it an insoluble *borate of zinc.* This salt may be precipitated in a white

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[*] *Opusc.* ii. 326.

[†] *Phil. Trans.* 1803, p. 23.

[‡] Ibid.

[§] Scheele, i. 35

powder, by pouring borate of soda into the nitrate or muriate of zinc; or by mixing boracic acid with liquid sulphate of zinc. When strongly heated, this borate becomes yellow, and is at last converted into an opaque slag *.

III. COMBUSTIBLE SALTS.

Sp. 9. *Acetate of Zinc.*

ACETIC ACID readily dissolves zinc, and yields by evaporation crystals of acetate of zinc, which were first mentioned by Glauber. This salt has a bitter metallic taste. Its crystals are rhomboidal or hexagonal plates, of a talky appearance. It is not altered by exposure to the air; it is soluble in water. When thrown upon live coals, it burns with a blue flame. When distilled, it yields water, an inflammable liquid, and some oil, and towards the end of the process oxide of zinc sublimes †.

This salt has been lately recommended by Dr Henry as an excellent application in cases of inflammation.

Sp. 10. *Succinate of Zinc.*

SUCCINIC ACID dissolves zinc with effervescence; and the solution yields long slender foliated crystals, the properties of which have not been examined ‡.

Sp. 11. *Benzoate of Zinc.*

ZINC is readily dissolved by benzoic acid. The so-

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* Wenzel's *Verwandtschaft*, p. 251.

† Monnet.

‡ Wenzel's *Verwandtschaft*, p. 240.

lution yields needle-shaped crystals, which are soluble in water and alcohol. When exposed to heat, their acid is volatilized [*].

Sp. 12. *Oxalate of Zinc.*

OXALIC ACID attacks zinc with a violent effervescence, and a white powder soon subsides, which is oxalate of zinc. The same salt is precipitated when oxalic acid is dropt into the solution of sulphate, nitrate, or muriate of zinc. It contains 75 *per cent.* of metal. This salt is scarcely soluble in water, unless there be an excess of acid [†].

Sp. 13. *Tartrate of Zinc.*

TARTARIC ACID attacks zinc with effervescence, and forms with it a salt difficultly soluble in water, the properties of which have not been examined [‡].

Sp. 14. *Citrate of Zinc.*

CITRIC ACID attacks zinc with effervescence, and gradually deposites small brilliant crystals of citrate of zinc. They are insoluble in water, and have a styptic and metallic taste. They are composed of

50 acid
50 oxide

100 [§]

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[*] Trommsdorf, *Ann. de Chim.* xi. 317.

[†] Bergman, i. 271.

[‡] Dijon Academicians.

[§] Vauquelin, *Fourcroy*, vii. 209.

Sp. 15. *Malate of Zinc.*

Malic acid dissolves zinc, and yields by evaporation beautiful crystals of malate of zinc *.

Sp. 16. *Lactate of Zinc.*

Lactic acid dissolves zinc with effervescence, and the salt formed is capable of crystallizing †.

IV. Metallic Salts.

Sp. 17. *Arseniate of Zinc.*

When arsenic acid is poured upon zinc, an effervescence ensues, arsenical hydrogen gas is emitted, and a black powder precipitates, which is arsenic in the metallic state. Hence we see that the zinc deprives both a portion of water and of arsenic acid of their oxygen. When one part of zinc filings and two parts of dry arsenic acid are distilled in a retort, a violent detonation takes place when the retort becomes red, occasioned by the sudden absorption of the oxygen of the acid by the zinc. The arseniate of zinc may be precipitated by pouring arsenic acid into the acetate of zinc, or by mixing the solution of the alkaline arseniates with the sulphate of zinc. It is a white powder, insoluble in water ‡.

Sp. 18, 19, *and* 20.

By the same process may the tungstate, molybdate,

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* Scheele, Crell's *Annals*, ii. 10. Eng. Trans.

† Scheele, ii. 65.

‡ Ibid. i. 181.

and chromate of zinc be obtained. They also are insoluble in water: the first two are white, the last of an orange-red colour.

V. TRIPLE SALTS.

Sp. 21. *Muriate of Ammonia-and-Zinc.*

WHEN muriate of ammonia is boiled upon the white oxide of zinc, a considerable portion is dissolved; but as the solution cools, a portion of the oxide is again deposited. What remains of the solution is neither thrown down by alkalies nor their carbonates. This triple salt does not crystallize [*].

Sp. 22. *Tartrate of Potash-and Zinc.*

THIS salt may be formed by boiling together tartar and zinc filings and water. It is very soluble in water, and not easily crystallized. No precipitation is produced in its solution by the alkalies or their carbonates [†].

Sp. 23. *Sulphate of Zinc-and-Iron.*

THIS salt may be obtained by mixing together the solutions of sulphate of iron and of zinc, or by dissolving iron and zinc together in diluted sulphuric acid. It crystallizes in rhomboids which have nearly the figure of sulphate of zinc, but its colour is a pale green. Its taste and solubility are nearly the same as those of sulphate of zinc. It contains a much greater proportion of zinc than iron.

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[*] Thenard, *Ann. de Chim.*

[†] Dijon Academicians; and Thenard, *Ann. de Chim.* xxxviii. 35.

Sp. 24. *Sulphate of Zinc-and-Cobalt.*

THIS salt, first pointed out by Link, may be obtained by digesting zafre in sulphate of zinc. Large four-sided prisms are obtained by evaporation, which effloresce when exposed to the air *.

GENUS XV. SALTS OF BISMUTH.

THE salts of bismuth have not been examined with much attention by chemists; indeed bismuth and its combinations have been hitherto very much neglected. These salts may be distinguished by the following properties:

Characters.

1. The solution of bismuth in acids is usually colourless. When water is poured into it, a white precipitate immediately falls, consisting chiefly of the white oxide of bismuth.

2. Triple prussiate of potash occasions in these solutions a precipitate of a white colour, sometimes with a shade of yellow.

3. Hydrosulphuret of potash and sulphureted hydrogen occasion a black precipitate.

4. Gallic acid and the infusion of nutgalls occasion an orange-coloured precipitate.

5. When a plate of copper or tin is put into the solution of bismuth, this last metal is often precipitated in the metallic state.

Sp. 1. *Nitrate of Bismuth.*

NITRIC ACID, when concentrated, attacks bismuth

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* Crell's *Annals*, 1796, i. 32.

with great violence, a vast quantity of nitrous gas is emitted, the metal is converted into a white oxide, much heat is evolved, and sometimes even sparks of fire, it is said, are darted out of the mixture. When the acid is diluted, the action is less violent, and the oxide of bismuth is dissolved as it forms. The solution is colourless; and on cooling lets fall crystals of a white colour, and generally attached to each other in the form of stars. They are small four-sided prisms, often terminated by four-sided summits.

This salt, when exposed to the air, attracts a little moisture, and its surface is covered with a crust of white oxide. On burning coals it detonates feebly, emitting red sparks, and leaves a yellowish powder not easily reduced. When triturated with phosphorus it detonates loudly [*]. When put into water it is immediately decomposed; that liquid absorbing its acid, and leaving the white oxide of bismuth combined with a small portion of acid. Hence the reason, that when we write upon paper with a solution of bismuth in nitric acid, the characters, at first invisible, become white when the paper is plunged into water, as Brugnatelli first observed [†].

When the solution of bismuth in nitric acid is diluted with water, the greatest part of the metal separates in the state of a subnitrate. In this state it was formerly known by the name of *magistery of bismuth*.

The paint called *pearl white*, frequently used as a cosmetic, is said to be precipitated from the nitrate of bismuth by means of common salt or tartar. Hence, in

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[*] Brugnatelli, *Ann. de Chim.* xxvii. 73.

[†] Ibid. iii. 296.

all probability, it is a submuriate or a tartrate of bismuth, according to circumstances *.

Sp. 2. *Muriate of Bismuth.*

Muriatic acid has scarcely any action on bismuth while cold; but when distilled off that metal previously reduced to powder, it gradually oxidizes, and brings it to the state of a white powder. Muriate of bismuth may be readily formed by dissolving the metal in nitromuriatic acid, or in oxy-muriatic acid. When the solution is evaporated, it is said to yield small prismatic crystals. The muriate of bismuth, when evaporated to dryness, sublimes by the application of a moderate heat, and forms a thick concrete mass, readily melting when heated, formerly known by the name of *butter of bismuth*. It was prepared also by distilling a mixture of two parts of oxymuriate of mercury and one part of bismuth: an amalgam of bismuth remains in the retort, while the *butter*, as it was called, sublimes †.

Sp. 3. *Sulphate of Bismuth.*

Sulphuric acid has no action on bismuth while cold; but by the assistance of heat it converts that metal into a white oxide, while at the same time sulphurous acid is exhaled, and even sulphur sublimed, if the heat be considerable. When the saline mass, thus formed, is washed with water, almost the whole of the acid is separated, carrying along with it a very small portion of the oxide; and this lixivium yields, by evaporation, small crystals in needles, which are decomposed, and

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* Black's *Lectures*, ii. 595.

† Pott, *Mem. Par.* 1713.

their base precipitated when any attempt is made to dissolve them in water.

Sp. 4. Sulphite of Bismuth.

SULPHUROUS ACID does not attack bismuth; but it combines with its oxide, and forms with it a salt insoluble in water even when assisted by an excess of acid. It has a sulphureous taste; and before the blowpipe melts into a reddish-yellow mass, which is soon reduced upon charcoal. When distilled, the acid is driven off, and the whole oxide remains in a state of purity *.

Sp. 5. Phosphate of Bismuth.

PHOSPHORIC ACID does not attack bismuth; but it combines with its oxide recently precipitated by an alkali. One portion of the salt formed remains in the state of an insoluble white powder; another portion is dissolved, and yields crystals, which do not deliquesce, and are soluble in water †. The white insoluble powder is most probably a subphosphate, and the crystals a superphosphate of bismuth.

Sp. 6, 7, 8. Carbonate, Fluate, Borate.

THE combinations which the oxide of bismuth forms with carbonic, fluoric, and boracic acids, have not hitherto been examined with accuracy. They may be formed by pouring into the solution of bismuth in nitric acid the alkaline carbonates, fluates, or borates. The salts required precipitate in the state of a white powder.

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* Fourcroy, v. 204.

† Wenzel's *Verwandtschaft*, p. 177.

Sp. 9. *Acetate of Bismuth.*

Acetic acid has but little action on bismuth; but the acetate of bismuth may be obtained by mixing together the solutions of nitrate of bismuth and acetate of potash. When the mixture is heated, it redissolves the precipitate which had at first formed, and at the same time yields a number of thin talky crystals resembling boracic acid. Morveau, to whom we are indebted for this experiment, has ascertained also, that the addition of acetic acid deprives nitrate of bismuth of the property of affording a precipitate when diluted with water *.

Sp. 10. *Succinate of Bismuth.*

Succinic acid does not attack bismuth; but it dissolves its oxide at a boiling temperature, and the solution yields yellow crystalline plates of succinate of bismuth. According to Wenzel, the solution of this salt in water does not yield a precipitate with alkalies. It dissolves in nitric acid, and the solution is not precipitated by water †.

Sp. 11. *Benzoate of Bismuth.*

Benzoic acid dissolves the oxide of bismuth with facility; and the solution yields white needle-shaped crystals, which are not altered by exposure to the air, are soluble in water, and very sparingly soluble in alcohol. Sulphuric and muriatic acids decompose this salt, and heat volatilizes its acid ‡.

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* *Encycl. Method. Chim.* i. 10.

† Wenzel's *Verwandtschaft*, p. 243.

‡ Trommsdorf, *Ann. de Chim.* xi. 317.

Sp. 12. *Oxalate of Bismuth.*

Oxalic acid scarcely attacks bismuth; but it combines with its oxide, and forms with it an oxalate in the state of a white powder, scarcely soluble in water. When oxalic acid is dropt into nitrate of bismuth, small transparent polygonous grains are gradually precipitated, which possess the same properties as the white powder, and do not become opaque when put into water *.

Sp. 13. *Tartrate of Bismuth.*

Tartaric acid does not attack bismuth; but when dropt into the solution of that metal in sulphuric, nitric, or muriatic acids, tartrate of bismuth precipitates in the state of a white crystalline powder insoluble in water †.

Sp. 14. *Arseniate of Bismuth.*

Arsenic acid oxidizes bismuth by a digesting heat; and the metal is covered with a white powder, which is arseniate of bismuth. Part also of the arseniate remains in solution, but the oxide is precipitated by the addition of water. The arseniate of bismuth precipitates when arsenic acid is poured into the nitrate of bismuth. The white powder thus obtained is difficultly fusible; but when heated with charcoal, arsenic sublimes, and the bismuth is reduced ‡.

Arseniate of bismuth is a white powder, often having a shade of green; it is tasteless, insoluble in water and

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* Bergman, i. 261.

† Gren's *Handbuch*, iii. 300.

‡ Scheele, i. 84.

nitric acid, but soluble in muriatic acid[*]. When heated upon charcoal, the smell of arsenic becomes perceptible. From the solution in muriatic acid, the bismuth is precipitated by sulphureted hydrogen.

Sp. 15. *Molybdate of Bismuth.*

MOLYBDIC ACID precipitates muriate of bismuth white, provided there be no excess of acid[†].

GENUS XVI. SALTS OF ANTIMONY.

ANTIMONY is one of those metals whose oxides seem to combine with difficulty, and to form compounds of little permanency with acids, unless there be present at the same time an alkali or an earth. This renders the investigation of the antimonial salts peculiarly difficult, and accounts for the little progress which has been made in it. Antimonial salts may be distinguished by the following properties:

Characters.

1. Their solutions are usually of a brownish yellow colour, and in most cases a white precipitate falls when they are diluted with water.

2. Triple prussiate of potash occasions a white precipitate when dropt into these solutions. This precipitate is merely the oxide of the metal precipitated by the water of the prussiate. When applied sufficiently concentrated, or in crystals, no precipitation takes place. In this property antimony agrees with platinum[‡].

3. Hydrosulphuret of potash occasions an orange-coloured precipitate.

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[*] Thenard, *Ann. de Chim.* l. 120.

[†] Hatchett.

[‡] Klaproth, Crell's *Annals*, 1798. i. 99.

4. Gallic acid and the infusion of nutgalls occasion a white precipitate, which is merely the oxide of the metal separated by the water of the infusion.

5. When a plate of iron or zinc is plunged into antimonial solutions, a black powder precipitates in great abundance, and very speedily when there is an excess of acid, and the solution is not too much concentrated.

I. DETONATING SALTS.

Sp. 1. *Nitrate of Antimony.*

NITRIC ACID attacks antimony slowly. Both the acid and water are decomposed, abundance of nitrous gas is emitted, and a considerable portion of ammonia is formed, and combines with the acid, while the metal is converted into an insoluble white oxide. A portion of the oxide is dissolved; but it does not yield crystals, and readily precipitates when the acid is diluted.

II. INCOMBUSTIBLE SALTS.

Sp. 2. *Muriate of Antimony.*

MURIATIC ACID has no effect upon antimony at first, but the metal is gradually dissolved when it is kept long in contact with that acid. The solution is yellow, and yields by evaporation small needle-form crystals, consisting no doubt of *muriate* of antimony, or of muriatic acid combined with antimony oxidized to a minimum.

Muriatic acid dissolves the oxides of antimony with facility; but it is nitro-muriatic acid which is considered as by far the best solvent of that metal. These solutions may be considered as containing an *oxymuriate* of antimony, or muriatic acid combined with antimony oxidized to a maximum. That salt was formerly known by the name of *Butter of antimony*. It was usually prepared by triturating together one part of antimony and two parts of oxymuriate of mercury, and then distilling them in a retort. At a moderate temperature the oxymuriate of antimony passes over. It is in the state of a thick fatty mass, of a greyish white colour, and often crystallized in four-sided prisms. It is exceedingly caustic, becomes coloured when exposed to the air, and melts at a very moderate temperature. When diluted with water, it is partly decomposed, and the greater part separates in the form of a white powder. In this state it was formerly known by the name of *powder of Algoroth*.

Butter of antimony.

Sp. 3. *Sulphate of Antimony.*

Sulphuric acid has no action on antimony while cold; but at the boiling temperature it oxidizes that metal with effervescence, sulphurous acid is exhaled, and even sulphur sublimed, and there remains in the retort a soft white mass, evidently composed of the peroxide and sulphuric acid. Water carries off the acid and a small portion of the oxide, but leaves the greater part in the state of a white powder. When the solution is evaporated, the remainder of the oxide precipitates, so that the salt cannot be obtained in a crystalline form. The white powder may be considered as a subsulphate of antimony, for it still retains a portion of acid.

Sp. 4. *Sulphite of Antimony.*

Sulphurous acid has no action on antimony while cold, but when hot it changes it into an oxide. The sulphite of antimony is precipitated in the state of an insoluble white powder when sulphurous acid is poured into the solution of antimony in muriatic acid. It has an acrid and astringent taste, melts when heated, and is volatilized and decomposed. When distilled in close vessels, it yields sulphurous acid; and there remains a reddish brown mass, consisting probably of hydro-sulphuret of antimony *.

Sp. 5. *Phosphate of Ammonia.*

Phosphoric acid does not attack antimony; but it combines with its oxide, and even dissolves a small portion of it when assisted by heat. The solution does not crystallize, but yields by evaporation a blackish green mass, which a strong heat converts into a transparent glass †.

Sp. 6. *Carbonate of Antimony.*

Neither antimony nor its oxides are attacked by carbonic acid; neither does the precipitate of that metal weigh more when thrown down by an alkaline carbonate than when by a pure alkali ‡. At present, then, no such salt as carbonate of antimony is known to exist.

Sp. 7. *and* 8. *Fluate and Borate.*

Fluoric acid does not attack antimony, but with its oxide it forms a fluate not hitherto examined. Nei-

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* Fourcroy, v. 231.

† Wenzel's *Verwandtschaft*, p. 178.

‡ Bergman, i. 37. ii. 392.

Book II, Division III.

ther is the metal acted on by boracic acid, but borax precipitates the metal from acids in the state of a white powder *.

III. COMBUSTIBLE.

Sp. 9. Acetate of Antimony.

ACETIC ACID has little or no action on antimony; but it dissolves a small portion of its oxide, as Morveau has shown, and the solution, according to Wenzel, yields small crystals †. This salt is soluble in water, and was employed by Angelus Sala and some subsequent physicians as an emetic ‡.

Sp. 19. Succinate of Antimony.

SUCCINIC ACID does not attack antimony, but it dissolves a portion of its protoxide, and forms a salt which has not been examined.

Sp. 11. Benzoate of Antimony.

BENZOIC ACID readily dissolves the oxide of antimony, and the solution yields crystals, which remain dry when exposed to the air, and are decomposed by heat §.

Sp. 12. Oxalate of Antimony.

OXALIC ACID scarcely attacks antimony; but it dissolves a small portion of its oxide. The solution yields

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* Gren's *Handbuch*, iii. 630.

† *Verwandtschaft*, p. 158.

‡ *Encyc. Method. Chim.* i. 6.

§ Trommsdorf, *Ann. de Chim.* xi. 317.

by evaporation small crystalline grains difficultly soluble in water. The same salt is precipitated by adding oxalic acid to the solution of antimony in acetic or sulphuric acid; but oxalic acid occasions no precipitate in the oxymuriate of antimony *.

Sp. 13. *Tartrate of Antimony.*

Tartaric acid has no action on antimony, but it dissolves a small portion of its oxides. The solution scarcely crystallizes; but easily assumes the form of a jelly †.

IV. Metallic Salts.

Sp. 14. *Arseniate of Antimony.*

When arsenic acid and antimony are digested together, a white powder separates, consisting of arseniate of antimony. This powder is soluble in muriatic acid, and precipitated again by the affusion of water. The alkaline arseniates precipitate the same salt from the solution of antimony in muriatic, tartaric, or acetic acids. When a mixture of one part of antimony and three parts of arsenic acid are distilled in a retort, it enters into fusion, and then takes fire; arsenic is sublimed together with a red mass, and sulphurous acid is exhaled ‡.

Sp. 15. *Molybdate of Antimony.*

Molybdic acid precipitates muriate of antimony white, provided there be no excess of acid §.

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* Bergman, i. 271. † Ibid. ‡ Scheele, i. 184. § Hatchett.

Book II.
Division III.

V. TRIPLE SALTS.

Sp. 16. *Phosphate of Lime-and-Antimony.*

THE well known medicine called *James's powder* has been shown, by the analysis of Dr Pearson, to be a compound of phosphoric acid, lime, and oxide of antimony: we may therefore consider it as a triple salt. It is usually in the form of a white powder, nearly insoluble in water, but partially soluble in acids. The energy with which it acts as an emetic is well known. From Dr Pearson's analysis it appears to be composed of about..........43 phosphate of lime

57 oxide of antimony

100

It may be composed by calcining in a white heat a mixture of equal parts of sulphuret of antimony and the ashes of bones *. Mr Chenevix has given the following easy formula for preparing this powder:

Dissolve in a minimum of muriatic acid equal parts of white oxide of antimony and of phosphate of lime, and pour the solution *into* a sufficient quantity of distilled water, containing pure ammonia in solution. The powder precipitates †.

Mr Chenevix considers this powder not as a compound, but a mechanical mixture, of phosphate of lime and submuriate of antimony.

It is not improbable that James's powder varies in its constituents. M. Pully, an Italian chemist, has lately ublished an analysis of it, different from the prece-

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* *Phil. Trans.* 1791, p. 317.

† *Phil. Mag.* xi. 110.

ding. According to him, its constituents are as follows:

Peroxide of antimony	7
Phosphate of lime	4
Sulphate of potash	4½
Potash holding protoxide of antimony in solution	3½
	19

He gives the following formula for making it, which, according to him, succeeds perfectly. Take of

Sulphuret of antimony	2 parts
Calcined bones	1½
Nitrate of potash	4

Triturate these bodies well together, and heat them strongly in a covered crucible *.

Sp. 17. *Tartrate of Potash-and-Antimony.*

History.

This salt, usually denominated *tartar emetic*, is much more employed in this country as a medicine than all the other antimonial preparations put together. It was first made known by Adrian de Mynsicht in his *Thesaurus Medico-Chymicus*, published in 1631. But the preparation was in all probability suggested by a treatise, entitled *Methodus in Pulverem*, published in Italy in 1620. This book, written by Dr Cornachinus, gives an account of the method of preparing a powder which had been invented by Dudley Earl of Warwick, and which had acquired great celebrity in Italy in consequence of the wonderful cures which it had performed. This powder was composed of scammony, sulphuret of

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* *Ann. de Chim.* lv. 74.

antimony, and tartar, triturated together. The extraordinary effects which it produced would naturally draw the attention of chemists to the combination of antimonial preparations with tartar.

Preparation.

Tartar emetic was first prepared by boiling together tartar and the *crocus metallorum* *, as it was called, in water, filtering the solution, and evaporating it till it yields crystals: glass of antimony was afterwards substituted for the crocus. But it would be needless to enumerate the various methods which have been adopted according to the fancy of different operators. These methods have been collected by Bergman, and are described by him in his treatise on *Antimoniated Tartar* †.

At present the glass of antimony, or the peroxide of antimony, are usually employed. Either of these is mixed with its own weight of tartar, and the mixture boiled in ten or twelve parts of water, till the tartar be saturated. The solution is then filtered and evaporated till a pellicle forms on its surface. On cooling it deposites regular crystals of tartar emetic. Thenard has observed, that there always remains in the solution a quantity of uncombined tartrate of potash; it ought not therefore to be evaporated too far, otherwise the crystals of that salt will mix with those of the tartar emetic ‡.

TARTAR EMETIC is of a white colour, and crystallizes in regular tetrahedrons. When exposed to the air,

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* An impure hydrosulphuret, formed by detonating in a crucible equal weights of sulphuret of antimony and nitre, and washing the residuum in water till the liquid comes off tasteless.

† *Opusc.* i. 338.

‡ *Ann. de Chim.* xxxviii. 39.

it gradually loses its transparency and effloresces. It is soluble in 14½ parts of cold water, and in about two parts of boiling water *. Heat decomposes it by destroying the acid, while the potash and oxide of antimony remain behind. It is decomposed by the alkaline earths, by the alkalies and their carbonates, and by the hydrosulphurets, and several of the metals. It is decomposed also by the decoctions of plants, particularly those that are astringent and bitter, as Peruvian bark, &c. Consequently it never ought to be given in conjunction with any of these bodies.

Composition.

From the analysis of Thenard, it appears that this salt is composed of......35·4 tartaric acid
39·6 oxide
16·7 potash
8·3 water
100·0

Or of......................56·3 tartrate of antimony
35·4 tartrate of potash
8·3 water
100·0 †

GENUS XVII. SALTS OF TELLURIUM.

TELLURIUM has been known for so short a time as a distinct metal, and the quantity of it hitherto examined has been so small, that the salts which it forms with acids cannot be supposed to be much known. Only the following facts have been ascertained.

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[*] Buckhal, *Ann. de Chim.* xlix. 70.

[†] *Ann. de Chim.* xxxviii. 39.

Book II. Division III.

Characters.

The salts of tellurium may be distinguished by the following properties:

1. Alkalies, when dropt into their solution, occasion a white precipitate, which disappears again if the alkali be added in excess.

2. Triple prussiate of potash occasions no precipitate.

3. Hydrosulphuret of potash occasions a brown or blackish precipitate.

4. The infusion of nutgalls occasions a flaky precipitate of a yellow colour.

5. Zinc, iron, and antimony, when plunged into these solutions, occasion the tellurium to separate in the state of a black powder, which resumes its metallic brilliancy when rubbed *.

Sp. 1. *Nitrate of Tellurium.*

Nitric acid dissolves tellurium with facility. The solution is colourless, and not rendered turbid by water. It yields, when concentrated, small, white, light, needle-formed dendritical crystals †.

Sp. 2. *Muriate of Tellurium.*

Nitromuriatic acid dissolves tellurium readily. The solution is transparent; but when diluted with water, it lets fall the oxide of tellurium in the state of a white precipitate, which is redissolved on adding more water. When the solution is precipitated by alcohol, and sufficiently washed, the white powder contains but a very small proportion of acid ‡.

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* Klaproth's *Beitrage*, iii. 1. and Crell's *Annals*, 1798, i. 98.

† Crell's *Annals*, 1798, i. 98.

‡ Klaproth's *Beitrage*, iii. 15.

Chap. III.

Sp. 3. *Sulphate of Tellurium.*

WHEN one part of tellurium is confined with 100 parts of sulphuric acid in a close vessel, it dissolves and gives the acid a crimson colour. When water is dropt into the acid, the red colour disappears, and the metal is precipitated in black flakes. When heated, the colour equally disappears, and the metal precipitates in the state of a white powder. Diluted sulphuric acid, mixed with a little nitric acid, dissolves a considerable portion of tellurium, the solution is colourless, and no precipitate is produced in it by water [*].

GENUS XVIII. SALTS OF ARSENIC.

ARSENIC is capable of assuming the form of an acid, and even its white oxide has several acid properties. Hence it is more disposed to combine with metallic bases than to form salts by uniting with acids. However, as several of the acids have the property of dissolving it, which must be considered as a species of combination, and as the knowledge of the properties of these solutions is sometimes of importance in mineralogical investigations, it will be proper to give an account of them in this place.

The solutions of arsenic may be distinguished by the following properties:

Characters.

1. Triple prussiate of potash occasions a white precipitate when poured into solutions containing arsenic [†].

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[*] Crell's *Annals*, 1798, i. 98.

[†] The solution of arsenic in those acids which converts it into an acid, is not disturbed by the triple prussiate of potash.

2. Hydrosulphuret of potash produces a yellow precipitate, or at least gives a yellow colour to the solution.

3. Gallic acid and the infusion of nutgalls occasion scarcely any change in the solutions of arsenic.

4. The addition of water occasions a white precipitate of oxide of arsenic *, which, when heated with charcoal, emits a white smoke having the smell of arsenic.

Sp. 1. *Nitrate of Arsenic.*

Nitric acid attacks arsenic with violence, and converts it into white oxide, while nitrous gas is disengaged. When diluted, this acid dissolves the oxide, and deposites it again crystallized like white oxide, but really combined with nitric acid. This nitrate is scarcely soluble in water; before the blowpipe it presents the same phenomena as sulphate of arsenic, but is dissipated more rapidly †.

Sp. 2. *Muriate of Arsenic.*

Muriatic acid has scarcely any action on arsenic while cold; but when heated it dissolves it readily; at the same time a quantity of arsenicated hydrogen gas is emitted. White oxide of arsenic is also dissolved by this acid with facility, especially if a little nitric acid be mixed with it. At a boiling heat the muriatic acid dissolves about the third part of its weight of white oxide; but allows the greater part to precipitate again as the solution cools. The addition of water precipitates the

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* Except when the arsenic is converted into an acid.

† Bergman, ii. 293.

greatest part of the remainder; but the muriate of arsenic, according to the experiments of Bergman, may be obtained in the state of crystals. It is very volatile, and but sparingly soluble in water *.

This salt may be formed also by triturating together equal parts of oxymuriate of mercury and oxide of arsenic, or metallic arsenic, and distilling the mixture with a moderate heat. There comes over a transparent liquor of the consistence of oil, part of which congeals in the receiver. This substance is muriate of arsenic. It was described by Lemery and others under the name of *butter of arsenic*, or *corrosive oil of arsenic.*

Sp. 3. *Sulphate of Arsenic.*

SULPHURIC ACID has no action on arsenic while cold; but when heated, sulphurous acid gas is emitted, and the metal is converted into a white oxide, a small portion only of which is retained in solution. The acid dissolves equally a small quantity of the white oxide of arsenic in a boiling heat, but it precipitates again as the acid cools in the form of small crystalline grains. These grains are a sulphate of arsenic. They are much less soluble in water than oxide of arenic. Before the blowpipe they emit a white smoke, and melt into a globule which evaporates slowly †.

Remaining Species.

Phosphate.

4. Phosphoric acid does not attack arsenic; but it dissolves its white oxide, and yields crystalline grains of phosphate, which have not been examined ‡.

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* Bergman, ii. 294.

† Ibid, p. 293.

‡ Ibid. p. 295.

Fluate. 5. Fluoric acid dissolves the white oxide of arsenic, and forms small crystalline grains, which have not been examined.

Borate. 6. Boracic acid combines with the white oxide of arsenic, and yields by evaporation borate of arsenic, partly in a white powder, and partly in needles *.

Acetate. 7. Acetic acid has no action on arsenic, but it dissolves the white oxide, and forms crystals scarcely soluble in water †.

Benzoate. 8. Benzoic acid dissolves the white oxide of arsenic, and the solution yields by evaporation very fine feather-shaped crystals, soluble in water. Their taste is acid and acrid. Alkalies occasion no precipitate in the solution of this salt. It sublimes in a moderate heat: a strong heat decomposes it ‡.

Oxalate and tartrate. 9. Both oxalic and tartaric acid dissolve the white oxide of arsenic, and yield by evaporation prismatic crystals, the properties of which have not been examined §.

Arseniate. 10. Arsenic acid dissolves the white oxide of arsenic, and yields crystalline grains scarcely soluble in water ‖.

The remaining salts of arsenic are entirely unknown.

GENUS XIX. SALTS OF COBALT.

THE salts of cobalt have attracted the attention of chemists, in consequence of the property which some of them have of changing their colour when heated, and thus forming what has received the name of *sympathetic*

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* Bergman, ii. 295.—Gren, iii. 390.

† Ibid.

‡ Trommsdorf.

§ Bergman, ii. 295.

‖ Ibid.

ink; an appellation given to all liquids, the characters formed by which are colourless and invisible when written upon paper, but become visible and coloured by undergoing certain processes; and likewise to those liquids which form characters upon paper susceptible of changing their colour by certain processes. It is probable that chemists have not hitherto had an opportunity of often examining the pure salts of cobalt; for several of the other metals adhere to cobalt with such persevering obstinacy, that it is very difficult to obtain it in a separate state. The salts of cobalt may be distinguished by the following properties:

Characters.

1. The greater number of them are soluble in water, and the solution has a reddish colour, at least when the salts are neutral *.

2. The alkalies, when dropt into these solutions, occasion a blue-coloured precipitate †.

3. Triple prussiate of potash occasions a brownish-yellow precipitate, often with a shade of blue.

4. Hydrosulphuret of potash occasions a black precipitate, soluble again if the hydrosulphuret be added in excess. Sulphureted hydrogen gas occasions no precipitate in these solutions ‡.

5. Gallic acid produces no change; but the tincture of nutgalls occasions a yellowish-white precipitate.

6. Cobalt is not precipitated from its solutions in acids by zinc.

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* The solution of cobalt in muriatic acid, when concentrated, has a bluish-green colour as long as there is an excess of acid.

† When the cobalt is contaminated with arsenic acid, or when it is dissolved in arsenic acid, the precipitate by alkalies is reddish brown.

‡ Proust, *Ann. de Chim.* xxxv. 54.

Sp. 1. *Nitrate of Cobalt.*

NITRIC ACID attacks cobalt when assisted by heat. The solution has a red colour, and yields by evaporation small prismatic crystals of a red colour, deliquescent in the air, and decomposed by heat, leaving a deep red powder.

Sp. 2. *Muriate of Cobalt.*

MURIATIC ACID acts with difficulty upon cobalt even when assisted by heat; but a solution may be readily obtained by adding a little nitric acid. Muriatic acid dissolves the peroxide of cobalt with an effervescence occasioned by the emission of oxymuriatic acid gas. The solution, when concentrated, is of a fine green, and blue if there be no excess of acid, but it becomes red when diluted with water. This solution, when sufficiently concentrated, yields small deliquescent crystals of muriate of cobalt. These crystals are blue, but become red when they absorb moisture.

Sympathetic ink.

The solution of this salt constitutes the first and best known of all the sympathetic inks. It is diluted with water till its colour almost disappears; and then the characters written with it on paper are invisible while cold; but if the paper be gently heated they acquire a fine green colour, which disappears again when the paper cools. This may be repeated as often as we please, provided care be taken not to heat the paper too much, otherwise the characters acquire a permanent brown colour. Klaproth affirms, that this change to green only takes place when the cobalt solution is contaminated with iron: if the cobalt be pure, the characters, instead of a green, acquire a blue colour when heated*. This sympathetic ink was first made known by Waitz in 1705 †; it was described a second time by Teichmeyer in 1731 ‡; and a third time by Hellot in 1737 §. The cause of this singular change of colour has not hitherto been explained in a satisfactory manner. It takes place equally in close vessels; so that it can scarcely be ascribed to the action of the air or of moisture. At present it is supposed, but without any direct proof, to be owing to the partial deoxidizement of the oxide of cobalt by heat, and its reabsorption of oxygen when cold.

But this supposition is not likely to be verified. Thenard has observed with justice, that the appearance of the green colour, when the paper is heated, is owing to the concentration of the solution; and its disappearing, when cold, to its dilution, by absorbing again the moisture it had lost ||. It is therefore exactly similar to the change of the solution from green to red when diluted with water; but the reason of this change remains still to be assigned.

When this salt is heated to redness in a retort, those parts of it only that touch the glass are decomposed, muriatic acid and oxymuriatic acid are disengaged, and the glass is tinged blue. The rest of the muriate melts, and sublimes in grey coloured flowers. These flowers dissolve with great difficulty in water. At last, however, a solution of common muriate of cobalt may be obtained ¶.

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* Klaproth's *Observations on the Fossils of Cornwall*, p. 64. Eng. Trans.

† See Wiegleb's *Geschichte*, i. 126.

‡ *Commerc. Literarum*, p. 91.

§ *Mem. Par.* 1737.

|| *Ann. de Chim.* xlii. 214.

¶ Proust, *Ann. de Chim.* lx. 269.

Sp. 3. *Sulphate of Cobalt.*

Sulphuric acid requires a boiling heat before it can attack cobalt: sulphurous acid gas is disengaged, and a brownish-red mass remains, which dissolves with facility in water. Sulphuric acid dissolves the peroxide of cobalt with difficulty; bubbles of gas are emitted during this solution, which Thenard supposes to be oxygen [*]. The solution is always red; and yields by evaporation small needle-form crystals, consisting of rhomboidal prisms, terminated by dihedral summits. This salt has a reddish colour. It is soluble in 24 parts of water, but insoluble in alcohol [†]. This salt is not altered by exposure to the air. When heated, it loses 42 *per cent.* of water. The residue is rose coloured and opaque. It may be exposed to a red heat in a retort without undergoing decomposition, except at those points which touch the glass [‡].

This salt, according to the analysis of Bucholz, is composed of..........26 acid

composed of	26 acid
	30 oxide
	44 water
	100 [§]

This species readily combines with sulphate of potash or sulphate of ammonia, and forms two species of triple salts, which have not hitherto been described with accuracy. The sulphate of potash-and-cobalt crystallizes in rhomboidal cubes. It is not so soluble

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[*] *Ann. de Chim.* xlii. 211.

[†] Gren's *Handbuch*, iii. 524.

[‡] Proust, *Ann. de Chim.* lx. 260.

[§] *Beitrage*, iii. 30.

in water as sulphate of cobalt, and yields only 26 *per cent.* of water when distilled [*].

Remaining Species.

Phosphate.

4. PHOSPHORIC ACID does not attack cobalt; but it dissolves its oxides, and forms a deep wine-red solution [†].

Carbonate.

5. The fixed alkaline carbonates precipitate cobalt from its solutions in the state of reddish-blue powder. This insoluble carbonate contains, according to Bergman, $\frac{1}{8}$th of its weight of carbonic acid [‡].

Fluate.

6. Fluoric acid does not attack cobalt, but it dissolves its oxide, and forms with it a yellow-coloured gelatinous solution [§].

Borate.

7. Boracic acid does not act upon cobalt, but it precipitates that metal from its solution in other acids in the state of a reddish-white powder. This borate is scarcely soluble in water. When heated it melts into a deep blue glass [||].

Acetate.

8. Acetic acid dissolves the oxide of cobalt with facility. The solution does not crystallize; and when evaporated to dryness, soon deliquesces again. It has a fine red colour while cold, but becomes blue when heated [¶]. This solution forms a sympathetic ink: the characters drawn in it are colourless while cold, but become blue when heated [**].

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[*] Proust, *Ann. de Chim.* lx. 260.

[†] Gren's *Handbuch*, iii. 528.

[‡] *Opusc.* ii. p. 388. and 392. It contained arsenic acid, as is obvious from its red colour.

[§] Scheele, i. 35.

[||] Wenzel's *Verwandtschaft*, p. 258.

[¶] Ibid. p. 150.

[**] Ilseman, Crell's *Annals*, 1785, ii. 25.

Oxalate.

9. Oxalic acid attacks cobalt, and converts it into a red powder, which is oxalate of cobalt. This salt is insoluble in water, but it dissolves in an excess of acid, and yields crystals. Oxalic acid precipitates an oxalate of cobalt from the solution of that metal in most acids *.

Tartrate.

10. Tartaric acid dissolves the oxide of cobalt, and forms a red solution which yields crystals †. When tartrate of potash is dropt into the solutions of cobalt, it precipitates the arseniates of iron and bismuth, if they be present, and they carry with them a portion of the cobalt. By spontaneous evaporation the liquid yields large rhomboidal crystals of tartrate of potash-and-cobalt.

Arseniate.

11. Arsenic acid, when digested upon cobalt, acquires a red colour, but it does not dissolve the metal completely. Arsenic acid does not precipitate cobalt from its solution in acids; but the alkaline arseniates occasion a precipitate of a fine red colour, which is arseniate of cobalt ‡. This salt is found native; sometimes in the state of a fine red efflorescence, and sometimes crystallized in small four-sided prisms or tables.

When the arseniate of cobalt is heated in a glass tube it becomes violet, but is not decomposed, nor does it tinge the glass blue. It dissolves in nitric acid without effervescence. When its solution in muriatic acid is mixed with sulphureted hydrogen, it does not become turbid till it has stood two hours. Potash precipitates blue oxide of cobalt, and combines with the acid §.

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* Bergman, i. 270.

† Gren, iii. 128.

‡ Scheele, i. 186.

§ Proust, *Ann. de Chim.* lx. 271.

Sp. 12. *Nitrate of Ammonia-and-Cobalt.*

When a solution of cobalt in nitric acid is supersaturated with ammonia, it is well known that no precipitate appears. When this solution is evaporated to dryness, and the residue is treated with water, a red solution is obtained, which yields by slow evaporation regular cubes of a red colour. These crystals are a triple salt, composed of nitric acid, ammonia, and oxide of cobalt. They were first observed by Thenard. Their taste is urinous; they are not altered by exposure to the air. When heated they burn with a yellowish-white flame, like nitrate of ammonia, leaving an oxide of cobalt. Their solution in water is neither precipitated by alkalies nor alkaline earths; but when boiled with potash, ammonia is disengaged, and the oxide of cobalt precipitates *.

GENUS XX. SALTS OF MANGANESE.

All the properties of this genus of salts with which we are even at present acquainted were ascertained by Bergman and Scheele, by whose labours the oxide of manganese, one of the most important of all our instruments, was first put into the hands of chemists. The salts of manganese may be distinguished by the following properties:

Characters.

1. They are almost all soluble in water; and the solution, when treated with fixed alkalies, deposites a

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* Thenard, *Ann. de Chim.* xlii. 245.

white or reddish coloured precipitate, which very soon becomes black when exposed to the air.

2. Triple prussiate of potash occasions a yellowish-white precipitate when dropt into these solutions.

3. Hydrosulphuret of potash occasions a white precipitate. Sulphureted hydrogen gas gives the solution a white colour, but produces no precipitate.

4. Gallic acid occasions no precipitate.

5. Manganese is not precipitated from its solution in the metallic state by any of the other metals.

Sp. 1. *Nitrate of Manganese.*

Nitric acid dissolves manganese with effervescence, occasioned by the emission of nitrous gas. It dissolves the white oxide with facility, and without the emission of any gas: but it has very little action on the black oxide; however, by very long digestion, it at last dissolves a part of it. The solution goes on much more rapidly if a little sugar or gum, or any similar substance, be added, and at the same time a quantity of carbonic acid gas is emitted. Hence we see that the black oxide must part with a portion of its oxygen before nitric acid can dissolve it. Nitrous acid acts upon the black oxide much more readily, and is converted entirely into nitric acid. The solution, in what manner soever it has been made, is always colourless, provided the manganese be pure. Hence we may conclude that it contains only the white oxide. So that, as far as is known at present, there is no such substance as *oxynitrate* of manganese. This solution does not crystallize how slowly soever it be evaporated. Heat decomposes it, and leaves the oxide *.

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* Scheele, i. 43, 64; and Bergman, ii. 216.

Chap. III.

Sp. 2. *Muriate of Manganese.*

Muriatic acid readily dissolves manganese with an effervescence, occasioned by the emission of hydrogen gas. It dissolves the white oxide without effervescence, and the solution is colourless. When allowed to remain cold upon the black oxide, it dissolves a portion of it, and forms a red solution, which deposites red oxide when diluted with water. When heat is applied to the mixture of black oxide of manganese and muriatic acid, an effervescence takes place, and oxymuriatic acid gas is emitted. The oxide becomes white and gradually dissolves. In this case the acid is divided into two portions ; one absorbs oxygen from the metal, and flies off in the state of gas ; the other dissolves the white oxide, as it is set at liberty by the decomposition of the black oxide. If sugar or any other similar vegetable substance is added, no oxymuriatic gas is emitted, but instead of it carbonic acid gas. From these facts it is obvious that muriatic acid combines both with the white and red oxides of manganese ; so that there is both a *muriate* and *oxymuriate* of that metal. But the properties of these salts are still almost unknown. According to Bergman, the muriate crystallizes with difficulty, and when evaporated to dryness yields a saline mass, which attracts moisture. The solution of the oxymuriate is red, and it seems to be partly decomposed by water[*].

Sp. 3. *Sulphated Manganese.*

Sulphuric acid acts with energy on manganese, es-

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[*] Bergman, ii. 217.—Scheele, i. 46. and 67.

Book II. Division III.

pecially when diluted with two or three times its weight of water, and forms with it a colourless solution. It dissolves also with equal facility the white and red oxides of manganese; but it has no action whatever on the black oxide unless assisted by heat. When that is the case, oxygen gas passes off in abundance, and the oxide is dissolved. The same solution takes place without the emission of that gas when a little sugar is added to the mixture. Hence we see that the black oxide is incapable of combining with sulphuric acid, since it always loses a portion of its oxygen before solution. But Bergman has shown, that both the white and the red oxide combine with that acid, and form with it a salt, So that we have two combinations of sulphuric acid and manganese: first, the combination of sulphuric acid and the white oxide, which forms *sulphate* of manganese; and, secondly, the combination of the acid with the red oxide, which constitutes *oxysulphate* of manganese.

1. *Sulphate of Manganese.* This salt is obtained pure by dissolving manganese in diluted sulphuric acid, or by dissolving the black oxide in that acid, adding at the same time a little sugar. The solution is colourless, and yields by evaporation transparent rhomboidal crystals of sulphate of manganese. These crystals have a very bitter taste, and are decomposed by heat, which drives off their acid. Alkalies precipitate from them the manganese in the state of a white oxide *.

2. *Oxysulphate of Manganese.* This salt may be obtained by distilling sulphuric acid from the black oxide of manganese, and washing the residuum in water. A

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* Bergman, ii. 210.

red or rather violet coloured liquor is thus obtained, which holds in solution the oxysulphate of manganese. This solution is difficultly crystallized, but passes readily into a gelatinous form. The few crystals which are mixed with this jelly are soft, and have but little permanency. When evaporated to dryness, it yields thin red coloured saline crusts, which precipitate successively from the surface, and which do not readily deliquesce. This salt is very soluble in water; and alkalies precipitate the manganese in the state of a red oxide, which soon becomes black when exposed to the air *.

Sulphurous acid readily dissolves the black oxide of manganese, and forms with it sulphate of manganese, as Scheele ascertained †. The theory of this is obvious. Part of its oxygen is abstracted from the manganese by the acid; in consequence of which, the black oxide is converted into white oxide, and the sulphurous into sulphuric acid. It is not known whether sulphurous acid forms with the oxides of manganese a permanent salt.

Haussman has lately proposed the sulphate of manganese for marking lines so as not to be effaced by the action of oxymuriatic acid. The solution of this salt in water is mixed up with any vegetable colouring matter to the proper consistence, and applied to the linen, which is then passed through an alkaline ley. The oxide of manganese is thus precipitated upon the cloth; and by the action of oxymuriatic acid, its colour becomes yellowish brown ‡.

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* Bergman, p. 215.

† Scheele, i. 43.

‡ *Ann. de Chim.* liii. 208.

Sp. 4. *Phosphate of Manganese.*

PHOSPHORIC ACID has but little action on manganese or its oxides, because it forms with them a salt difficultly soluble in water. But phosphate of manganese may be obtained in the form of a precipitate, by mixing an alkaline phosphate with the solution of manganese in any of the three mineral acids [*]. This salt has not been hitherto examined.

Sp. 5. *Carbonate of Manganese.*

LIQUID CARBONIC ACID attacks manganese or its black oxide, and dissolves a small portion. When the solution is exposed to the air, the acid gradually escapes, and a white pellicle forms on its surface, consisting of white oxide. During the solution of manganese in this acid, an odour similar to that of burning fat is perceptible [†].

Sp. 6. *and* 7. *Fluate and Borate of Manganese.*

THE fluoric and boracic acids form likewise with the oxides of manganese salts difficultly soluble in water, the properties of which have not hitherto been much examined. These acids have but little action on manganese and its oxides; but the fluate or borate of manganese may be easily formed by pouring the alkaline fluates or borates into sulphate or muriate of manganese.

Remaining Species.

Acetate. 8. ACETIC ACID has butlittle effect upon manganese

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[*] Scheele, i. 48.—Bergman, ii. 219.

[†] Bergman, i. 35.; and Scheele, i. 51.

immediately; but it dissolves a small portion by long digestion, as it does also of the black oxide. The solution does not yield crystals, and when evaporated to dryness soon deliquesces again *. Vauquelin has employed acetic acid in order to separate iron from manganese. When a mixture of these two metals is dissolved in acetic acid, and the solution evaporated to dryness, the acid adheres to the manganese, but abandons the iron. Water dissolves the acetate of manganese, but leaves the oxide of iron on the filter. Two or three evaporations and solutions are sufficient to deprive acetate of manganese of the whole of its iron †.

Benzoate.

9. Benzoic acid dissolves the white oxide of manganese with facility. The solution yields small crystalline scales easily soluble in water, but sparingly in alcohol. They are not altered by exposure to the air ‡.

Succinate.

10. *Succinate of Manganese.* When a succinate of potash or soda is dropt into a neutral solution of manganese, no precipitate is thrown down; but if iron be present, it falls in combination with succinic acid. Hence Gehlen has proposed an alkaline succinate as the best means of separating iron and manganese from each other.

Oxalate.

11. Oxalic acid attacks manganese, and dissolves the black oxide with effervescence. The solution, when saturated, lets fall the oxalate of manganese in the state of a white powder. Oxalic acid precipitates the same powder from the solution of manganese in sulphuric, nitric, or muriatic acid §.

Tartrate.

12. Tartaric acid dissolves black oxide of manganese

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* Bergman, ii. 219.

† *Ann. de Chim.* xli. 249.

‡ Trommsdorf, Ibid. xi. 317.

§ Bergman, i. 272. and ii. 219.

cold; but the solution is blackish: When heated, an effervescence ensues, owing to the decomposition of part of the oxide and the escape of carbonic acid gas, and the solution becomes colourless.

Citrate.

13. Citric acid acts upon the black oxide of manganese exactly as tartaric acid [*].

Arseniate.

14. Arsenic acid dissolves the white oxide of manganese with facility; and when it approaches the point of saturation, the solution becomes thick, with small crystals, which separate. These crystals are arseniate of manganese. They are precipitated when an alkaline arseniate is dropt into the solution of manganese in an acid. These crystals do not melt when heated; neither does arsenic sublime, unless charcoal be mixed with them [†].

15. *Tartrate of Potash-and-Manganese.* When tartrate of potash is mixed with a solution of manganese, no immediate change takes place; but if the mixture be set aside, a great number of small prismatic crystals of a reddish brown colour are deposited, consisting of tartrate of potash combined with the oxide of manganese. They are sparingly soluble in water. Heat decomposes them by destroying the acid. Richter proposed the formation of this salt as one of the best means of procuring an oxide of manganese in a state of purity; but succinate of potash answers the purpose better, by effectually separating the iron, the only metal with which manganese is contaminated in common cases.

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[*] Bergman, ii. 220.

[†] Scheele, i. 188.

GENUS XXI. SALTS OF CHROMIUM.

THIS genus of salts is still very little known; the small quantity of chromium hitherto obtained in the metallic state not having permitted chemists to examine the action of acids upon it with much attention. For the few facts known, we are indebted to Richter * and Godon †.

The presence of Chromium may be detected by the following properties:

Characters.

1. Triple prussiate of potash occasions a brown precipitate.

2. The infusion of nutgalls occasions a brown precipitate.

3. The hydrosulphuret of potash occasions a green precipitate, which a few drops of nitric acid change to yellow.

When chromium is in the metallic state, the acids act upon it with great difficulty, neither nitric acid nor nitromuriatic dissolving it rapidly. The latter by long digestion dissolves a small portion, and forms a green coloured solution ‡.

Even the protoxide of chromium, formed by exposing chromic acid to a strong heat, is but very feebly attacked by acids. The nitric at last, however, acidifies the greater part; but if chromic acid thus obtained be precipitated by nitrate of mercury, the liquor retains an amethyst colour, and yields by evaporation octahe-

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* Gehlen's *Jour.* v. 351.

† *Ann. de Chim.* liii. 222.

‡ Richter, Ibid.

dral crystals of a fine violet colour, which Godon found to be nitrate of chromium *.

Genus XXII. Salts of Molybdenum.

This genus is still problematical. Indeed it has been ascertained that the oxides of molybdenum are incapable of forming crystallizable salts with acids. But many acids dissolve them; and the resulting solutions are remarkable for the changes of colour to which they are liable. For the most accurate set of experiments on this subject we are indebted to Bucholz, who has lately published an elaborate dissertation on the properties of molybdenum †.

Nitrate.

1. When molybdenum in powder is treated with diluted nitric acid, it dissolves very slowly unless the action of the acid be assisted by heat. The solution thus formed has a yellowish brown colour, with a shade of red. When evaporated to dryness, it leaves a reddish-brown residue almost all soluble in distilled water. Its taste is acid and bitter, leaving a metallic flavour in the mouth. Ammonia throws down a brownish-red flaky precipitate from the solution, mixed with a few crystals of molybdic acid. When more molybdenum is employed than the acid can dissolve, the solution gradually assumes a blue colour, and lets fall blue oxide of molybdenum ‡.

Muriate.

2. Muriatic acid does not attack molybdenum; but oxymuriatic dissolves it, and forms a blue-coloured so-

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* Godon, *Ann. de Chim.* liii. 222.

† Gehlen's *Jour.* iv. 636.

‡ Bucholz, Ibid. p. 637.

Chap. III.

lution *. Muriatic acid dissolves the oxide of molybdenum in a boiling heat, and the solution assumes a deep blue colour, and a blue sediment falls. Muriatic acid dissolves likewise molybdic acid. The solution is of a pale yellowish green colour, but becomes blue when saturated with potash †.

Sulphate.

3. Sulphuric acid does not act upon powdered molybdenum at the temperature of the atmosphere; but when it is assisted by heat, sulphurous acid is driven off, and a yellowish-brown thick solution is formed. If this solution be allowed to remain upon undissolved molybdenum, its colour gradually changes to blue, and blue oxide precipitates ‡. When diluted sulphuric acid is digested on molybdic oxide, a solution takes place, which is green while hot, but becomes blue on cooling §. Sulphuric acid dissolves molybdic acid by the assistance of heat. The solution is colourless while hot; but on cooling it assumes a deep blue colour, which is heightened by saturating the solution with soda ‖.

Phosphate.

4. Phosphoric acid does not act upon molybdenum at the temperature of the atmosphere; but when they are heated together in an open vessel, a portion of the metal is oxidized at the expence of the acid. When water is poured upon the dry mass, a yellowish-brown solution is obtained, containing the oxide of molybdenum in combination with phosphoric acid. Though this solution be kept over molybdenum in powder, it does not change colour like the preceding, and no blue oxide is precipitated ¶.

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* Buch. Gehlen's *Jour.* iv. 640. † Hatchett. ‡ Buch. Ib. p. 636.

§ Ilseman; as quoted by Gren, *Handbuch*, iii. 712.

‖ Hatchett, *Phil. Trans.* 1795, p. 123.

¶ Bucholz, Gehlen's *Jour.* iv. 642.

Fluate.

5. Fluoric acid dissolves the oxides of molybdenum, The solution, while hot, is greenish yellow; when concentrated by evaporation, it becomes yellow; and when reduced to a dry mass, greenish blue. When this mass is well washed, it assumes a fine green colour: the water employed acquires a dirty grass green *.

Borate.

6. Boracic acid appears scarcely to act upon molybdenum †. Neither has it any action upon its oxides ‡.

Acetate.

7. Acetic acid does not act upon molybdenum while cold; but when assisted by heat, it dissolves a portion forming a yellowish-brown solution §.

Succinate.

8. Succinic acid acts very feebly upon molybdenum, but by heat it forms a greenish-coloured solution ||.

Oxalate.

9. Oxalic acid forms a blue solution with molybdic oxide, which does not change colour by evaporation; but when diluted with water, it becomes green: a large addition renders it brown ¶.

Tartrate.

10. Tartaric acid and citric acid act very feebly, though when assisted by heat they dissolve a small portion of the metal **.

Molybdate.

11. The oxide of molybdenum is precipitated brown from acids by triple prussiate of potash, and deep brown by tincture of nutgalls ††.

GENUS XXIII. SALTS OF URANIUM.

THIS genus of salts has been hitherto examined only

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* Heyer, Crell's *Annals*, 1787, ii. 121.

† Bucholz, Gehlen's *Jour.* iv. 643.

‡ Gren's *Handbuch*, iii. 713.

§ Bucholz, Ibid. p. 643.

|| Ibid.

¶ Heyer, Crell's *Annals*, 1787, ii. 121.

** Bucholz, Gehlen's *Jour.* iv. 643.

†† Gren's *Handbuch*, iii. 713.

by Klaproth, Richter, and Bucholz. This last chemist has lately published a very particular description of the sulphate and nitrate of uranium.

Characters.

The salts of uranium may be distinguished by the following properties:

1. The greater number of them are soluble in water, and the solution has a yellow colour.

2. The pure alkalies occasion in these solutions a yellow precipitate; the alkaline carbonates a white precipitate, soluble in an excess of alkali.

3. Triple prussiate of potash occasions a brownish-red precipitate, which does not assume the form of flakes like the prussiate of copper.

4. Hydrosulphuret of potash occasions a brownish-yellow precipitate.

5. The infusion of nutgalls occasions a chocolate-coloured precipitate.

6. No precipitate is occasioned by zinc, iron, or tin *.

Sp. 1. *Nitrated Uranium.*

Nitric acid readily dissolves uranium with the emission of nitrous gas. The solution has a yellowish colour †. The oxide of uranium is dissolved by this acid with still greater facility. From the trials of Bucholz ‡ it follows, that the acid unites with the oxide in two proportions, forming a nitrate and subnitrate of uranium.

1. *Nitrate.* This salt is best formed, as Klaproth showed, by dissolving the oxide of uranium in nitric

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* Klaproth, Crell's *Annals*, i. 130. Eng. Transl.—Richter's *Neuern Gegenstande*.—Gren's *Handbuch*, iii. 741.

† Bucholz, Gehlen's *Jour.* iv. 36.

‡ Ibid. p. 158.

acid, and bringing the solution to crystallization. The best method of obtaining regular crystals is to expose the solution to a very moderate heat. When a saturated hot solution is cooled quickly, crystals likewise are obtained, but not so regular. The crystallization succeeds best when there is a slight excess of acid *. The colour of the crystals varies somewhat according to the method of crystallizing. When the solution is fully saturated with oxide, the crystals are of a lemon yellow, and greenish at the edges; but when there is an excess of acid present, they have all a greenish colour. The crystals have the form of tables, often hexagonal; but by cautious management, they may be obtained in large four-sided rectangular flat prisms †.

They are extremely soluble in water; 93 parts of that liquid at the common temperature being capable of dissolving 200 parts of nitrate of uranium. Boiling water dissolves any quantity; the water of crystallization being sufficient at that temperature to keep the salt in solution. They are still more soluble in pure alcohol; one part of that liquid dissolving $3\frac{1}{3}$d parts of the nitrate. The solution has a yellow colour, and is of the consistence of a syrup. Boiling alcohol dissolves any quantity, but a portion of the salt precipitates again as the solution cools. By evaporation the solution yields regular crystals of nitrate of uranium. If it be kept for a long time in the temperature of about 112°, the salt is partly decomposed, a yellow powder precipitating; a portion of which is oxide of uranium, and a portion of the same oxide, united probably to a vegetable

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* Bucholz, Gehlen's *Jour.* iv. 145.

† Ibid. 146.

acid. When four parts of nitrate of uranium and one part of alcohol are distilled in a very moderate heat, the first portion which comes over has the smell of nitric ether; the second contains a portion of acetic acid [*].

Sulphuric ether dissolves about $\frac{1}{4}$th of its weight of this salt; the solution is lemon yellow; but when exposed to the sun's rays, it becomes in a few minutes green, and in some hours a watery portion subsides, of a green colour, containing uranium. The ether acquires the smell of nitric ether, and a quantity of black oxide of uranium precipitates [†].

When nitrate of uranium is exposed to the air at the temperature of about 100°, it very soon falls into a white powder; but in cold and damp air it very soon deliquesces into a liquid [‡].

When heated, it undergoes the watery fusion; the water which it contains is gradually dissipated, carrying along with it a portion of the acid. If the heat be increased, nitrous gas makes its escape, and at last a portion of oxygen gas is disengaged. By this process, not only the whole of the acid and water is dissipated, but the metal loses also a considerable portion of its oxygen [§].

Composition.

From the experiments of Bucholz, it follows that this salt is composed of......61 oxide
25 acid
14 water

100 [||]

2. *Subnitrate*. When nitrate of uranium is heated

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[*] Bucholz, Gehlen's *Jour*. iv. 151.
[†] Ibid. p. 156.
[‡] Ibid. p. 150.
[§] Ibid. p. 149.
[||] Ibid p. 148.

till its colour becomes orange-yellow, it does not dissolve completely in water, leaving behind a lemon-yellow powder. A portion of the same powder likewise precipitates from the solution before it can be brought to crystallize. This powder is insoluble in water, and has been shown by Bucholz to be a subnitrate of uranium[*].

Sp. 2. *Muriate of Uranium.*

URANIUM in the metallic state is scarcely attacked by muriatic acid[†]; but it dissolves the oxide, and forms with it deliquescent crystals of a yellowish-green colour, having the form of four-sided tables[‡].

Sp. 3. *Sulphate of Uranium.*

SULPHURIC ACID, whether concentrated or diluted, has but little effect upon uranium in the metallic state[§]. By boiling the oxide obtained from nitrate of uranium by means of heat, with a sufficient quantity of diluted sulphuric acid, and setting the solution aside in a warm place, Mr Bucholz obtained needle-form crystals of sulphate of uranium. As these crystals contained an excess of acid, though a portion of the oxide remained undissolved, Bucholz redissolved them in water, added a little nitric acid, and boiled them to dryness over a new portion of oxide of uranium. The mass was dissolved again in water, filtered, and set aside. After some months very small prismatic crystals separated;

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[*] Bucholz, Gehlen's *Jour.* iv. 158.
[†] Ibid. p. 36.
[‡] Klaproth, Crell's *Annals*, i. 130, Engl. Transl.
[§] Bucholz, Gehlen's *Jour.* iv. 36.

and by continuing the evaporation some crystals were obtained in the shape of tables.

The colour of these crystals is lemon yellow. They dissolve in $\frac{5}{8}$ths of their weight of cold water, and in $\frac{9}{20}$ths of their weight of that liquid when boiling hot. The solution has the consistency of a syrup, and gradually yields regular crystals when subjected to spontaneous evaporation. Pure alcohol at the common temperature of the air dissolves $\frac{1}{25}$th part, and boiling alcohol $\frac{1}{20}$th part of its weight of them. When the solution was exposed to the sun, its colour, at first light yellow, became green, and the whole of the oxide gradually precipitated, carrying along with it a portion of sulphuric acid. At the same time the smell of ether became perceptible in the liquid.

When crystallized sulphate of uranium is exposed to a red heat, it loses 14 *per cent.* of its weight; but in a white heat it loses the whole of its acid and water. The residue, which weighs $\frac{46}{100}$ths of the original salt, is a greyish-black powder, consisting of pure oxide of uranium.

This salt, according to the experiments of Bucholz, to whom we are indebted for the whole of the facts above enumerated, is composed of

18 acid
70 oxide
12 water

100 *

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* Gehlen's *Jour.* iv. 134.

Remaining Species.

Phosphate. 4. Phosphoric acid forms with oxide of uranium yellowish-white flakes, scarcely soluble in water. The salt may be precipitated by adding phosphoric acid to the acetate of uranium *.

Fluate. 5. Fluoric acid dissolves the yellow oxide, and forms with it crystals which do not deliquesce.

Acetate. 6. Concentrated acetic acid dissolves oxide of uranium by digestion, and yields beautiful yellow crystals in the form of long, slender, transparent, four-sided prisms terminated by four-sided pyramids. When heated gradually, the acid is decomposed and driven off, but the remaining oxide still retains the form of the crystals †.

Tartrate. 7. Tartaric acid forms with the oxide of uranium a salt scarcely soluble in water.

Arseniate. 8. When an alkaline arseniate is dropt into nitrate of uranium, the arseniate of uranium precipitates in the state of a yellowish-white powder.

9. and 10. The tungstate and molybdate of uranium may be obtained by a similar process. The first is a brownish-white powder, insoluble in water: the second is whitish-yellow, and difficultly soluble.

Richter formed also the borate, oxalate, citrate, malate, benzoate, succinate, and sebate of uranium; but the properties of these salts have not been described.

GENUS XXIV. SALTS OF TUNGSTEN.

This genus of salts is altogether unknown; the scarcity of tungsten, and the difficulty of obtaining it in a

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* Klaproth, Crell's *Annals*, i. 135, Engl. Transl. † Ibid.

state of purity, having hitherto prevented the possibility of attempting to ascertain the compounds which its oxides are capable of forming with acids. Indeed it has not been demonstrated that the oxides of tungsten are capable of combining with acids and forming salts.

Neither sulphuric nor muriatic acids seem capable of altering the metal; but nitromuriatic acid attacks it at a boiling heat; and nitrous gas is emitted *.

Genus XXV. Salts of Titanium.

For all that is at present known respecting this genus of salts, we are indebted to the experiments of Gregor, Klaproth, Vauquelin, and Hecht. The salts of titanium may be distinguished by the following properties:

Characters.

1. They are in general colourless, and in some degree soluble in water.

2. The alkaline carbonates occasion in these solutions a white flaky precipitate.

3. Triple prussiate of potash occasions a grass-green precipitate mixed with brown. When an alkali is dropt in after the prussiate, the precipitate becomes purple, then blue, and at last white.

4. Hydrosulphuret of potash occasions a dirty glass-green precipitate. Sulphureted hydrogen gas occasions no precipitate.

5. The infusion of nutgalls occasions a very bulky reddish-brown precipitate. If the solution is concentrated, it assumes the appearance of curdled blood.

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* Scheele, i. 188.

Book II. Division III.

6. When a rod of tin is plunged into a solution of titanium, the liquid around it gradually assumes a fine red colour. A rod of zinc, on the other hand, occasions a deep blue colour *.

Nitrate.

Sp. 1. Nitric acid has no action on the red oxide of titanium, and scarcely any upon the metal; but it dissolves the carbonate, provided heat be applied; and the solution yields, by evaporation, transparent crystals, in the form of elongated rhombs, having two opposite angles truncated, so as to represent six-sided tables. According to Vauquelin and Hecht, this solution only succeeds when the metal is combined with a minimum of oxygen.

Muriate.

2. Muriatic acid dissolves titanium; but it has no effect upon its red oxide. The carbonate of titanium is readily dissolved by this acid; and the solution, according to Klaproth, yields transparent cubic crystals. According to Vauquelin and Hecht, the solution is yellow, and assumes the form of a jelly when evaporated. Heat occasions the emission of oxymuriatic acid, and the oxide precipitates, and is no longer soluble in muriatic acid, unless it be boiled in nitric acid. Hence they conclude, that the muriate contains titanium combined with a maximum of oxygen, and that the protoxide is incapable of uniting with muriatic acid.

Sulphate.

3. Boiling sulphuric acid oxidizes titanium, and dissolves a small portion of it; but on the red oxide of titanium that acid has no action whatever. It dissolves the carbonate of that metal with effervescence, occasion-

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* Klaproth's *Beitrage*, i. 233.

ed by the emission of carbonic acid. The solution, when evaporated, is converted into a white opaque gelatinous mass.

4. and 5. When the phosphoric or arsenic acid is dropt into the solution of titanium in acids, it occasions a white precipitate.

6. When one part of red oxide of titanium and six parts of carbonate of potash are melted together in a crucible, the mass, when washed sufficiently with water, leaves a white powder, with a slight red tinge, which Vauquelin and Hecht have ascertained to be carbonate of titanium. According to the experiments of these chemists, it is composed of

75	white oxide
25	carbonic acid
100	

7. and 8. Oxalic and tartaric acids likewise occasion a white precipitate, but it is redissolved again almost as soon as formed*.

GENUS XXVI. SALTS OF COLUMBIUM.

THE scarcity of this metal having prevented Mr Hatchett, the discoverer, from multiplying his experiments on it, we are not to expect many facts respecting the combination of its oxides with acids. The salts of columbium may be distinguished by the following properties:

Characters.

1. Their solutions, as far as known, are transparent and colourless.

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* *Jour. de Min.* No. xv. p. 1.

2. Alkaline carbonates occasion a white flaky precipitate in these solutions.

3. Triple prussiate of potash changes them to an olive green, and occasions a beautiful olive-coloured precipitate.

4. Hydrosulphuret of ammonia occasions a reddish chocolate-coloured precipitate.

5. Tincture of nutgalls throws down a very high orange-coloured precipitate.

6. A rod of zinc throws down a white flaky precipitate.

Mr Hatchett, to whom we are indebted for all the facts known belonging to this genus of salts, has rendered it probable that there are several oxides of columbium; but nothing has been ascertained respecting the particular oxides which combine with acids.

Nitrate.

1. Nitric acid is incapable of dissolving the oxides of columbium. It seems to have the property of converting the white oxide into columbic acid.

Muriate.

2. Boiling muriatic acid dissolves columbic acid. The solution is colourless, and may be diluted with water without any change being produced. When the solution was evaporated to dryness, it left a pale yellow substance, insoluble in water, and difficultly soluble in muriatic acid.

Sulphate.

3. Boiling sulphuric acid dissolves columbic acid, and forms a transparent colourless solution. When largely diluted with water, this solution becomes milky, and deposites a white precipitate. When allowed to dry, this precipitate cracks, and becomes at first lavender-blue, and afterwards brownish grey. It is a subsulphate of columbium, and in a boiling temperature is slightly soluble in muriatic acid and in potash ley.

The diluted sulphuric acid solution still retains a supersulphate of columbium.

Phosphate.

4. When phosphoric acid is added to the concentrated solution of columbium in sulphuric acid, the whole assumes the form of an opaque, white, stiff jelly insoluble in water. From muriate of columbium phosphoric acid throws down a white flocculent powder.

5. Acetic acid has no effect on columbic acid *.

Genus XXVII. Salts of Cerium.

For all the facts respecting this genus of salts at present known, we are indebted to the labours of Klaproth, Hisinger and Berzelius, and Vauquelin. The salts of cerium possess the following properties:

Characters.

1. They are either white or yellow coloured, according to the state of oxidizement of the oxide.

2. Their solutions in water have a sweet taste.

3. Hydrosulphuret of potash occasions only a white precipitate consisting of the oxide of cerium. Sulphureted hydrogen occasions no precipitate.

4. Prussiate of potash occasions a milk-white precipitate, soluble in nitric and muriatic acids.

5. Gallic acid and the infusion of nutgalls occasion no precipitate.

6. The oxalate of ammonia occasions a white precipitate, which is insoluble in nitric and muriatic acids.

Sp. 1. Nitrated Cerium.

Nitric acid unites with both the oxides of cerium.

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[*] Hatchett on "A Mineral Substance from North America." *Phil. Trans.* 1802.

With the white oxide it combines most readily, especially when that oxide is in the state of a carbonate. The solution is colourless, crystallizes with difficulty, retains an excess of acid, and has an austere and sweet taste.

The red oxide dissolves with difficulty in cold nitric acid, but readily when the action of the acid is promoted by heat. The solution is yellow; and when it contains an excess of acid, it yields small white crystals, which deliquesce when exposed to the air. The saturated solution does not crystallize.

Both the nitrate and oxynitrate of cerium are soluble in alcohol. Heat decomposes them, leaving a red-coloured oxide*.

Sp. 2. Hyperoxymuriate of Cerium.

From an experiment of Vauquelin, it does not appear that the peroxide of cerium is capable of combining with hyperoxymuriatic acid. He caused a current of oxymuriatic acid gas to pass through water into which the oxide of cerium had been put. A very small portion only of the oxide was dissolved. When precipitated by ammonia it was still in the state of white oxide. In all probability it was kept in solution by common muriatic acid †.

Sp. 3. Muriate of Cerium.

When red oxide of cerium is treated with muriatic acid, a considerable effervescence is produced, and oxy-

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* Hisinger and Berzelius, Gehlen's *Jour.* ii. 409. Vauquelin, *Ann. de Chim.* liv. 51.

† *Ann. de Chim.* liv. 54.

muriatic acid gas escapes. The solution obtained is a yellowish red, and the shade is the lighter the longer the liquid has boiled. By concentration and cooling, small four-sided prismatic crystals are deposited of a yellowish white colour. They are soluble in alcohol, and deliquesce when exposed to the air. Their taste is astringent and sweet. When the oxymuriate of cerium, thus formed, is exposed to heat, it is completely decomposed. The water of crystallization and excess of acid pass over first, and then oxymuriatic acid; the residue is a white oxide, difficultly soluble in acids. If iron be present it is volatilized in the state of muriate.

If too strong a heat has not been applied, a portion of the salt remains undecomposed. It is white, and forms a colourless solution in water, being in reality a *muriate* of cerium *.

Sp. 4. *Sulphate of Cerium.*

SULPHURIC ACID dissolves the red oxide of cerium with difficulty. By digesting the oxide in diluted acid for a sufficient length of time, a solution may be obtained. It is of an orange colour, and yields by evaporation small octahedral and needle-form crystals of oxysulphate of cerium. Their colour is partly lemon yellow, partly orange. The salt thus obtained is not soluble in water, except by means of an excess of acid. Then its taste is acid and sweet. When the crystals are exposed to the air, they soon fall into a yellow powder.

Sulphuric acid combines very readily with the white

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* Klaproth, Gehlen's *Jour.* ii. 312. Hisinger and Berzelius, Ibid. Vauquelin, *Ann. de Chim.* liv. 54.

oxide of cerium, especially when it is in the state of a carbonate. The solution is colourless, has a sweet taste, and readily yields crystals of sulphate of cerium. When oxysulphate of cerium is treated with muriatic acid, oxymuriatic acid gas is disengaged; the salt loses its colour, and is converted into sulphate of cerium. A moderate heat disengages oxygen, and produces the same change *.

Sp. 5. *Sulphite of Cerium.*

Sulphurous acid dissolves the red oxide of cerium, and the solution yields by evaporation crystals of a pale amethyst colour †.

Sp. 6. *Phosphate of Cerium.*

When a mixture of oxide of cerium and phosphoric acid is digested in water, a white insoluble powder is obtained, which is phosphate of cerium. The same powder is thrown down when the solutions of cerium are mixed with phosphate of soda. It is soluble in nitric and muriatic acids ‡.

Sp. 7. *Carbonate of Cerium.*

Carbonic acid combines readily with the white oxide of cerium. The easiest way of forming the carbonate is to precipitate white oxide of cerium from its solution by means of an alkaline carbonate. The precipitate is granular, of a silvery whiteness, and insoluble in water acidulated with carbonic acid. Accord-

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* Klaproth, Hisinger and Berzelius, Vauquelin.

† Klaproth, Gehlen's *Jour.* ii. 312.

‡ Klaproth, Hisinger, Berzelius.

ing to the analysis of Klaproth, carbonate of cerium is composed of..........23 acid

23	acid
65	oxide
12	water
100	

This salt may be formed by causing a current of carbonic acid gas to pass through water having the oxide of cerium suspended in it. So great indeed is the avidity of this oxide for carbonic acid that it absorbs it even from the air *.

Sp. 8. *Acetate of Cerium.*

Acetic acid readily dissolves the oxide of cerium, newly precipitated by means of alkalies. The solution, when saturated, has a sweet taste, and yields by evaporation small granulated crystals; readily soluble in water, but sparingly soluble in alcohol, and not altered by exposure to the air †.

Sp. 9. *Succinate of Cerium.*

When a few drops of succinate of ammonia are poured into muriate or nitrate of cerium, a precipitate is formed which soon disappears. When more of the reagent is added, the succinate of cerium is separated in the state of a white powder. This salt is not wholly insoluble in water, as a small portion still remains in solution. Succinate of ammonia does not precipitate cerium from the acetate. This furnishes us with a ready means of separating iron from cerium when they happen to be mixed ‡.

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* Klaproth, Hisinger and Berzelius, Vauquelin.

† Hisinger and Berzelius, Gehlen's *Jour.* ii. 414. ‡ Ibid.

Book II.
Division III.

Sp. 10. *Benzoate of Cerium.*

Benzoic acid occasions no precipitate in muriate of cerium; but when it is digested on recently precipitated oxide of cerium, a solution takes place. On cooling, the liquid first lets fall crystals of benzoic acid, then the benzoate of cerium falls in the state of a white insoluble powder[*].

Sp. 11. *Oxalate of Cerium.*

Oxalic acid and oxalate of ammonia precipitate cerium from its solutions. The precipitate, with the peroxide, is red; with the protoxide, white. An excess of acid does not redissolve it; but ammonia readily effects its solution, giving it a yellow colour[†].

Sp. 12. *Tartrate of Cerium.*

When tartaric acid is digested upon recently precipitated oxide of cerium, it forms a salt readily soluble in water, in consequence of the excess of acid which it contains. When the solution is mixed with a great quantity of water, white insoluble flakes of tartrate of cerium are precipitated. Tartaric acid occasions no precipitate in the sulphate, nitrate, or muriate of cerium; but tartrate of potash throws down the tartrate of cerium in the state of a white powder. It is soft, light, tasteless, and insoluble in water. It is soluble in nitric, muriatic, and sulphuric acids, and in pure alkalies[‡].

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[*] Hisinger and Berzelius, Gehlen's *Jour.* ii. 413. [†] Id. Ibid.

[‡] Hisinger and Berzelius, Vauquelin.

Sp. 13. *Citrate of Cerium.*

Muriate of cerium is not precipitated by citric acid. By digesting the acid on recently precipitated oxide, an insoluble compound is formed, which is rendered soluble by an excess of acid. The solution does not crystallize. Alcohol deprives it of its water and of part of its acid, but does not dissolve it*.

Sp. 14. *Arseniate of Cerium.*

Arsenic acid does not occasion a precipitate when dropt into muriate of cerium. When digested with oxide of cerium, an insoluble compound is obtained, which may be rendered soluble by adding an excess of acid. The solution does not crystallize; when evaporated, it deposites insoluble arseniate, and the residue dries into a gelatinous colourless mass †.

Sp. 15. *Molybdate of Cerium.*

Molybdate of ammonia occasions no precipitate in the supersalts of cerium; but from the neutral solutions it precipitates molybdate of cerium in the form of a white salt not soluble in acids ‡.

Sp. 16. *Sulphate of Potash-and-Cerium.*

When supersulphate or superoxysulphate of cerium is decomposed by potash, a triple salt is deposited, white with the first, and yellow with the second salt. This triple salt melts when heated. Nitric acid dissolves

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* Hisinger and Berzelius, Gehlen's *Jour.* ii. 413.

† Id. Ibid.

‡ Id. ibid.

andt decomposes it. The same triple salt is deposited when muriate of cerium is poured into a solution of sulphate of potash *.

SECT. III.

REMARKS ON THE SALTS.

Such are the properties of all the salts which have been hitherto examined by chemists, and which amount to about six hundred. Great as this number is, it cannot be doubted that the class of salts will be considerably increased hereafter.

Importance of the salts.

Of these bodies, there are some, as alum, copperas, &c. which constitute the basis of different arts and manufactures, and which therefore are of sufficient importance to deserve an accurate examination even on their own account. Others, again, are the source from which chemists obtain many of the most valuable of their instruments of analysis; as nitre, common salt, phosphate of lime, sal ammoniac, sulphate of barytes, &c. and therefore naturally claim the particular attention of all those who cultivate the science. But it must be allowed, that by far the greater number of saline bodies are at present of no apparent use whatever, either in the arts or in chemistry. At first sight it may appear a very useless piece of labour to be at the the trouble of examining and describing these: but there are several

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* Hisinger and Berzelius, Gehlen's *Jour*. ii. 413.

reasons which render a precise knowledge of all the salts not only proper but even necessary.

Were we to limit ourselves to the examination of those things whose usefulness is already known, there would be an end of all improvement. Every thing must be useless, as far as regards us, till its properties be known, and the purposes to which it may be applied ascertained. Many of those salts which we at present consider as of no utility, may hereafter be found of the greatest consequence, when their properties have been more completely investigated. This remark has been verified more than once within these few years. The muriate of lime, for instance, was formerly thrown away, but is now applied with great advantage to produce artificial cold; and the oxymuriates, though a new class of salts, constitute an essential ingredient in the process of bleaching. Want of utility therefore is but a meagre reason for neglecting the examination of the salts, unless it could be demonstrated *a priori* that they never can be applied to any use.

But were we even certain that this were the case, still the examination of a great number of these salts would be indispensible: For those salts which are the most useful are seldom or never found in a state of purity; they are constantly mixed and contaminated with other salts, from which it is necessary to free them before they will answer the purposes to which they are usually applied. Now these foreign salts cannot be separated unless we be acquainted with them, at least sufficiently to know the effect of different agents upon them; that is, unless we be acquainted with their properties. Thus we see that it is not possible to obtain those salts which are really useful, without at the same time knowing the nature of many salts which have been applied to no use. Thus common salt is always mixed with muriate of magnesia, and cannot be obtained unless we understand the method of separating or decomposing that salt.

But it is not strictly true that many of the salts are altogether useless. It may be affirmed, with the greatest truth, that, even at present, there is not one among them, the knowledge of whose properties is not of some advantage. One of the most important and difficult things in chemistry is to ascertain exactly the nature and composition of different bodies. Now this can only be done by observing the changes produced upon them by other bodies, and the compounds which they are capable of forming. Thus if, on examining a substance, I find, that when combined with sulphuric acid, it forms a heavy insoluble white powder; with muriatic acid, a very soluble salt, which crystallizes in tables, and is insoluble in alcohol; with phosphoric and oxalic acid likewise an insoluble powder, &c,—I conclude, without hesitation, that it is barytes. A substance which dissolves in sulphuric acid, and forms a salt of a blue colour, crystallized in rhomboidal prisms, of an acrid taste and caustic, which forms with muriatic acid a green salt, which becomes blue when mixed with ammonia, and which when mixed with alkalies occasions a blue or green precipitate—I conclude to be copper. Thus it is the knowledge of the salts which the different alkalies, earths, metals, and acids are capable of forming, which enables us to discover their presence when they enter as ingredients into different compounds. Here, then, is a reason for studying the properties of the salts, independent of their utility as individual bodies; and it may be affirmed with truth, that chemical skill is in every case proportional to the extent of this knowledge.

The great number of saline bodies renders it a difficult task to remember the properties of each. Indeed the thing would be impossible, were it not that the salts naturally arrange themselves into certain groups, the individuals belonging to which all agree in certain general properties which may be remembered with facility; and after these general properties have indicated the group to which a given salt belongs, it is much easier to ascertain the species.

Salts divided into two classes.

The salts may be divided conveniently into two classes, under one or other of which every salt is to be placed. These two classes constitute the two first Sections of this Chapter. The first class comprehends under it all the earthy and alkaline salts; the second class all the metalline salts.

First class.

The first class may be distinguished by the following characters: The salts belonging to it are either, 1. Soluble in water; and in that case the solution is not precipitated by hydrosulphuret of potash *, triple prussiate of potash †, or infusion of nutgalls ‡: or, 2. Insoluble in water; and in that case they are either soluble in muriatic acid, or become so when heated to redness, or fused with carbonate of potash; and the solution yields a precipitate when sulphuric acid is added, or if not, at least when potash is added. The insoluble

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* Except salts with base of alumina or zirconia.

† Except salts with base of yttria or zirconia.

‡ Except salts with base of yttria, glucina, or zirconia.

salts afford with borax, before the blowpipe, a white glass or enamel.

Divided into two orders.

As the salts belonging to this class are very numerous, it has been divided into two orders. The salts belonging to the first order are incombustible when suddenly heated to redness [*]; those belonging to the second order contain combustible acids, and when suddenly heated either burn partially, leaving incombustible salts behind them, or the acid is totally decomposed and driven off, leaving the base mixed with charcoal. The first order contains 14 genera, the second contains 18. The characters by which each of these genera may be distinguished have been given in the first Section of this Chapter, and need not be repeated here. Having found the genus to which any salt belongs, the species is to be ascertained by a careful examination of the properties described as belonging to each. But the investigation will be much facilitated by attending to the following observations:

1. The species may be distinguished into two kinds; those whose base is an *alkali*, and those which have an *earthy* base.

2. The alkaline salts are all soluble in water. Potash occasions no precipitate of a white powder when added to the solution; neither does oxalic acid occasion any precipitate.

3. The salts with an ammoniacal base are all either dissipated entirely, or converted into an acid when exposed to a red heat.

4. Many of the earthy salts are insoluble in water;

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[*] Except nitrate of ammonia and hyperoxymuriate of ammonia.

Chap. III.

a white powder is precipitated from the soluble salts either by the addition of potash or of sulphuric acid.

5. The salts whose base is barytes are all * insoluble in water, or nearly so, except five; namely, the nitrate, muriate, acetate, benzoate, and prussiate; from the solutions of these, sulphuric acid or sulphate of soda throws down a white heavy insoluble precipitate.

6. All salts whose base is strontian are nearly insoluble in water, as far as they have been examined, except six; namely, nitrate, muriate, hyperoxymuriate, acetate, tartrate, and citrate. These also yield an insoluble white powder with sulphuric acid. But the alkalies occasion no precipitate either in the solutions of barytic or strontian salts.

7. All salts whose base is lime are very sparingly soluble in water except eight; namely, nitrate, muriate, hyperoxymuriate, arseniate, acetate, malate, benzoate, and prussiate. The lime is precipitated from these solutions by oxalic acid, fixed alkalies, and by sulphuric acid if the solution be concentrated, but not by ammonia.

8. The magnesian salts are all soluble in water except seven; namely, phosphite, fluate, carbonate, oxalate, tartrate, saccolate, and camphorate. Their solution yields a white precipitate with ammonia, which disappears by adding ammonia in excess, provided there be an excess of acid present. This precipitate forms with sulphuric acid a very soluble bitter salt.

9. The alkaline earths form with acids a greater

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* Four of them are still unknown; namely, the molybdate, chromate, gallate, and sebate.

number of salts soluble in water in proportion as the alkaline properties of the earth diminish. Barytes forms salts, the greater number of which are insoluble; strontian seems to form a greater number of soluble salts than barytes; lime forms a still greater number; and almost the whole of the magnesian salts are soluble in water.

10. Six of the aluminous salts are insoluble in water; namely, sulphite, phosphate, borate, arseniate, tungstate, and saccolate. The aluminous salts are all deprived of their acid by heat. With potash they yield a precipitate which dissolves in sulphuric acid; and when sulphate of potash is added to the solution, crystals of alum are gradually obtained. The aluminous salts let fall a precipitate when hydrosulphuret of potash is dropt into their solution, and at the same time sulphureted hydrogen gas is exhaled.

11. The salts of yttria are decomposed by heat and by alkalies; they have a sweetish astringent taste; triple prussiate of potash and infusion of nutgalls occasion a precipitate when poured into their solutions. The succinate of potash occasions no precipitate.

12. The salts of glucina are decomposed by heat and by alkalies; they have a sweetish taste. The precipitate separated from them by alkalies, redissolved in nitric or muriatic acid, is again precipitated by the infusion of nutgalls, but not by triple prussiate of potash. It is precipitated also by succinate of potash.

13. The zirconian salts have an austere taste: they are decomposed by heat and by alkalies. The precipitate separated from them by these last bodies, when redissolved in muriatic acid, is precipitated by hydrosul-

phuret of potash, triple prussiate of potash, and by the infusion of nutgalls.

Second class.

The second class of salts, the metalline, may be distinguished by the following properties: The salts belonging to it are either, 1. Soluble in water; in which case they afford a precipitate with hydrosulphuret of potash, triple prussiate of potash [*], and the infusion of nutgalls [†]: or, 2. Insoluble in water; in which case, when fused with borax by the blow-pipe upon charcoal, they either afford a button of metal, or form with the borax a coloured glass.

Divided into two orders.

This class might with propriety enough be divided into two orders. The first order would comprehend those genera, the salts belonging to which are crystallizable and permanent, indicating a marked affinity between the acid and base; the second order would consist of those salts which want permanency, and indicate a very weak affinity between the acid and base. The first order would consist of 17 genera; namely,

1. Salts of gold
2. .... platinum
3. .... silver
4. .... mercury
5. .... palladium
6. .... rhodium
7. .... iridium
8. .... copper
9. .... iron
10. Salts of nickel
11. .... lead
12. .... zinc
13. .... cobalt
14. .... manganese
15. .... uranium
16. .... titanium
17. .... cerium

The second order would consist of 10 genera; namely,

1. Salts of osmium
2. Salts of tin

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[*] Except salts of gold, platinum, antimony, and tellurium.

[†] Except salts of platinum, zinc, arsenic, manganese, and cerium.

3. Salts of bismuth
4. ...... antimony
5. ...... tellurium
6. ...... arsenic
7. Salts of tungsten
8. ...... molybdenum
9. ...... chromium
10. ...... columbium

The genera may be recognised without much difficulty by the characters given in the second Section of this Chapter. As the species are very numerous, it greatly facilitates investigation to subdivide them into sets. This accordingly has been done in the description of the genera, whenever the state of our knowledge rendered it practicable. These subdivisions are the five following: 1. Detonating salts. These detonate when heated with a combustible, and generally also when wrapt in a paper with a little phosphorus, and struck smartly with a hammer. The acids in these salts are the nitric and hyperoxymuriatic. 2. Incombustible salts. These often lose their acid or a part of it when heated; but they do not burn, nor are they capable of setting fire to combustibles. The acids in these salts are the muriatic, sulphuric, sulphurous, phosphoric, phosphorous, carbonic, fluoric, boracic. The phosphates and borates are not decomposed by heat, but melt readily into a glass. Those sulphates that are soluble in water lose a great portion of their acid in a strong heat; but the insoluble sulphates scarcely lose any, unless the base be volatile. The muriates are readily volatilized when strongly heated. The sulphites and phosphites are converted by heat partly to sulphates and phosphates, and partly to sulphurets and phosphurets. The carbonates are decomposed by heat. The fluates undergo a partial decomposition, and usually melt into a glass. 3. Combustible salts. These contain the combustible acids. When heated, they are decomposed; the base, usually contaminated with charcoal, and partially reduced to the metallic state, remains behind. Most of these salts are but imperfectly known. 4. Metallic salts. These contain both a metallic base and acid. They are all insoluble in water and alcohol, and seldom or never completely decomposed by heat. They often exist native. The analysis of them is usually difficult. 5. Triple salts. They contain, besides a metallic base, an alkali or earth. They are very numerous, though but imperfectly examined. In general, it may be laid down as a rule, that all metallic oxides soluble in alkalies are capable of forming triple salts with these alkalies and acids. The metallic triple salts claim peculiar attention on another account. Alkalies or earths are seldom capable of throwing down their metallic base. Unless, then, we be acquainted with all the triple salts that are liable to be formed, we must be very apt to fall into mistakes when these salts happen to occur in the course of our analysis.

The species in the different metallic genera may be distinguished from each other by the properties of the different acids which form them; and these properties have been enumerated in the first Section as the characteristic marks of the genera of earthy and metallic salts.

The following TABLE, which gives a synoptical view of the properties of the most important salts, will add considerably to the facility of distinguishing the different species.

Book II. Division III.

Salts.	Taste.	Figure of Crystals.	Action of Air.	Solubility in 100 Parts Water.		Action of Heat.
				at 60°.	at 212°.	
Sulphate of barytes	None	Rhomboidal prisms	None	0·002	0·	Decrepitates
potash	Bitter	Six-sided prisms	None	6·25	24·	Decrepitates
soda	Bitter	Six-sided prisms	Effloresces	35·	125·	Watery fusion
strontian	None	Rhomboidal prisms	None	0 00	0·02	
lime	Little	Rhomboidal prisms	None	0·2	0·22	Decrepitates
ammonia	Bitter	Six-sided prisms	Subdeliquesces	50·	100·	Decrepitates and melts
magnesia	Bitter	Four-sided prisms	Effloresces	100·	133·	Watery fusion
Alum	Astringent	Octahedrons	Little	5·	133·	Watery fusion
Sulphite of barytes	None	Tetrahedrons	Chang. to Sulph.	0·	0·	
lime	None	Six-sided prisms	Effloresces	·125		Falls to powder
potash	Sulphur	Rhomboidal plates	Effloresces	100·		Decrepitates
soda	Sulphur	Four-sided prisms	Effloresces	25·	100·	Watery fusion
ammonia	Sulphur	Six-sided prisms	Subdeliquesces	100·		Decrepitates
magnesia	Little	Tetrahedrons	Effloresces	5·		Swells
Nitrate of barytes	Acrid	Octahedrons	None	8·3	25·	Decrepitates
potash	Cooling	Six-sided prisms	None	14·3	100·	Melts
soda	Cooling	Rhomboidal prisms	Subdeliquesces	33·	100· +	Melts
strontian	Pungent	Octahedrons	Little	100·	200·	Decrepitates and melts
lime	Bitter	Six-sided prisms	Deliquesces	400·	Any quantity	Watery fusion
ammonia	Acrid	Six-sided prisms	Deliquesces	50·	200·	Melts
magnesia	Bitter	Rhomboidal prisms	Deliquesces	100·	100· +	Watery fusion
Muriate of barytes	Astringent	Four-sided prisms	None	43·		Decrepitates
potash	Bitter	Cubes	None	33·		Decrepitates
soda	Salt	Cubes	None	35·46	36·16	Decrepitates
strontian	Sharp	Six-sided prisms	Little	150·	Any quantity	Watery fusion
lime	Bitter	Six-sided prisms	Deliquesces	400·		Watery fusion
ammonia	Acrid	Four-sided pyramids	Subdeliquesces	31·		Sublimes
magnesia	Bitter	Needles	Deliquesces	151·		Watery fusion

Salts.	*Taste.*	*Figure of Crystals.*	*Action of Air.*	*Solubility in 100 Parts Water.*		*Action of Heat.*
				at 60°.	*at 212°.*	
Hyperoxymuriate of potash	Cooling	Rhomboidal plates	None	6·	40·	Gives out oxygen
Phosphate of barytes	None	0	None	0·	0·	Little
strontian	None	0	None	0·	0.	Little
lime	None	Six-sided prisms	None	0·	0.	Little
potash	Salt	A gelatinous mass	Deliquesces	Very	soluble	Watery fusion
soda	Salt	Rhomboidal prisms	Effloresces	25·	50·	Watery fusion
ammonia	Cooling	Four-sided prisms	None	25·	25·+	Watery fusion
magnesia	Cooling	Six-sided prisms	Effloresces	6·6		Falls to a powder
Fluate of lime	None	Cubes	None	0·	0·	Decrepitates
Borax	Styptic	Six-sided prisms	Subeffloresces	5·	16·8	Watery fusion
Carbonate of barytes	None	Various	None	0·023	0·043	Little
strontian	None		None	0·	0·065	Little
lime	None	Rhomboidal prisms	None	0·	0·	Decrepitates
potash	Alkaline	Four-sided prisms	None	25·	83⅓	Watery fusion
soda	Alkaline	Octahedr. truncated	Effloresces	50·	100·+	Watery fusion
magnesia	None	Six-sided prisms	Effloresces	2·		Decrepitates
ammonia	Urinous	Irregular	None	50·+	100·	Evaporates
Acetate of barytes	Bitter	Needles	Subeffloresces	80·		Decomposed
potash	Hot	Plates	Deliquesces	99·		Melts
soda	Sharp	Striated prisms	None	35·		Melts
strontian			None	40·	40·8	Decomposed
lime	Bitter		None			Decomposed
ammonia	Cool	Slender prisms	Deliquesces	Very	soluble	Melts and sublimes
magnesia	Sweetish	0	Deliquesces	Very	soluble	Decomposed
Tartar	Acid	Irregular prisms	None	1⅔	3⅓	Melts
Tartrate of potash	Bitter	Four-sided prisms	None	25·		Melts
Tartrate of potash-and-soda	Bitter	Eight-sided prisms	Effloresces	25·		Melts

CHAP. IV.

OF HYDROSULPHURETS.

Properties of sulphureted hydrogen.

SULPHURETED HYDROGEN GAS possesses the properties of an acid. It is absorbed by water in considerable quantities, and the solution reddens vegetable blues; it combines also with alkalies and earths, and with several metallic oxides. The greater number of these properties were first pointed out with precision by Mr Kirwan; but they were afterwards much more fully developed by Berthollet*.

Liquid sulphureted hydrogen, or sulphureted hydrogen gas dissolved in water, is not decomposed by exposure to the air, but the gas gradually separates without decomposition. When sulphurous acid is mixed with this solution, both the sulphureted hydrogen and the acid are in a great measure decomposed; the hydrogen of the one combines with the oxygen of the other, and forms water; while the sulphur of both is precipitated, as was first observed by Fourcroy, and more fully ascertained by Berthollet. Nitric acid produces the same effect unless it be too much diluted with water. Hence the reason that sulphur precipitates

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* See Vol. I. of this Work, p. 89.

when that acid is mixed with water holding sulphureted hydrogen in solution, as Bergman first observed. Oxymuriatic acid likewise precipitates sulphur when used in small quantities; but when a sufficient proportion is used, the sulphur is redissolved and converted into sulphuric acid.

Precipitates metals.

Sulphureted hydrogen has a strong action on the greater number of metallic oxides; its hydrogen abstracts oxygen from these bodies, and thus either brings them to the metallic state or to a minimum of oxygen; while at the same time its sulphur combines with the metal thus regenerated. Hence the reason of the change produced upon the solutions of the metallic salts by the infusion of liquid sulphureted hydrogen. All the genera of metallic salts are precipitated by this substance excepting six; namely, those which contain the following metals:

1. Iron;
2. Nickel;
3. Cobalt;
4. Manganese;
5. Titanium;
6. Cerium.

Nature of the precipitates.

Berthollet and Proust have shown, that the oxides of these metals are reduced by sulphureted hydrogen to a minimum of oxygen; but as in that state they have but little affinity for sulphur, they continue combined with the acids which held them at first in solution. Tin, on the other hand, which at a minimum of oxidizement has a strong affinity for sulphur, is precipitated, though sulphureted hydrogen only reduces it to a minimum of oxidizement.

The metallic solutions differ considerably in the facility with which they afford precipitates with sulphureted hydrogen; and Mr Proust has shown that, with a little address, metals may, in many cases, be separated from each other by means of this agent. For instance, if copper, lead, zinc, and iron, be held in solution together in nitric acid, sulphureted hydrogen first separates the copper in the form of a black precipitate, which may be removed by filtration; next the lead; and lastly, the zinc; while the iron still continues in solution *. The different metals may be distinguished by the colour of the precipitate which their solutions yield with sulphureted hydrogen. The colours of these different precipitates may be seen in the following TABLE:

Gold and Platinum	Reduced
Silver	Black
Mercury	Black
Palladium	Dark brown
Copper	Black
Tin	Brown
Lead	Black
Zinc	White
Bismuth	Black
Antimony	Orange
Arsenic	Yellow
Molybdenum	Chocolate

Supersulphureted hydrogen.

Sulphureted hydrogen has the property of combining with sulphur, and of forming a compound which has the appearance of a yellow oil. It was first observed by Scheele †; and Berthollet ‡, who first examined its nature, has given it the name of *hydrogenated sulphur*.

When liquid potash and sulphur are boiled together,

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* *Jour. de Phys.* li. 174.

† Scheele on *Fire*, p. 192. Eng. Transl.

‡ *Ann. de Chim.* xxv. 247.

Chap. IV.

a brown coloured solution is obtained, formerly known by the name of *liquid hepar sulphuris*. If this liquid be poured by little and little into muriatic acid, scarcely any sulphureted hydrogen gas is exhaled, but hydrogenated sulphur gradually precipitates to the bottom of the vessel, under the form of a yellowish brown oil. This substance, when heated, easily allows the sulphureted hydrogen gas to exhale, and is converted into sulphur. The same change takes place when it is exposed to the open air.

The easiest method of procuring this substance, according to Proust, is to pour into a phial about $\frac{1}{3}$d of its capacity of muriatic acid, of the specific gravity 1·07, add about an equal bulk of the liquid hepar, cork the phial and shake it, the hydrogureted sulphur gradually separates[*].

Thus we see that sulphur and hydrogen are capable of combining in two proportions, or, which is the same thing, that hydrogen combines with two doses of sulphur. The first of these constitutes sulphureted hydrogen gas or hepatic air; which, according to Thenard, is composed of about.........29 hydrogen

71 sulphur

100

The addition of another dose of sulphur constitutes *hydrogureted sulphur*, which Mr Kirwan has with great propriety denominated *supersulphureted hydrogen*; a name which certainly ought to be adopted[†]. Both of

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[*] *Jour. de Phys.* lix. 270.

[†] Kirwan on *Mineral Waters*, p. 11.

Book II. Division III.

these substances combine with different bases, and constitute very peculiar genera of compounds, which deserve a particular examination on account of the important purposes which they serve in analysis. The combinations which sulphureted hydrogen forms with bases have been called by Berthollet *hydrosulphurets*, and by Chenevix *sulphureted hydrogurets*. The compounds of supersulphureted hydrogen with bases have been called by Berthollet *hydrogenated sulphurets*, and by Chenevix *hydrogureted sulphurets* *. Mr Chenevix's terms are certainly more precise than those of Berthollet; but as the word *hydrosulphuret* has been long in general use, it will be necessary to retain it. *Hydrogureted sulphuret*, however, may be still adopted; as the compounds denoted by it have been but seldom mentioned by chemists since the original paper by Berthollet on the subject.

I. HYDROSULPHURETS.

SULPHURETED HYDROGEN combines with alkalies and earths, and forms with them compounds which may be distinguished by the following properties:

Properties.

1. They are all soluble in water, and the solution is colourless.

2. When the solution is exposed to the air, it becomes green or greenish yellow.

3. After long exposure to the air, the solution becomes limpid and colourless; and on examination is

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* On the *Chemical Nomenclature*, p. 201. Mr Kirwan uses the term *hepatule* instead of *hydrosulphuret*, and *hepar* for *hydrogureted sulphuret*.

found to contain only the sulphate of the base of the original hydrosulphuret.

4. The solution of the hydrosulphurets precipitates all metallic solutions; iron and lead, black; antimony, orange; arsenic, yellow *.

How formed.

The hydrosulphurets may be formed by dissolving or mixing the bases respectively with water, and causing sulphureted hydrogen gas to pass through them till they refuse to absorb any more. The excess of the gas is driven off by heating the solution. It is proper to cause the sulphureted hydrogen gas to pass through a small vessel of water before it reaches the base with which it is to combine, in order to separate any impurities with which it might be mixed. By this method solutions of the different hydrosulphurets in water may be obtained.

If these compounds be decomposed while they are colourless, by pouring upon them sulphuric acid, muriatic acid, or any other acid which does not act upon hydrogen, the sulphureted hydrogen gas exhales without the deposition of a single particle of sulphur; but if the hydrosulphuret has become yellow, some sulphur is always deposited during its decomposition, and the quantity of sulphur is proportioned to the deepness of the colour.

The yellow colour, therefore, which hydrosulphurets acquire by exposure to the atmosphere, is owing to a commencement of decomposition. Part of the hydrogen of the sulphureted hydrogen abandons the sulphur,

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* When the hydrosulphurets are kept in glass phials, the inside of the vessel is gradually coated with a black crust. This, as I am informed by Dr William Henry, consists of a portion of the lead from the glass, reduced to the metallic state, and combined with sulphur.

combines with the oxygen of the atmosphere, and forms water. By degrees, however, a portion of the sulphur is also converted into an acid; and when the proportion of sulphureted hydrogen is diminished, and that of the sulphur increased to a certain point, the sulphur and the hydrogen combine equally with oxygen.

If sulphuric or muriatic acids be poured upon a hydrosulphuret after it has been for some time exposed to the air, a quantity of sulphureted hydrogen gas exhales, sulphur is deposited, and after an interval of time sulphurous acid is disengaged. It is therefore sulphurous, and not sulphuric acid, which is formed while the hydrosulphuret spontaneously absorbs oxygen. This acid however, is not perceptible till after a certain interval of time, when separated from the hydrosulphuret by means of an acid; because as long as it meets with sulphureted hydrogen a reciprocal decomposition takes place. The oxygen of the acid combines with the hydrogen of the gas, and the sulphur of both is precipitated.

Sp. 1. *Hydrosulphuret of Barytes.*

WHEN sulphate of barytes is converted into sulphuret, by mixing it with charcoal and keeping it red hot in a crucible, if boiling water be poured upon the black mass, and filtered while hot, the green coloured solution thus obtained yields by evaporation a great number of crystals. These crystals are hydrosulphuret of barytes. They are to be separated immediately by filtration, and dried between the folds of filtering paper *.

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* Berthollet, *Ann. de Chim.* xxv. 241.

They are white, and have a silky lustre. They have usually the form of scales, whose shape cannot be easily ascertained. This compound is soluble in water, and the solution has a very slight tinge of green. Its taste is acrid and sulphureous: and when exposed to the air it is readily decomposed.

Sp. 2. *Hydrosulphuret of Strontian.*

I HAVE procured this compound by the same process as the hydrosulphuret of barytes, and its properties are so nearly similar, that it requires no peculiar description.

Sp. 3. *Hydrosulphuret of Potash.*

THIS compound may be procured by saturating potash with sulphureted hydrogen; but it is formed also during the solution of sulphuret of potash, and may be obtained by evaporation. Its properties have been lately described by Mr Vauquelin. It is transparent and colourless, and crystallizes in large prismatic crystals, not unlike sulphate of soda. They are usually four-sided, and terminated by four-sided pyramids. Sometimes both the prisms and terminating pyramids are six-sided. Its taste is alkaline and extremely bitter. When exposed to the air, it soon deliquesces into a liquid of a syrupy consistence, tinging green all bodies with which it happens to be in contact. But this colour is not permanent, unless some metallic body happens to be in contact. The crystals have no smell; but when they have deliquesced, they emit a fetid odour. They dissolve both in water and alcohol; and during the solution the temperature of the liquid sinks considerably. Acids drive off the sulphureted hydrogen with a violent effervescence, and no sulphur is deposited. When thrown into sulphate of alumina, crystals of alum are soon deposited. This salt, like the other hydrosulphurets, precipitates all metals from their solutions *.

Sp. 4. *Hydrosulphuret of Soda.*

THIS compound may be prepared by the same processes as the last. It is the best known of all the hydrosulphurets, as it is usually employed as a reactive. The properties of its solution in water were first pointed out by Berthollet, but Vauquelin first obtained it crystallized. Having laid aside a concentrated solution of impure carbonate of soda † to crystallize, crystals of hydrosulphuret of soda formed in it spontaneously. The crystals of this hydrosulphuret are transparent and colourless, having the figure of four-sided prisms terminated by quadrangular pyramids, and sometimes of octahedrons. Its taste is alkaline and intensely bitter. It is very soluble both in water and alcohol ; and during the solution cold is produced. When exposed to the air it deliquesces, and assumes a green colour. Acids decompose it, driving off the sulphureted hydrogen. Its other properties are common to the hydrosulphurets ‡.

Hydrosulphureted sulphite of soda.

Though sulphureted hydrogen and sulphurous acid mutually decompose each other when both are uncombined, this does not appear to be the case when they are united to a base. When water impregnated with sulphureted hydrogen gas is mixed with liquid sulphite

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* Vauquelin, *Ann. de Chim.* xlii. 40.

† This carbonate had been procured by decomposing sulphate of soda by charcoal, and separating sulphur by means of lime.

‡ Vauquelin, *Ann. de Chim.* xli. 190.

of soda, the smell of the gas is destroyed, and by evaporation a salt is obtained which appears to be a triple compound of the two gaseous bodies with soda. A salt similar to this has been described by Vauquelin, who indeed formed it artificially by the process just detailed. This salt is white and transparent, crystallizes in four-sided prisms, has no smell, and is not altered by exposure to the air. Its taste is cooling, bitter, and slightly alkaline. When heated it melts, then becomes again solid, gives out sulphur, and the residue assumes a deep red colour. No gas is disengaged [*].

Sp. 5. *Hydrosulphuret of Lime.*

THIS compound is easily prepared by passing sulphureted hydrogen gas through lime suspended in water. The lime dissolves and the hydrosulphuret forms. The solution is colourless, and has an acrid and bitter taste. Its properties are analogous to the other hydrosulphurets. No attempts have been yet made to procure this compound in crystals.

Sp. 6. *Hydrosulphuret of Ammonia.*

THIS compound is easily procured by passing a current of sulphureted hydrogen through liquid ammonia. The solution very readily assumes a greenish yellow colour. When equal parts of lime, sal ammoniac, and sulphur, are distilled in a retort, a yellow liquid is obtained, usually distingushed by the name of *fuming liquor of Boyle,* because first prepared by that philosopher. This liquid constantly emits white fumes, and has a

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[*] Vauquelin, *Ann. de Chim.* xxxii. 296.

strong ammoniacal and fetid odour. Berthollet ascertained that it owed its property of emitting fumes to a quantity of uncombined alkali. It consists chiefly of hydrosulphuret of ammonia holding an excess of sulphur. This liquid gradually loses the property of fuming, and deposites likewise its excess of sulphur. It is then a hydrosulphuret of ammonia nearly pure.

Sp. 7. Hydrosulphuret of Magnesia.

WATER, impregnated with sulphureted hydrogen, dissolves magnesia, and forms a hydrosulphuret, the properties of which have not been examined *.

Sp. 8. and 9. Hydrosulphuret of Glucina and Yttria.

FROM the experiments of Vauquelin and Klaproth, we know that the hydrosulphurets do not precipitate those earths from acids. Hence it is likely that they are capable of combining with sulphureted hydrogen; though the compounds have never been examined by chemists. Neither alumina nor zirconia combine with sulphureted hydrogen. Hence the hydrosulphurets precipitate these earths from acids, in consequence of the affinity of their base for the acid, which holds the earths in solution; and at the same time sulphureted hydrogen gas is emitted.

II. HYDROGURETED SULPHURETS.

THE different alkaline and earthy bases are capable of combining with supersulphureted hydrogen, and form-

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* Berthollet, *Ann. de Chim.* xxv. 235.

ing with it compounds which have been longer known than the hydrosulphurets, though their properties have not been examined with the same precision. They may be formed by boiling the base together with sulphur in a quantity of pure water, or by dissolving their sulphurets in water; in either case, supersulphureted hydrogen is formed, which combines with the base. These compounds were known formerly by the name of *liquid hepars*, or *livers of sulphur*. They may be formed also, as Berthollet has shown, by pouring a liquid hydrosulphuret upon sulphur. A portion of the sulphur is dissolved without the assistance of heat; the liquid becomes dark-coloured, and is converted into hydrogureted sulphuret *. When prepared by the first process, they contain an excess of sulphur, which separates when sulphureted hydrogen is made to pass through them.

How formed.

The simplest way of considering these compounds is to conceive them as combinations of sulphureted hydrogen, sulphur, and the respective base. The relative proportions of the sulphur and sulphureted hydrogen seem capable of very considerable variation. A discussion has taken place upon this subject between Berthollet and Proust, interesting in the highest degree, both from the importance of the point in dispute, and the sagacity and profound knowledge of the disputants. Berthollet endeavoured long ago to demonstrate, that the alkaline bases are incapable of holding sulphur in solution, except by means of sulphureted hydrogen; in his *Statique Chimique* he illustrated his former opinion

The constituents vary considerably.

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* *Ann. de Chim.* xxv. 242.

at considerable length. Proust admits that sulphureted hydrogen is always present; but has brought a number of experiments to show, that in many cases the quantity is extremely minute, and that therefore it cannot be the medium of union between the liquid base and the sulphur. These experiments may be reduced under the three following heads: 1. Many of the hydrogureted sulphurets do not effervesce when treated with an acid, but merely deposite sulphur. 2. When the liquid hydrogurets are mixed with muriatic acid, hydrogureted sulphur is deposited; but the proportion of this last substance formed depends upon the proportion of sulphureted hydrogen contained in the hydroguret. Now many hydrogureted sulphurets, when treated in this manner, furnish only a few atoms of hydrogureted sulphur, and of course contain only a minute quantity of sulphureted hydrogen. 3. When mercury is agitated with a colourless hydrosulphuret, no change is produced upon the metal; but when it is agitated with a hydrogureted sulphuret, it combines with the sulphur and forms a black sulphuret. By this means the whole of the sulphur may be separated, and nothing remain but a colourless solution, consisting of the sulphureted hydrogen and the bases holding a little black sulphuret of mercury in solution. When the solution is sufficiently diluted with water this black sulphuret falls down, and leaves a pure hydrosulphuret behind. Now when this method is taken with some hydrogureted sulphurets, only a very minute portion of hydrosulphuret remains. Such are the proofs which Mr Proust has brought forward in support of his opinion.

Berthollet allows the accuracy of the two first experiments, but explains them in a different manner. He had formerly shown, that when sulphurous acid and sulphureted hydrogen came into contact, they mutually decompose each other, and are converted into water and sulphur; that when a hydrosulphuret is exposed to the air it becomes coloured, in consequence of the decomposition of a portion of sulphureted hydrogen by the absorption of oxygen, water being formed, and a quantity of sulphur disengaged, which enters into combination with the liquid, and converts it into a hydrogureted sulphuret; and that when the decomposition of the sulphureted hydrogen had proceeded in this way till a certain portion of sulphur was set at liberty, then the oxygen absorbed began to combine likewise with the sulphur, converting it into sulphurous acid. Now, according to him, all those hydrogureted sulphurets which do not effervesce with acids, and which form but a minute quantity of hydrogureted sulphur when mixed with acids, contain both sulphurous acid and sulphureted hydrogen. When an acid is added they are disengaged together, and mutually decompose each other. If the sulphurous acid exceed, there is no smell of sulphureted hydrogen whatever; but the odour of burning sulphur gradually becomes sensible. The contrary happens if the proportion of hepatic gas be greatest. This explanation is exceedingly ingenious, and it must be allowed also to be satisfactory, provided it can be shown that sulphurous acid is actually present in the cases alleged. This is very likely to be the case, though it may be difficult to demonstrate it in every case.

As to the third experiment of Proust, Berthollet denies its precision. Proust lays it down as established, that when mercury is agitated with a hydrogureted sulphuret, it combines only with the sulphur, and does not touch the sulphureted hydrogen; while the red oxide of mercury, on the other hand, decomposes the sulphureted hydrogen, and combines with its sulphur without touching the sulphur of the hydrogurot. The result of Berthollet's trials was, that both mercury and its red oxide acted upon the sulphur and the sulphureted hydrogen, but that the phenomena varied according to the proportions of the different substances employed *. Upon the whole, Berthollet's opinion appears to be well founded, though he has perhaps pushed it a little too far.

Hydrogureted sulphuret of potash.

1. When the hydrate of potash and flowers of sulphur are mixed together in a phial, they act upon each other in a very short time, heat is evolved, and hydrogureted sulphuret formed of a fine red colour, which exhales sulphureted hydrogen gas when treated with an acid. Liquid potash of the specific gravity 1·26, when kept for 10 or 12 hours upon flowers of sulphur, dissolves it and forms a similar compound. When heat is applied the combination takes place much sooner. When dry sulphuret of potash is dissolved in water, the same kind of compound is produced †. In all these cases the appearance of the hydrogureted sulphuret is the same, though its properties differ considerably. When it is formed by heat, the quantity of sulphureted hydrogen which it yields by means of acids is always inconsiderable, and often not perceptible. By trial, I find that this depends in a great measure upon the care with which it has been kept from the contact of the air.

Liquid hydrogureted sulphuret of potash or soda, thus formed, is a liquid of a deep red colour verging upon

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* *Jour. de Phys.* lix. 260.; lx. 284, and 347.

† Proust, *Jour. de Phys.* lix. 266.

brown; sometimes it has no smell; sometimes, as noticed by Proust, it has the smell of radishes; and by keeping it acquires the smell of sulphureted hydrogen. Its taste is acrid, and as it were bitter and cooling. It stains the skin of a deep green. When kept in close vessels, it is said to deposite sulphur and to become colourless, being converted into a hydrosulphuret *. It attacks with great energy every metal, and often reduces it to the state of a sulphuret. Stahl demonstrated long ago, that it is capable of dissolving even gold. The nature of his solution has not been ascertained. By means of acids the gold is thrown down in the metallic state, and mixed with sulphur.

Ammonia.

2. When ammonia is kept in contact with the flowers of sulphur, it gradually dissolves a portion of it, and assumes a yellow colour, but does not acquire the odour of sulphureted hydrogen †. Hydrogureted sulphuret of ammonia may be obtained by pouring on sulphur the hydrosulphuret of ammonia. The last portion of the liquid which passes over during the distillation of the *fuming liquor of Boyle* is also a hydrogureted sulphuret. This compound very readily deposites the excess of sulphur which it contains, and approaches to the state of a hydrosulphuret.

Barytes and strontian.

3. The hydrogureted sulphurets of barytes and strontian may be procured by dissolving their sulphurets in water, or even by exposing them to the open air. They have a green colour and acrid taste, but much inferior

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* With me this has never happened, though I have kept it in close vessels for years. It soon becomes colourless in vessels not closely shut, being converted into sulphate of potash.

† Proust, *Jour. de Phys.* lix. 269.

in intensity to the fixed alkaline hydrogureted sulphurets: neither is their action on other bodies so powerful.

Lime.

4. When a mixture of lime and sulphur is boiled in water, the liquid assumes a beautiful orange colour, and contains in solution hydrogureted sulphuret of lime. This liquid has likewise a very bitter taste. It is the only liquid at present known which is capable of dissolving a notable quantity of azotic gas. When kept in close phials, it gradually deposites sulphur in the state of black crust, and becomes perfectly colourless.

Magnesia,

5. The hydrogureted sulphuret of magnesia may be formed by the same processes as the others. This compound has scarcely been examined. It has but little permanency.

6. It has not been proved that the earths proper are capable of combining with supersulphureted hydrogen, and forming hydrogureted sulphurets.

III. METALLIC HYDROSULPHURETS AND HYDROGURETED SULPHURETS.

The hydrosulphurets and hydrogureted sulphurets have the property of precipitating all metallic bodies, except rhodium, from any solution in which they may be contained. They are therefore very valuable tests of the presence of metals, as they do not precipitate any of the earths except alumina and zirconia. The metallic precipitates are occasioned by the combination of sulphureted hydrogen, supersulphureted hydrogen, or of sulphur, with the metallic body, which is always deprived of a portion or of the whole of its oxygen, while at the same time the base of the hydrosulphuret combines with the acid which held the oxide in solution.

The precipitate of alumina and zirconia is occasioned by the base of the hydrosulphuret, while the sulphureted hydrogen is exhaled in the state of gas, not being susceptible of combining with these earths. Hydrosulphuret, or hydrogureted sulphuret of potash or ammonia, is usually made choice of for these precipitations; and the peculiar metal precipitated may in many cases be ascertained by the colour of the precipitate. The colour of these different precipitates may be seen by the following Table:

Colour of the precipitates.

Metals.	Precipitate by	
	Hydrosulphuret of Potash.	Hydrogureted Sulphuret of Potash.
Gold	Black	Black.
Platinum	Black	Black.
Silver	Black	Black.
Mercury	Brown black	Brown, becoming black.
Palladium	Black	
Copper	Black	Brown.
Iron	Black	Black, becoming yellow.
Nickel	Black	Black.
Tin	Black	Black.
Lead	Black	White, becoming black.
Zinc	White	White.
Bismuth	Black	Black.
Antimony	Orange	Orange-yellow.
Tellurium	Black?	Deep brown or black.
Arsenic	Yellow	Yellow.
Cobalt	Black	Black.
Manganese	White	White.
Chromium	Green	
Molybdenum	Reddish brown	

Metals.	Precipitate by Hydrosulphuret of Potash.	Hydrogureted Sulphuret of Potash.
Uranium ..	Brown	Brownish-yellow *.
Titanium ..	Glass green .	Bluish-green *.
Columbium	Chocolate.	
Cerium....	Brown.	

The nature of these precipitates has been very much overlooked by chemists; yet the subject deserves a very particular investigation, as it would enable us to ascertain the nature of the compounds which metals and their oxides form with sulphur and its compounds with hydrogen. The following remarks are all that can be at present offered.

1. Almost all the metals combine with sulphur, and form sulphurets which are tasteless, insoluble in water, brittle, and often possess the metallic lustre †.

Sulphurets.

2. In all these combinations there is a certain portion of sulphur only, which can be made to combine with the metal. If a greater quantity be used, the surplus makes its escape during the combination. In most metallic sulphurets, the metals are combined with a maximum of sulphur, and no other combination can be produced; while in others the proportion of sulphur varies. In these last, two distinct sets of compounds have been recognized; the first set contains a minimum, and the second a maximum of sulphur. The first of these, for the sake of distinction, may be called *sulphu-*

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* In these experiments hydrosulphuret of ammonia was used by Klaproth.

† See Volume I. p. 395, and Book I. Division I. Chapter IV.

rets, the second *supersulphurets*. The following Table exhibits the names and respective colours of all of these two sets hitherto ascertained to exist:

	Sulphuret.	Supersulphuret.
Mercury	Black	Red
Copper	Yellow	Yellow
Iron	Yellow	Yellow
Lead	Blue	Blue

3. Sulphur reduces many oxides to the metallic state; but with others it seems to combine, and to form compounds which may be called sulphureted oxides. Two such compounds have been examined and described by chemists; namely sulphureted oxide of tin, and of manganese.

Action of sulphureted hydrogen.

4. Whether sulphureted hydrogen be capable of combining with metals has not been ascertained. The analogy of other acids would lead us to conclude that it is not; but in chemistry analogies are always dangerous, and generally mislead. The facility with which sulphureted hydrogen gas tarnishes lead, brass, and silver, is known to all practical chemists; but in these cases the gas seems decomposed, and a simple sulphuret only to be formed. Water impregnated with this gas dissolves some of the metals, especially iron; but it is probable that the metal in these cases is converted into an oxide.

5. It seems to have the property of reducing the greater number of oxides to the metallic state. Hence the reason of the precipitates which it throws down

from metallic solutions. The hydrogen of the gas and the oxygen of the oxide mutually unite, while the sulphur and the metal reduced fall down in combination. Most of the metallic precipitates are nothing else than common sulphurets. To this, however, there are several exceptions.

Hydrosulphuret of mercury,

Proust has shown that the red oxide of mercury has the property of decomposing the sulphureted hydrogen of hydrosulphurets *, while Berthollet has ascertained that the rapidity of the effect depends upon the proportion of the substances employed †. When red oxide of mercury is agitated in a liquid hydrosulphuret, a black powder is formed. This black powder, when heated, passes rapidly into cinnabar. The same change takes place slowly if it be exposed to the light. From these facts Berthollet has concluded, that this black powder consists, at least partly, of oxide of mercury and sulphureted hydrogen, and that by the action of heat the mutual decomposition of the gas and oxide is accelerated. If this be correct, the black powder may be considered as consisting, at least partly, of hydrosulphuret of mercury.

Of tin.

When sulphureted hydrogen or a hydrosulphuret is poured into a salt of tin, a precipitate is produced, varying in colour according to the state of oxidizement of the metal. With the peroxide it is a golden yellow; with the protoxide, a dark brown. Proust informs us, that both of these precipitates are hydrosulphurets, or combinations of sulphureted hydrogen with the respective oxides of tin unchanged. When muriatic acid is

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* *Jour. de Phys.* lix. 268.

† Ibid. lx. 288.

poured upon them, the sulphureted hydrogen is driven off, and muriated tin formed*.

Metals not precipitated by sulphureted hydrogen.

There are five metals known which are not precipitated from their solution in acids by sulphureted hydrogen; namely, iron, nickel, cobalt, manganese, titanium, cerium. Hence we are entitled to conclude, that this substance is unable to reduce the oxides of these metals to the metallic state. It is probable that sulphureted hydrogen is capable of uniting with the oxides of these metals, and forming with them hydrosulphurets. We know that this is the case with some of them; nor is it unreasonable to believe, that several other metallic protoxides are capable of entering into similar combinations. The following are the metallic hydrosulphurets at present known:

Hydrosulphuret of Tin. Both oxides of tin unite with sulphureted hydrogen: Hydrosulphureted protoxide is dark brown; hydrosulphureted peroxide, golden yellow.

Hydrosulphuret of Zinc. Zinc is thrown down from acids in the state of a yellowish-white mass by the hydrosulphuret of potash or ammonia. This mass dissolves completely in muriatic acid, and at the same time a great quantity of sulphureted hydrogen is exhaled. Hence it is obviously a hydrosulphuret. It may be formed also by treating the white oxide of zinc with hydrosulphuret of ammonia†. Vauquelin remarks, that the transparent specimens of *native sulphuret of zinc* or *blende* often dissolve in the same way, emitting sul-

Blende.

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* *Jour. de Phys.* lix. 336.

† See Berthollet's Table, *Ann. de Chim.* xxv. 272.

phureted hydrogen *. It is possible that these specimens approach the nature of hydrosulphuret of zinc. In that case there would be three different kinds of minerals at present confounded under the term *blende*; namely, sulphuret of zinc, sulphureted oxide of zinc, and hydrosulphuret of zinc. But this must be left for subsequent investigation.

Hydrosulphuret of Antimony. When hydrosulphuret of potash or ammonia is dropt into an acid solution of antimony, a beautiful orange-coloured precipitate falls, which the experiments of Berthollet, Thenard, and Proust have demonstrated to be a hydrosulphuret of antimony. This compound, under the name of *kermes mineral*, acquired very great celebrity for its medical virtues about the beginning of the 18th century. The method of preparing it was first discovered by Glauber, and afterwards by Lemery the Elder; but it was first brought into vogue in France by a priest called Simon, who was taught the secret of preparing it by La Ligerie, a surgeon, to whom it had been communicated by a pupil of Glauber. The French government purchased the secret from La Ligerie, and published the process in 1720. It was very tedious and ill contrived, consisting in boiling repeatedly a very diluted solution of potash on sulphuret of antimony; a small portion of kermes precipitated as the solution cooled. The process of Lemery was therefore adopted by apothecaries. It is the following:

Kermes mineral.

Sixteen parts of sulphuret of antimony, eight parts of potash of commerce, and one part of sulphur, are tri-

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* *Ann. de Chim.* xxxvii. 66.

turated together in a mortar, melted in a crucible, and the mass poured into an iron vessel. When cold it is pounded, and boiled in a sufficient quantity of water, and the solution is filtered while hot. On cooling, it deposites the kermes abundantly in the state of a yellow powder, which is edulcorated with a sufficient quantity of water, and dried: Or six parts of potash may be dissolved in twenty parts of water; and to this solution, previously made boiling hot, one part of pounded sulphuret of antimony may be added. The solution, well agitated, boiled for seven or eight minutes, and filtered while hot, deposites on cooling abundance of kermes.

This powder occupied a good deal of the attention of chemists. Bergman first demonstrated that it contained sulphureted hydrogen; but it was Berthollet who first pointed out its true composition. From the analysis of Thenard it follows that it is composed of

20·30	sulphureted hydrogen
4·15	sulphur
72·76	protoxide of antimony
2·79	water and loss
100·00 *	

When this substance is exposed to the air, it gradually absorbs oxygen and becomes white, and the sulphureted hydrogen exhales.

After the mineral kermes has precipitated from its solution, prepared by either of the formulas above described, if an acid be added to the liquid, another pre-

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* *Ann. de Chim.* xxxii. 268.

Book II. Division III.

Sulphur auratum.

cipitate is produced of an orange colour; hence called *sulphur auratum*. According to the analysis of Thenard, it is composed of

17·87	sulphureted hydrogen
68·30	protoxide
12·00	sulphur
98·17 [*]	

Hence it is a hydrosulphuret with excess of sulphur and a smaller proportion of base. Goettling has proposed the following process for obtaining this compound: Two parts of sulphuret of antimony and three parts of sulphur, well mixed, are dissolved in a boiling solution of pure potash; the solution is then diluted with water, and precipitated by means of weak sulphuric acid [†].

Hydrosulphuret of Manganese. When the black oxide of manganese is treated with sulphureted hydrogen water, its black colour disappears; a portion of the sulphureted hydrogen is decomposed at the expence of the oxygen of the black oxide; and the white oxide, thus evolved, is dissolved by the sulphureted hydrogen, and by evaporation a white mass is obtained, which dissolves completely in muriatic acid, while abundance of sulphureted hydrogen is exhaled. It is therefore a hydrosulphuret of manganese [‡]. The same compound is

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[*] *Ann. de Chim.* xxxii. 268.

[†] Bergman, iii. 172. The experiments of Proust on these compounds are highly interesting, but too long for insertion here. See *Jour. de Phys.* lv. 328.

[‡] Berthollet, *Ann. de Chim.* xxv. 238.

obtained when hydrosulphuret of potash is mixed with a salt of manganese.

Hydrosulphuret of Arsenic. Sulphureted hydrogen combines with the white oxide of arsenic dissolved in water. The liquid assumes a yellow colour, but no precipitate appears. Hence the hydrosulphuret of arsenic, like that of manganese, is soluble in water, at least by the assistance of an excess of sulphureted hydrogen. This hydrosulphuret exactly resembles in appearance yellow sulphuret of arsenic.

Hydrosulphuret of Iron. Sulphureted hydrogen combines with the green oxide of iron, and the compound is soluble in water; but the solution soon lets fall a black powder, which is a hydrogureted sulphuret of iron.

6. Whether any of the metals or their oxides be capable of forming the combinations called hydrogureted sulphurets, has not been ascertained in a satisfactory manner, though it is not improbable that they are. But this important subject requires a much more complete investigation than it has hitherto received.

Book II. Division III.

CHAP. V.

OF SOAPS.

THE fixed oils have the property of combining with alkalies, earths, and metallic oxides, and of forming with these bodies a class of compounds which have received the name of SOAPS. As these soaps differ from each other very materially, according as their base is an alkali, an earth, or an oxide, it will be proper to consider each set separately. This will be the subject of the three following Sections.

SECT. I.

OF ALKALINE SOAPS.

As there are a great number of fixed oils, all or most of which are capable of combining with alkalies, earths, and oxides, it is natural to suppose that there are as many genera of alkaline soaps as there are oils. That there are differences in the nature of soaps, corresponding to the oil which enters into their composition, is certain; but these differences are not of sufficient importance to require a particular description. It will be sufficient therefore to divide the alkaline soaps into as many species as there are alkalies, and to consider those soaps which have the same alkaline base, but differ in their oil, as varieties of the same species.

Sp. 1. *Soap of Soda or Hard Soap.*

History.

THE word *soap* (*sapo*, *σαπων*) first occurs in the works of Pliny and Galen, and is evidently derived from the old German word *sepe*[*]. Pliny informs us that soap was first discovered by the Gauls; that it was composed of tallow and ashes; and that the German soap was reckoned the best[†].

Preparation.

Soap may be prepared by the following process: A quantity of the soda of commerce is pounded and mixed in a wooden vessel with about a fifth part of its weight of lime, which has been slacked and passed through a sieve immediately before. Upon this mixture a quantity of water is poured, considerably more than what is sufficient to cover it, and allowed to remain on it for several hours. The lime attracts the carbonic acid from the soda, and the water becomes strongly impregnated with the pure alkali. This water is then drawn off by means of a stop-cock, and called the *first ley*. Its specific gravity should be about 1·200.

Another quantity of water is then to be poured upon the soda, which, after standing two or three hours,

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[*] Beckmann's *History of Inventions*, iii. 239. A similar word is still used by the common people of Scotland.

[†] Pliny, lib. xviii. c. 51.

is also to be drawn off by means of the stop-cock, and called the *second ley*.

Another portion of water is poured on; and after standing a sufficient time, is drawn off like the other two, and called the *third ley*.

Another portion of water may still be poured on, in order to be certain that the whole of the soda is dissolved; and this weak ley may be put aside, and employed afterwards in forming the first ley in subsequent operations.

A quantity of oil, equal to six times the weight of the soda used, is then to be put into the boiler, together with a portion of the *third* or *weakest ley;* and the mixture must be kept boiling and agitated constantly by means of a wooden instrument. The whole of the third ley is to be added at intervals to the mixture; and after it is consumed, the *second ley* must be added in the same manner. The oil becomes milky, combines with the alkali, and after some hours it begins to acquire consistence. A little of the *first ley* is then to be added, not forgetting to agitate the mixture constantly. Portions of the first ley are to be added at intervals; the soapy substance acquires gradually greater consistency, and at last it begins to separate from the watery part of the mixture. A quantity of common salt is then to be added, which renders the separation much more complete. The boiling is to be continued still for two hours, and then the fire must be withdrawn, and the liquor must be no longer agitated. After some hours repose, the soap separates completely from the watery part, and swims upon the surface of the liquor. The watery part is then to be drawn off; and as it contains a quantity of carbonate of soda, it ought to be reserved for future use.

The fire is then to be kindled again; and, in order to facilitate the melting of the soap, a little water, or rather weak ley, is to be added to it. As soon as it boils, the remainder of the first ley is to be added to it at intervals. When the soap has been brought to the proper consistence, which is judged of by taking out small portions of it and allowing it to cool, it is to be withdrawn from the fire, and the watery part separated from it as before. It is then to be heated again, and a little water mixed with it, that it may form a proper paste. After this let it be poured into the vessels proper for cooling it; in the bottom of which there ought to be a little chalk in powder, to prevent the soap from adhering. In a few days the soap will have acquired sufficient consistence to be taken out, and formed into proper cakes *.

The use of the common salt in the above process is to separate the water from the soap; for common salt has a stronger affinity for water than soap has.

Olive oil has been found to answer best for making soap, and next to it perhaps tallow may be placed: but a great variety of other oils may be employed for that purpose, as appears from the experiments of the French chemists above quoted. They found, however, that linseed oil and whale oil were not proper for making *hard soaps,* though they might be employed with advantage in the manufacture of *soft soaps.* Whale oil has been long used by the Dutch for this last purpose.

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* See the Memoir of Darcet, Lelievre, and Pelletier, in the *Ann. de Chim.* xix. 253.

Soaps may also be made without the assistance of heat; but in that case a much longer time and a larger proportion of alkali is necessary.

Sophistication.

Manufacturers have contrived various methods of sophisticating soap, or of adding ingredients which increase its weight without increasing its value. The most common substance used for that purpose is water; which may be added in considerable quantities, especially to soap made with tallow (the ingredient used in this country), without diminishing its consistency. This fraud may be easily detected, by allowing the soap to lie for some time exposed to the air. The water will evaporate from it, and its quantity will be discovered by the diminution of the weight of the soap. As soap sophisticated in this manner would lose its water by being kept, manufacturers, in order to prevent that, keep their soap in saturated solutions of common salt; which do not dissolve the soap, and at the same time, by preventing all evaporation, preserve, or rather increase the weight of the soap. Messrs Darcet, Lelievre, and Pelletier, took two pieces equal in weight of soap sophisticated in this manner, and placed the one in a dry place in the open air, and the other in a saturated solution of common salt. After a month the first had lost 0·56 of its weight, the other had gained about 0·10 parts *. Various other methods have been fallen upon to sophisticate soap; but as they are not generally known, it would be doing an injury to the public to describe them here.

Analysis.

Different chemists have analysed soap, in order to as-

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* *Ann. de Chim.* xix. 330.

certain the proportions of its ingredients; but the result of their experiments is various, because they used soap containing various quantities of water. From the experiments of Darcet, Lelievre, and Pelletier, it appears that soap newly made and exposed to sale contains

60·94	oil
8·56	alkali
30·50	water
100·00	

Soap is soluble both in water and in alcohol. Its properties as a detergent are too well known to require any description.

Soap made with tallow and soda has a white colour, and is therefore known by the name of *white* soap: but it is usual for soap-makers, in order to lower the price of the article, to mix a considerable portion of rosin with the tallow; this mixture forms the common *yellow soap* of this country.

Sp. 2. *Soap of Potash or Soft Soap.*

Formation.

Potash may be substituted for soda in making soap, and in that case precisely the same process is to be followed. It is remarkable, that when potash is used, the soap does not assume a solid form; its consistence is never greater than that of hog's lard. This is what in this country is called *soft soap*. Its properties as a detergent do not differ materially from those of *hard soap*, but it is not nearly so convenient for use. The alkali employed by the ancient Gauls and Germans in the formation of soap was potash; hence we see the reason that it is described by the Romans as an unguent.

The oil employed for making soft soap in this country is whale oil. A little tallow is also added, which, by peculiar management, is dispersed through the soap in fine white spots.

Some persons have affirmed that they knew a method of making hard soap with potash. Their method is this: After forming the soap in the manner above described, they add to it a large quantity of common salt, boil it for some time, and the soap becomes solid when cooled in the usual way. That this method may be practised with success has been ascertained by Messrs Darcet, Lelievre, and Pelletier; but then the hard soap thus formed does not contain potash but soda; for when the common salt (muriate of soda) is added, the potash of the soap decomposes it, and combines with its muriatic acid, while at the same time the soda of the salt combines with the oil, and forms hard soap: and the muriate of potash formed by this double decomposition is dissolved in water, and drawn off along with it *.

Soap of wool.

Chaptal has lately proposed to substitute wool in place of oil in the making of soap. The ley is formed in the usual manner, and made boiling hot, and shreds of woollen cloth of any kind are gradually thrown into it; they are soon dissolved. New portions are to be added sparingly, and the mixture is to be constantly agitated. When no more cloth can be dissolved, the soap is made †. This soap is said to have been tried with success. It might doubtles be substituted for soap with advantage in several manufactures, provided it can be

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* *Ann. de Chim.* xix. 322.

† Ibid. xxi. 27.

obtained at a cheaper rate than the soaps at present employed.

Fish soap.

Some time ago a proposal was made to substitute the muscles of fish instead of tallow or oil in the manufacture of soap; but the experiments of Mr Jameson have demonstrated that they do not answer the purpose*.

Sp. 3. *Soap of Ammonia.*

THIS soap was first particularly attended to by Mr Berthollet. It may be formed by pouring carbonate of ammonia on soap of lime. A double decomposition takes place, and the soap of ammonia swims upon the surface of the liquor in the form of an oil; or it may be formed with still greater ease by pouring a solution of muriate of ammonia into common soap dissolved in water.

It has a more pungent taste than common soap. Water dissolves a very small quantity of it; but it is easily dissolved in alcohol. When exposed to the air, it is gradually decomposed. The substance called *volatile liniment*, which is employed as an external application in rheumatisms, colds, &c. may be considered as scarcely any thing else than this soap.

All the alkaline soaps agree in the properties of solubility in water and alcohol, and in being powerful detergents.

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* Nicholson's *Jour.* iii. 113.

SECT. II.

OF EARTHY SOAPS.

THE earthy soaps differ essentially from the alkaline in their properties. They are insoluble in water, and incapable of being employed as detergents. They may be formed very readily by mixing common soap with a solution of an earthy salt: the alkali of the soap combines with the acid of the salt, while the earth and oil unite together and form an earthy soap. Hence the reason that all waters holding an earthy salt are unfit for washing. They decompose common soap, and form an earthy soap insoluble in water. These waters are well known by the name of *hard* waters. Hitherto the earthy soaps have been examined by Mr Berthollet only.

Sp. 1. *Soap of Lime.*

THIS soap may be formed by pouring lime-water into a solution of common soap. It is insoluble both in water and alcohol. Carbonate of fixed alkali decomposes it by compound affinity *. It melts with difficulty, and requires a strong heat.

Soap of barytes and of strontian resemble almost exactly the soap of lime.

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* Thouvenel.

Sp. 2. Soap of Magnesia.

THIS soap may be formed by mixing together solutions of common soap and sulphate of magnesia. It is exceedingly white. It is unctuous, dries with difficulty, and preserves its whiteness after desiccation. It is insoluble in boiling water. Alcohol and fixed oil dissolve it in considerable quantity. Water renders its solution in alcohol milky. A moderate heat melts it; a transparent mass is formed, slightly yellow, and very brittle [*].

Sp. 3. Soap of Alumina.

THIS soap may be formed by mixing together solutions of alum and of common soap. It is a flexible soft substance, which retains its suppleness and tenacity when dry. It is insoluble in alcohol, water, and oil. Heat easily melts it, and reduces it to a beautiful transparent yellowish mass [†].

SECT. III.

OF METALLIC SOAPS AND PLASTERS.

METALLIC OXIDES are capable of combining with oils by two different processes: 1. By mixing together a solution of common soap with a metallic salt; 2. By

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[*] Berthollet, *Mem. Par.* 1780, or Nicholson's *Jour.* i. 170.

[†] Ibid.

uniting the metallic oxide with the oil directly, either cold or by the assistance of heat. The first of these combinations is called a *metallic soap*; the second a *plaster*. Let us consider each of these in their order.

I. *Metallic Soaps.*

THESE soaps have been examined by Mr Berthollet, who has proposed some of them as paints, and others as varnishes; but it does not appear that any of them has been hitherto applied to these purposes.

1. *Soap of mercury* may be formed by mixing together a solution of common soap and of corrosive muriate of mercury. The liquor becomes milky, and the soap of mercury is gradually precipitated. This soap is viscid, not easily dried, loses its white colour when exposed to the air, and acquires a slate colour, which gradually becomes deeper, especially if exposed to the sun or to heat. It dissolves very well in oil, but sparingly in alcohol. It readily becomes soft and fluid when heated *.

2. *Soap of zinc* may be formed by mixing together a solution of sulphate of zinc and of soap. It is of a white colour, inclining to yellow. It dries speedily, and becomes friable †.

3. *Soap of cobalt*, made by mixing nitrate of cobalt and common soap, is of a dull leaden colour, and dries with difficulty, though its parts are not connected.

Mr Berthollet observed, that towards the end of the

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* Berthollet, *Mem. Par.* 1780, or Nicholson's *Journal*, i. 170.

† Ibid.

precipitation there fell down some green coagula, much more consistent than soap of cobalt. These he supposed to be a soap of nickel, which is generally mixed with cobalt *.

4. *Soap of tin* may be formed by mixing common soda with a solution of tin in nitro-muriatic acid. It is white. Heat does not fuse it like other metallic soaps, but decomposes it †.

5. *Soap of iron* may be formed by means of sulphate of iron. It is of a reddish-brown colour, tenacious, and easily fusible. When spread upon wood, it sinks in and dries. It is easily soluble in oil, especially of turpentine. Berthollet proposes it as a varnish ‡.

6. *Soap of copper* may be formed by means of sulphate of copper. It is of a green colour, has the feel of a resin, and becomes dry and brittle. Hot alcohol renders its colour deeper, but scarcely dissolves it. Ether dissolves it, liquefies it, and renders its colour deeper and more beautiful. It is very soluble in oils, and gives them a pleasant green colour §.

7. *Soap of lead* may be formed by means of acetate of lead. It is white, tenacious, and very adhesive when heated. When fused it is transparent, and becomes somewhat yellow if the heat be increased ||.

8. *Soap of silver* may be formed by means of nitrate of silver. It is at first white, but becomes reddish by exposure to the air. When fused, its surface becomes covered with a very brilliant iris; beneath the surface it is black ¶.

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* Berthollet, *Mem. Par.* 1780, or Nicholson's *Jour.* i. 170.

† Ibid. ‡ Ibid. § Ibid. || Ibid. ¶ Ibid.

9. *Soap of gold* may be formed by means of muriate of gold. It is at first white, and of the consistence of cream. It gradually assumes a dirty purple colour, and adheres to the skin, so that it is difficult to efface the impression *.

10. *Soap of manganese* may be formed by means of sulphate of manganese. It is at first white, but it assumes in the air a reddish colour, owing evidently to the absorption of oxygen. It speedily dries to a hard brittle substance, and by liquefaction assumes a brown blackish colour †.

II. *Plasters.*

Properties.

Plasters are combinations of oils and metallic oxides destined to be spread upon leather or cloth, and in that state to be applied as a covering of ulcers, &c. They ought to be solid bodies, not so hard as to refuse to spread easily and equally, nor so soft as to run into oil when heated by the skin. They ought to admit of being easily kneaded when heated with the hand, to adhere firmly to the skin, but to be capable of being removed without leaving behind them any stain. Without these properties they do not answer the purpose for which they are destined, which is chiefly adhesion.

The only chemist who has hitherto examined plasters with attention is Deyeux, to whom we are indebted for some excellent observations on the method of preparing them ‡.

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* Berthollet, *Mem. Par.* 1780, or Nicholson's *Journal*, i. 170.

† Ibid.

‡ *Ann. de Chim.* xxxiii. 50.

The oxides hitherto employed for making plasters are those of lead; and *litharge* is usually considered as the best adapted for that purpose of any of these oxides. But the oxides of several of the other metals, as bismuth and mercury, are also capable of forming plasters, and might perhaps in some cases be employed with advantage. Some metallic oxides, however, as those of iron, are not susceptible of that kind of combination with oils which constitutes plasters *. Oxides used.

All the fixed oils are capable of forming plasters; but they do not all form plasters with the same properties. The *drying* oils, linseed oil for instance, form plasters of a much softer consistency than the *fat* oils; but these last acquire the same properties as the drying oils if they be combined with mucilage. Thus olive oil, boiled for some time with linseed or fenugrec, forms with litharge plasters as soft as those composed of linseed oil and litharge. According to Deyeux, olive oil answers better for plasters than any other. Oils.

There are three different ways of forming plasters. The first consists in simply mixing together oil and litharge in proper proportions, and allowing the mixture to remain a considerable time in the common temperature of the atmosphere, agitating it occasionally. The oxide gradually loses its colour and combines with the oil, and the mixture acquires consistence. This process is tedious, and does not furnish plasters sufficiently solid to answer the purposes for which they are intended. It is not therefore employed. Formation. 1st Process.

The second method consists in throwing the oxide 2d Process.

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* Deyeux, *Ann. de Chim.* xxxiii. 50.

Book II. Division III.

into the oil while boiling. Plasters formed by this process have always a deep colour and a peculiar odour, occasioned by the decomposition of a portion of the oil. When this process is followed, it is necessary that the oxide should be in the state of a fine powder; and that by agitation it should be made to combine with the oil as fast as possible, otherwise the metal will be revived altogether, in consequence of the strong tendency which oil has to combine with oxygen when raised to a high temperature.

3d Process.

The third method is most frequently practised, because it is not liable to the same inconveniences as the other two. This method consists in boiling the oil and the oxide together in a sufficient quantity of water. By this liquid the heat is moderated at first till the oil and oxide combine, which prevents the revival of the metal; and afterwards when the water is dissipated, the temperature is sufficiently high to give the plaster the requisite consistency.

Plasters, when long kept, become often too hard to be fit for use, especially if the requisite proportion of oil has not been employed at first. This defect is easily remedied, by melting them with a small portion of new oil. Plasters, when long kept, likewise change their colour, and most of their sensible properties: owing either to the absorption of oxygen, or to some change produced in their component parts by the action of the air.

CHAP. VI.

REMARKS ON THE SECONDARY COMPOUNDS.

The secondary compounds are incomparably more numerous than the primary; because they approach much nearer the actual component parts of the mineral, vegetable, and animal kingdoms. Indeed a very considerable proportion of them exist native, especially in the mineral kingdom; and that number will no doubt increase as the science of chemistry extends its bounds.

Secondary compounds resemble simple bodies.

Few of the secondary compounds have that activity, that violent action upon other bodies, which distinguish the primary compounds. In this respect they bear a strong resemblance to the simple substances. Sulphur, for instance, is a body which has scarcely any taste, and which acts but feebly upon animals, and not at all perceptibly upon vegetables and minerals; and oxygen, though it undoubtedly merits the appellation of an active body, shows neither in its taste nor in its action on animals and vegetables any thing which deserves the name of acrid or caustic; but sulphuric acid, though composed of these two inoffensive bodies, is one of the most active and corrosive substances known, and burns and decomposes almost all the animal and vegetable bodies which are exposed to its influence. Potash is, if possible, still more corrosive; even the hardest mineral is unable to resist its action. But sulphate of potash, though composed of these two formidable bodies, is not more active than sulphur itself. This singular correspondence between simple substances and secondary compounds, and the striking contrast between them and the primary compounds, deserve attention. It demonstrates to us, that the activity of bodies is not proportional to their simplicity, as has been hitherto supposed; and that there is some other cause, besides combination with other bodies, to blunt their energy.

None of them gaseous

Several of the simple bodies exist commonly in the state of gas: this is the case also with the primary compounds; but no gaseous body is found among the secondary compounds, and only a comparatively small number of liquid bodies. Almost all of them are solid, and probably every one of them is susceptible of assuming that form. Hence we see that gaseous bodies have all of them a considerable degree of simplicity; few of them, as far as is known, containing more than two component parts, if we omit the consideration of light and caloric altogether; or three component parts, if we include these bodies.

Or combustible.

None of the secondary compounds are, properly speaking, combustible. The soaps, indeed, and the vegetable acid salts, are susceptible of undergoing a kind of combustion, but not till they have been previously decomposed by heat; and even then their combustion is not to be compared to that of some of the simple substances and primary compounds. Two genera of salts, namely, the nitrates and hyperoxymuriates, are supporters of combustion in a remarkable degree, occasioning violent detonations when triturated or heated along with combustibles. Many of the metallic salts are doubtless susceptible of supporting combustion as well as these genera, though hitherto the experiment has not been tried except upon a small number.

Better known than other bodies.

The scondary compounds have been analysed with more precision than any other class of bodies belonging to chemistry; and their formation and decomposition are more completely in the power of the chemist. The greater number of them may be formed and decomposed at pleasure; and approaches have been made towards ascertaining the proportions of the component parts of several of them. Accordingly it is from them that almost all our notions of the nature of affinity have been derived. It is to them that we have always recourse to illustrate these notions, or to put them to the test of experiment. What have been called *tables of affinity*, are nothing else than lists of the substances by which certain secondary compounds may be decomposed, or of the precipitations which take place when different secondary compounds are mixed together. It was necessary therefore to be acquainted with these bodies, and to know the mutual changes which they are capable of producing on each other, the decompositions of which they are susceptible, and the proportions of their component parts, before entering upon the consideration of *affinity*; which may be considered as constituting in reality the whole of the scientific part of chemistry, and as comprehending under it the general principles to which the immense mass of facts enumerated in the two preceding Books may be referred, and under which they may be arranged. We are now therefore prepared for entering upon this important subject, which will employ the whole of the succeeding Book.

BOOK III.

OF

AFFINITY.

Book III. In the two preceding Books the different substances which occupy the attention of chemists have been enumerated, their properties have been described, and the changes which they produce on each other have been fully detailed. We are thus in possession of the immense body of facts of which the science of chemistry is composed: they have been arranged in that order which seemed most proper for showing their mutual dependence on each other; and referred to a small number of general heads, that they might be remembered with facility or consulted without difficulty. It were to be wished that chemical phenomena could be referred to a few general laws, and shown to be the necessary results of these laws. It were to be wished that we knew the nature of these laws so precisely, as to be able to foretel beforehand the changes which result from the mutual action of bodies in every particular circumstance. This would save us the trouble of learning in detail an immense number of insulated facts which

Chemical laws.

at present are necessary for the practice of chemistry; it would enable us to apply the science with more effect to the arts and manufactures; it would enable us to trace the chemical changes which are going on in the atmosphere and the earth to their origin, and to foresee the future changes to which they are liable; and thus to form, what has hitherto been attempted in vain, a complete theory of meteorology and geology.

Still imperfectly known.

Unfortunately the efforts of philosophers to establish these general principles have not hitherto been attended with complete success; partly owing to the difficulty of the subject, and partly to the unaccountable negligence of the greater number of chemists, who have been more anxious to ascertain particular facts than to investigate general principles, and who have often seemed to look upon general principles as altogether foreign to their science. Happily this has not been the case with all chemists. Several, and these the most illustrious, have carefully classified the phenomena, and referred them under general heads; and if they have not succeeded in discovering laws sufficiently comprehensive to include all the chemical phenomena, have at least pointed out several pretty general ones, from the knowledge of which the mutual action of many bodies on each other may, in not a few cases, be foreseen, even prior to experiment. Among these philosophers, none stands higher than Bergman, who was not less distinguished by his industry and enthusiasm, than by his enlarged views and the happy acuteness with which he drew general conclusions. To Black and Lavoisier we are indebted for two of the most general and most important laws hitherto discovered in chemistry. Much has been done by Kirwan, whose profound knowledge, fortunately for the science, almost constantly leads him to general views. Morveau has been no less distinguished in this important career: with a mind capable of the most comprehensive range, he has classified the most difficult phenomena, and thrown light upon the abstrusest part of the science. And Berthollet has lately reviewed the general doctrines of chemistry with a sagacity peculiar to himself; and has not only corrected various errors which had passed current without detection, but has new-modelled the whole, and pointed out several new laws of the greatest importance.

The general principles of chemistry will form the subject of this third Book, which will be divided into five Chapters. In the *first* Chapter, we shall consider the nature of AFFINITY in general; in the *second*, we 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.

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 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 planetory 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. Attraction.

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. Universal.

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; consequently they are kept together 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, 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 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 the power of acting upon matter at a distance, as the power of being acted upon and changed by matter in actual contact.

But without reason.

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 contact 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.

Of two kinds.

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.

1. At sensible distances.

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 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 disap-

pear 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.

2. Affinity.

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 homogeneous 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 denoted 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 towards 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 compound bodies. Thus an integrant particle of water is composed of particles of hydrogen and oxygen, urged towards each other, and kept at an insensible distance by heterogeneous 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. Heterogeneous 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 taken for granted; though it is certainly assuming more than even analogy can warrant.

Increases with the mass.

11. Affinity, like sensible attraction, varies with the mass and the distance of the attracting bodies. That cohesion varies with the mass, cannot indeed be ascertained; because we have no method of varying the mass without at the same time altering the distance. But in cases of the adhesion of the surfaces of homogeneous bodies, which is undoubtedly an instance of homogeneous affinity, it has been demonstrated, that the force of adhesion increases with the surface, that is to say, with the mass; for the number of adhering particles must increase with the surface.

That heterogeneous affinity increases with the mass, has been observed long ago in particular instances, and has been lately demonstrated by Berthollet to hold in every case: thus a given portion of water is retained more obstinately by a large quantity of sulphuric acid than by a small quantity. Oxygen is more easily abstracted from those oxides which are oxidized to a maximum, than from those which are oxidized to a minimum; that is to say, that a large mass of metal retains a given quantity of oxygen more violently than a small mass. Lime deprives potash of only a portion of its carbonic acid, and sulphuric acid deprives phosphoric acid of only a portion of the lime with which it is united in phosphate of lime. In these, and many other instances that might be enumerated, a small portion of one body is retained by a given quantity of another more strongly than a large quantity. And Berthollet has shown, that in all cases a large quantity of a body is capable of abstracting a portion of another from a small portion of a third; how weak soever the affinity between the first and second of these bodies is, and how strong soever the affinity between the second and the third. Thus 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 base with which it was previously combined; tho' 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.

Inversely as the distance.

That the force of affinity increases as the distance diminishes, and the contrary, is obvious; for it becomes insensible whenever the distance is sensible, and, on the other hand, becomes exceedingly great when the distance is exceedingly diminished. But the particular rate which this variation follows is still unknown, as we have no method of measuring either the distances at which it acts, or its relative intensity at these distances. Some have supposed that it follows a greater ratio than $\frac{1}{d^2}$, and that it diminishes at least as $\frac{1}{d^3}$, if not at some greater rate. But their reasoning has depended altogether upon the supposition, that the particles of bodies united by affinity are in actual contact, and loses its force, or at least a considerable part of it, if we suppose, what seems actually to be the case, that even then these particles are at a distance. Others have supposed that the intensity of affinity varies inversely as the square of the distance, resting chiefly upon the analogy of sensible attraction, which follows that law. This is certainly a kind of presumption in favour of the opinion, and it must be allowed that no sufficient arguments have been advanced to prove that this law is incompatible with the phenomena of affinity. But neither, on the other hand, has any thing like proof been advanced to show that affinity actually varies according to that law. The truth is, that at present the subject is beyond the reach of philosophy. We must therefore suspend our judgment altogether till future discoveries put it in our power to determine the point.

12. Affinity, then, agrees with sensible attraction in

every point which it has been hitherto possible to determine. Like sensible attraction, it increases with the mass, and diminishes as the distance augments; consequently we must conclude that attraction, whether it be sensible or insensible, is in all cases the same kind of force, and regulated by precisely the same general laws.

We have seen that sensible attraction, though in all cases the *same kind* of force, is not always the *very same* force; for though the mass and the distance of two bodies be equal, the absolute force by which they are attracted towards each other by gravitation is not equal to the force by which they are attracted towards each other by magnetism. The forces of sensible attraction are three in number, namely, gravitation, magnetism, and electricity; the first is always the same when the mass and distance are the same, but the two last vary even when the mass and distance continue unaltered.

Affinity varies in intensity.

The forces of affinity, though also the same in kind, are still more numerous than those of sensible attraction; for instead of three, they amount to as many as there are heterogeneous bodies. The rate, indeed, at which they vary when the distance of the attracting bodies increases or diminishes, is probably the same in all, and so is also their variation as far as it regards the mass. But even when both of these circumstances, as far as we can estimate them, are the same, the affinity of two bodies for a third is not the same. Thus barytes has a stronger affinity for sulphuric acid than potash has: for if equal quantities of each be mixed with a small portion of sulphuric acid, the barytes seizes a much greater proportion of the acid than the potash does. This difference in intensity extends to particles of all bodies; for there are scarcely any two bodies whose particles have precisely the same affinity for a third, and scarcely any two bodies, the particles of each of which cohere together with exactly the same force.

It is this difference in intensity which constitutes the most important characteristic mark of affinity, and which explains the different decompositions and changes which one body occasions in others.

Thus it appears at first sight, that there are as many different affinities as there are bodies; and that affinity, instead of being one force like gravitation, which is always the same when the circumstances are the same, consists of a variety of different forces, regulated, indeed, by the same kind of laws, but all of them different from each other. These affinities do not vary like magnetism and electricity, though the mass continues the same, but are always of equal intensity when other circumstances are equal. Hence it is reasonable to conclude, that these affinities cannot, like magnetism and electricity, depend upon peculiar fluids, the quantity of which may vary; but that they are permanent forces, inherent in every atom of the attracting bodies.

13. It is very possible that this variation of intensity, which forms so remarkable a distinction between affinity and gravitation, may be only apparent and not real. For even in gravitation the intensity varies with the distance and the mass, and the same variation holds in affinity. But as the attraction of affinity acts upon bodies situated at insensible distances from each other, it is evident that, strictly speaking, we have no means of ascertaining that distance, and consequently that it may vary without our discovering the variation. But every such variation in distance must occasion a correspond-

ing variation in the intensity of the attracting force. It may be, then, that barytes attracts sulphuric acid with greater intensity than potash, because the particles of barytes, when they act upon the acid, are at a smaller distance from it than the particles of the potash are.

Owing perhaps to the figure of the particles.

But it may be asked, Why, if barytes, potash, and sulphuric acid, are all mixed together in water, the particles of potash do not approach as near the acid as those of the barytes, since they are both at liberty to act? To this it may be answered, that in all probability they do approach each of them to the same *apparent* distance, (if the expression be allowable), but that, notwithstanding, their *real* distance may continue different. The particles of bodies, how minute soever we suppose them to be, cannot be destitute of magnitude. They must have a certain length, breadth, and thickness, and therefore must always possess some particular figure or other. These particles, indeed, are a great deal too minute for us to detect their shape; but still it is certain that they must have some shape. Now it is very conceivable that the particles of every particular body may have a shape peculiar to themselves, and differing from the shape of the particles of every other body. Thus the particles of sulphuric acid may have one shape, those of barytes another, and those of potash a third.

But if the particles of bodies have length, breadth, and thickness, we cannot avoid conceiving them as composed of an indeterminate number of still more minute particles or atoms. Now the affinity of two integrant particles for each other must be the sum of the attractions of all the atoms in each of these particles for all the atoms in the other: But the sum of these attractions must depend upon the number of attracting atoms, and upon the distance of these atoms from each other respectively; and this distance must depend upon the figure of the particles. For it is obvious, that if two particles, one of which is a tetrahedron and the other a cube, and which contain the same number of atoms, be placed at the same relative distance from a third particle, the sum of the distances of all the atoms of the first particle from all the atoms of the third particle, will be less than the sum of the distances of all the atoms of the second particle from those of the third. Consequently, in this case, though the apparent distance of the particles be the same, their real distance is different; and of course the cube will attract the third particle more strongly than the tetrahedron; that is, it will have a greater affinity for it than the tetrahedron.

Owing perhaps to the figure of the particles.

But if the particles of bodies differ from each other in figure, they may differ also in density and in size: and this must also alter the absolute force of affinity, even when the distances and the figure of the attracting particles are the same. The first of these two circumstances indeed may be considered as a difference in the mass of the attracting bodies, and therefore may be detected by the weight of the aggregate; but the second, though also no less a variation in the mass, cannot be detected by any such method, though its effect upon the strength of affinity may be very considerable.

There is no doubt that, upon the supposition that such differences in the figure, density, and size of the attracting particles, really exist, and it is in the highest degree probable that they do exist, the variation in intensity which characterises chemical affinity may be accounted for, without supposing that the intensity of affinity, as a force inherent in the ultimate particles or atoms of bodies, is really different. The same thing may be applied to electricity and magnetism. It is certainly possible, therefore, that attraction, both sensible and insensible, may not only vary at the same rate, and according to the same laws, but be absolutely the same force inherent in the atoms of matter, modified merely by the number and situation of the attracting atoms. This is certainly possible; and it must be allowed that it corresponds well with those notions of the simplicity of Nature in which we are accustomed to indulge ourselves. But the truth is, that we are by no means good judges of the simplicity of Nature; we have but an imperfect glimpse here and there through the veil with which her operations are covered; and from the few points which we see, we are constantly forming conjectures concerning the whole of the machinery by which these operations are carried on. Superior beings smile at our theories as we smile at the reasonings of an infant; and were the veil which conceals the machine from our view to be suddenly withdrawn, we ourselves, in all probability, would be equally astonished and confounded at the wide difference between our theories and conjectures, and the real powers by which the machinery of the universe is moved. Let us not therefore be too precipitate in drawing general conclusions; but let us rather wait with patience till future discoveries enable us to advance farther; and satisfy ourselves in the mean time with arranging those laws of affinity which have been ascertained, without deciding whether it be the same force with gravitation, or a different one.

May be the same with gravitation.

14. The characteristic marks of affinity may be reduced to the three following:

Its characters.

I. It acts only at insensible distances, and of course affects only the particles of bodies.

II. This force is always the same in the same particles, but it is different in different particles.

III. This difference is modified considerably by the mass. Thus though A have a greater affinity for C than B has, if the mass of B be considerably increased while that of A remains unchanged, B becomes capable of taking a part of C from A.

But in the present state of chemistry general reasoning can lead us but a very little way. It will be of more importance to take a particular view of the different combinations which the different substances described in the preceding part of this Work are capable of forming, arranged according to the three great classes of *gases*, *liquids*, and *solids*. This will be the subject of the three following Chapters.

Chap. II.

CHAP. II.

OF GASES.

THE gases are a very 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 presupposes 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

Gases elastic.

conclusion, though there does 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 in-

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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.

creases; 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 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 $\frac{1}{300}$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 become almost seven times greater, and of course their repulsion is diminished almost sevenfold.

Some gases approach the nature of vapours.

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

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[*] *Principia*, Lib. ii. Prop. 23.

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.

List of gases.

3. The gases are probably very numerous; but those hitherto examined with accuracy amount only to 21. 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; three vapours which deserve attention, and which will assist us in examining the nature of various bodies considered as gaseous.

I. SIMPLE GASES.

1. Oxygen
2. Hydrogen
3. Azote
4. Muriatic acid
5. Fluoric acid

II. COMPOUND GASES.

a. Simple gases combined.

6. Steam
7. Nitrous oxide

8. Nitrous gas
9. Nitric acid
10. Ammonia
11. Oxymuriatic acid
12. Hyperoxymuriatic acid

b. Oxygen and a solid base.

13. Carbonic oxide
14. Carbonic acid
15. Sulphurous acid

c. Hydrogen and a solid base.

16. Carbureted hydrogen
17. Olefiant gas
18. Phosphureted hydrogen
19. Sulphureted hydrogen
20. Arsenical hydrogen

d. Triple or quadruple compounds.

21. Prussic acid
22. Vapour of ether
23. Vapour of alcohol

4. The gaseous bodies are all invisible, or transparent and incapable of reflecting the rays of light, except two; namely, oxymuriatic acid and hyperoxymuriatic acid, which have a yellowish green colour. But these two approach very nearly to the nature of vapour; a moderate pressure and a cold not greater than 36° being sufficient to convert the first, and probably also the second, into a solid or liquid. When gases very different in specific gravity are mixed together, they become visible, pretty much in the same way as when liquids of different specific gravities are mixed together. Thus when a great quantity of carbonic acid is poured at once into air, it becomes very visible.

5. 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 31 grains troy *.

Table of their specific gravity and weight.

Gases.	Specific Gravity.	Weight of 100 Inches.
Air	1·000	31·00
Oxymuriatic acid	2·766	85·84
Nitric acid	2·427	75·25
Sulphurous acid	2·265	70·21
Vapour of ether †	2·250	69·75
Vapour of alcohol †	2·100	65·10
Muriatic acid	1·929	59·80
Hyperoxymuriatic acid	—	—
Fluoric acid	—	—
Nitrous oxide	1·603	49·69
Carbonic acid	1·500 1·524	46·50 47·26 ‡
Sulphureted hydrogen	1·106 1·236	34·29 38·32
Oxygen	1·103 1·090	34·19 33·82 ‡
Nitrous gas	1·094	33·92
Azote	0·978	30·34
Carbonic oxide	0·956	29·64
Olefiant gas	0·909	28·18

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

† According to the recent experiments of Mr Dalton.

‡ By the late experiments of Allen and Pepys.

Gases.	Specific Gravity.	Weight of 100 Inches.
Steam	0·700	21·70
Ammonia	0·602	18·67
Carbureted hydrogen	0·600	18·60
Arsenical hydrogen	0·529	16·40
Phosphureted hydrogen	—	—
Prussic acid	—	—
Hydrogen	0·084	2·61

Nitric acid, in the state of vapour, is no less than 28½ times heavier than hydrogen gas.

6. This difference between the density of the gases, while their elasticity is the same, must be owing to one of two causes: Either the *repulsive force*, or the *weight* of the atoms, differs in different gases. The first supposition is by no means probable, supposing the size and weight of the particles of different gases the same, and indeed would but ill agree with the analogy of nature; but the second is very likely to be the true cause. And if we suppose the size and weight of the atoms of different gases to differ, this in reality includes the first cause likewise; for every variation in size and weight must necessarily occasion a corresponding variation in the repulsive force, even supposing that force abstractedly considered to be the same in all.

Dalton's hypothesis respecting the weight of the atoms of gases.

We have no direct means of ascertaining the weight of the atoms of bodies; but Mr Dalton, to whose uncommon ingenuity and sagacity the philosophic world is no stranger, has lately contrived an hypothesis which, if it prove correct, will furnish us with a very simple method of ascertaining that weight with great precision. Though the author has not yet thought fit to publish his hypothesis, yet as the notions of which it consists are original and extremely interesting, and as they are intimately connected with some of the most intricate parts of the doctrine of affinity, I have ventured, with Mr Dalton's permission, to enrich this Work with a short sketch of it *.

The hypothesis upon which the whole of Mr Dalton's notions respecting chemical elements is founded, is this: When two elements unite to form a third substance, it is to be presumed that *one* atom of one joins to *one* atom of the other, unless when some reason can be assigned for supposing the contrary. Thus oxygen and hydrogen unite together and form water. We are to presume that a particle of water is formed by the combination of *one* atom of oxygen with *one* atom of hydrogen. If we represent an atom of oxygen, hydrogen, and azote, by the following symbols,

Oxygen . . . . ○
Hydrogen. . . ⊙
Azote . . . . . ⊖

Then a particle of water will be represented by the following symbol:

Water . . . . ○⊙

But if this hypothesis be allowed, it furnishes us with a ready method of ascertaining the relative weight of those atoms that enter into such combinations; for it

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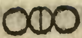
* Mr Dalton has not yet published a detailed account of his hypothesis, though he has noticed it in the 1st Volume of his *New System of Chemical Philosophy*, published in 1808. The full explanation is reserved for the second volume of that Work, which has not yet made its appearance.

has been proved by analysis, that water is composed of $85\frac{2}{3}$ of oxygen and $14\frac{1}{3}$ of hydrogen. A particle of water of course is composed of $85\frac{2}{3}$ parts by weight of oxygen and $14\frac{1}{3}$ parts of hydrogen. Now, if it consist of one atom of oxygen united to one atom of hydrogen, it follows that the weight of one atom of hydrogen is to that of one atom of oxygen as $14\frac{1}{3}$ to $85\frac{2}{3}$, or as 1 to 6 very nearly. Thus we have obtained the following relative weights of these two elementary bodies.

Hydrogen	1
Oxygen	6

To find out the weight of an atom of azote, we may examine its combinations with oxygen. But azote and oxygen unite in various proportions, forming nitrous oxide, nitrous gas, and nitric acid, besides some other compounds which need not be enumerated. The preceding hypothesis will not apply to all these compounds; Mr Dalton, therefore, extends it farther. Whenever more than one compound is formed by the combination of two elements, then the next simple combination must, he supposes, arise from the union of *one* atom of the one with *two* atoms of the other. If we suppose *nitrous gas*, for example, to be composed of *one* atom of azote and *one* of oxygen, we shall have two new compounds, by uniting an atom of nitrous gas to an atom of azote, and to an atom of oxygen, respectively. If we suppose, farther, that nitrous oxide is composed of an atom of nitrous gas and an atom of azote, while nitric acid consists of nitrous gas and oxygen, united atom to atom; then the following will be the symbols and constituents of these three bodies:

Nitrous gas........○⦶
Nitrous oxide......... ⦶○⦶

Nitric acid.............. 

The first gas consists only of two atoms, or is a binary compound, but the two others consist of three atoms, or are ternary compounds; nitrous oxide contains two atoms of azote united to one of oxygen, while nitric acid consists of two atoms of oxygen united to one of azote.

When the atoms of two elastic fluids join together to orm *one* atom of a new elastic fluid, the density of this new compound is always greater than the mean. Thus the density of nitrous gas, by calculation, ought only to be 1·045; but its real density is 1·094. Now as both nitrous oxide and nitric acid are specifically heavier than nitrous gas, though the one contains more of the lighter ingredient and the other more of the heavier ingredient than that compound does, it is reasonable to conclude, that they are combinations of nitrous gas with azote and oxygen respectively, and that this is the reason of the increased specific gravity of each; whereas, were not this the case, nitrous oxide ought to be specifically lighter than nitrous gas. Supposing, then, the constituents of these gases to be as represented in the preceding table, let us see how far this analysis will correspond with the weight of their elements as deduced from the hypothesis.

Nitrous gas is composed of 1·00 azote and 1·36 oxygen, or of 6 oxygen and 4·41 azote. This would make the weight of an atom of azote about 4½.

Nitrous oxide is composed of 2 azote and 1·174 oxygen, or of 6 oxygen and 5·11 + 5·11 azote.

Nitric acid of 1 azote and 2·36 oxygen, or of 6 + 6 oxygen and 5·08 azote.

These three give us the relative weights of oxygen and azote as follows, reckoning the weight of oxygen 6 as before:

Oxygen.		Azote.
6	:	4·41
	:	5·11
	:	5·08

The weight of an atom of azote, as deduced from the analysis of these three bodies, does not come out exactly the same for each. Yet the difference is not great, and surely not greater than might have been expected from the difficulty of making such minute experiments with precision. The mean of the whole gives the weight of an atom of azote 4·87. We may therefore take 5 as a convenient whole number without deviating far from the truth.

Table of the composition and weight of the gases.

On the supposition that the hypothesis of Mr Dalton is well founded, the following Table exhibits the weight of the atoms of the simple gases, and of those which are composed of elastic fluids, together with the symbols of the composition of these compound atoms:

⊙	Hydrogen	1
⦶	Azote	5
○	Oxygen	6
⊖	Muriatic acid......	18
⊙○	Water............	7
○⦶	Nitrous gas........	11
⦶○⦶	Nitrous oxide......	16
○⦶○	Nitric acid........	17

The weight of the remaining gases, into the composition of which the atoms of solid bodies enter, will come under our consideration in a subsequent Section.

I have purposely omitted the consideration of *am-*

monia, because its composition has not been ascertained with sufficient precision to admit of calculation. It was considered as composed of 80 parts azote and 20 hydrogen, and of course as binary compound of one atom of azote and one atom of hydrogen. But the late experiments of Davy and Berzelius have shown that oxygen is also one of its constituents. But the proportion of this last ingredient is so small, that in order to make the weight of the constituents of ammonia tally with the numbers deduced above, it would be necessary to consider it as a compound of a considerable number of atoms. The subject is still very obscure, and not yet ripe for investigation. It may probably lead to views that will overturn a great part of our presently received Chemical Philosophy. But as it does not materially affect the hypothesis of Mr Dalton, it is not necessary to enter upon the subject here.

Elasticity of the gases ascribed to heat.

7. 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, described in a preceding part of this work *, 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.

Quantity of water contained in gases.

8. 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 electric

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* Vol. I. p. 612. † *Phil. Mag.* xxi. 362.

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 very same weight. This accords completely with Mr Dalton's experiments on the subject.

All gases in common cases contain moisture; for

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* *Ann. de Chim* xlii. 125.

† Ibid.

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? The experiments of Dr William Henry have demonstrated that the latter is the case. He has pointed out a method of depriving gases of a considerable portion of water after they have been rendered as dry as possible by means of alkaline salts. When electric explosions were made to pass through muriatic acid gas, dried by means of muriate of lime, and confined over mercury, the bulk of the gas diminished, muriate of mercury was formed; and when the gas was absorbed by a liquid, there remained 6 *per cent.* of hydrogen gas. When the experiment was made in close glass vessels, oxymuriatic acid was formed, and hydrogen equally evolved. This evolution of hydrogen, and formation of oxymuriatic acid, doubtless took place in both cases, and was owing to the decomposition of water which the dry gas contained. It had a limit beyond which electric explosions produced no farther effect*. The quantity of hydrogen, evolved in this case, indicates rather more than one grain of water as existing in 100 cubic inches of muriatic acid gas, previously made as dry as possible. Now this is considerably more than can be detected in gases by means of saline substances. Dr Henry found that carbureted hydrogen gas from acetate of potash, after

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* Henry, Nicholson's *Quarto Jour.* iv. 211.

Chap. II.

being dried thoroughly by means of alkalies, underwent a dilatation from electricity, amounting to about $\frac{1}{6}$th of the whole bulk of the gas. This increase he showed to be occasioned by the evolution of hydrogen gas from the decomposition of water still retained in the carbureted hydrogen *. Were we to ascribe the whole increase rigidly to hydrogen, it would indicate the presence of nearly three grains of moisture in the dry carbureted hydrogen. Some of the late experiments of Mr Davy indicate a still greater proportion of water in the dry gases.

Thus it appears that the moisture abstracted from gaseous bodies by means of dry salts, constitutes but a small portion of what they contain; since electricity afterwards separates a much greater portion by decomposing it. Whether by this last method gases may be deprived of all their moisture, or whether a portion still continues to adhere, we have no means of ascertaining. It is certain that water has considerable influence in facilitating the combination of carbonic acid gas with bodies, and its separation from them. Perfectly dry lime and magnesia do not absorb it, but slacked lime absorbs it readily. On the other hand, Dr Priestley showed that the separation of carbonic acid gas from the native carbonate is facilitated by the vapour of water. Clement and Desormes have endeavoured to show, that the experiments of Priestley are erroneous, that water does not facilitate the separation of the gas, that heat separates the whole of the gas from the carbonate, and that carbonic acid thus obtained is perfectly free from mois-

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* Nicholson's *Quarto Jour.* ii. 244.

Book III.

ture; but Berthollet has shown that their consequences have been pushed rather too far. The native carbonate of barytes may, and probably does, contain moisture, though it adheres too obstinately to be separated, except along with the carbonic acid. Upon the whole, we are not perhaps at present in possession of any method of obtaining gases perfectly free from moisture; though it does not appear that there is any reason for believing that they may not exist in that state. There is nothing either in the nature of gaseous bodies or of water, that should induce us to believe that the pressure of the latter body is essential to the elastic state of the former. Indeed, when the water is separated by Dr William Henry's method, we have every reason to believe that the quantity of moisture which remains is small, and that it may be safely neglected without producing any considerable error.

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.

Nature of vapours.

9. 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 with oxymuriatic acid; and it is extremely probable that it is the case also with hyperoxymuriatic acid, 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* form *sal ammoniac*, and *nitrous gas* and *oxygen* form *nitric* acid. There are others which mix together without any 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.

Gases *mix*, and *combine*.

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

Table of the gases that mix.

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

Oxygen with fluoric and carbonic acids.
Hydrogen with muriatic acid, fluoric acid, carbonic oxide, olefiant gas, carbureted hydrogen, phosphureted hydrogen, arsenical hydrogen, sulphureted hydrogen, ammonia.
Azote with almost all the other gases.
Muriatic acid with all gases except oxygen, and a few of the gaseous combinations of oxygen and azote.
Fluoric acid with all gases.—&c.

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

Oxygen with hydrogen, azote, muriatic acid, carbonic oxide, sulphurous acid, nitrous oxide, oxymuriatic acid.

Hydrogen and azote.

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

Oxygen with carbureted hydrogen, olefiant gas, arsenical hydrogen, sulphureted hydrogen, ammonia.

Hydrogen with carbonic acid, nitrous gas, nitrous oxide, oxymuriatic acid, sulphurous acid.—&c.

All gases mix equally

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 the gases. When the gases have once diffused themselves 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 fluoric 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 lately 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 †.

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

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* Priestley *On Air*, ii. 441.

† *Phil. Mag.* xxiv. 8

The bulk is not altered,

3. When two or more gases are mixed together, the bulk is not sensibly altered. If two gases, each two cubic inches, be mixed, the bulk after mixture will still continue 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 require any particular illustration.

Nor the specific gravity.

4. The specific gravity of such mixtures is precisely the mean of that of the gases mixed, allowance being made 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 to dissolve each other.

According to the first, which is the common explanation, all the gases have an affinity for each other, and they mix, and continue mixed or united, in consequence of this affinity. 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 produces no sensible change in the bulk or specific gravity of the compound. For that reason, Berthollet, who has considered this subject at great length, and treated it with his usual address, has given the combination the name of *dissolution* *.

Supposed to mix mechanically.

The second explanation was first proposed by Mr

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* *Statique Chimique*, i. 274 and 487.

Dalton, who published a most ingenious dissertation on the subject in the fifth volume of the Manchester Memoires. According to him, the particles of one elastic fluid possess no repulsive nor attractive power, or are perfectly inelastic with regard to an 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, presents, it must be acknowledged, 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 before 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.

And not to be mutually elastic.

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 $m+n$ mea-

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* *Manchester Mem.* v. 543.

sures 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 abstractedly, 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*.

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

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* *Manchester Memoires*, v. 453.

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

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* *Phil. Mag.* xxiv. 103.

† *Statique Chimique*, i. 485, &c.

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 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.

Thus it does not appear that the phenomena of the mixture of the gases accord with the hypothesis of Dalton, that the atoms of different elastic fluids are mutually non-elastic. But if Dalton's hypothesis be considered as not proved, and if on that account we refuse to admit it, then we must admit, however problematical it may appear at first view, that the gases not only mutually repel each other, but likewise mutually attract; and that all gases, as Berthollet states it, have the property of *dissolving* the other elastic fluids. For without supposing an attraction, it is impossible to account for their constantly mixing, notwithstanding their difference in specific gravity, remaining mixed, and presenting all the properties of a homogeneous compound *.

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* Mr Dalton, in his New System of Chemical Philosophy, (p. 175.) observes, upon this statement of mine, that he has no doubt, that if I had taken due time to consider this conclusion, I would with him have pronounced it absurd. I must acknowledge, that the objections which he has brought against it appear to me very forcible indeed; and I would abandon it with pleasure for any other hypothesis not liable to objections equally forcible. His own hypothesis seems to me, after the most patient reflection, liable to objections which cannot be answered. Some of these I have stated in the text, and others which have since struck me might have been added. But this is not necessary, as the hypothesis has been abandoned by Mr Dalton himself; and has not, as far as I know, been adopted by any other person. Mr Dalton now admits, that atmospheres of heat, surrounding the particles of gases, are the cause of their repulsion; he even admits, as indeed follows as a consequence from the first admission, that the different gases are mutually elastic (p. 189.) He now accounts for their mutual diffusion through each other when mixed by the different size of the particles of each. The consequence of this inequality of size, he says, will be an intestine motion, which will continue till the gases are equally diffused. If Mr Dalton can demonstrate the truth of this consequence, there will be little hesitation in adopting this new explanation; for that the particles of the different gases differ in size, will not, I presume, be disputed. But the consequence is surely not self-evident. To ascertain the motions which will be produced when gases,

Vapours mix with gases in the same manner as gases.

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 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 $= 1 + \frac{f}{p-f}$, or, (which is the same thing) $= \frac{p}{p-f}$. Thus let the temperature be 180°, $p = 30$ inches, and let the liquid be water; then $f = 15$ inches[*]. Then $\frac{p}{p-f} = \frac{30}{30-15} = 2$. 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, sup-

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whose particles differ in size, are brought into contact, is a problem of some difficulty. It is very possible that Mr Dalton's conclusion may be correct; but I own I have some doubts on the subject. If Mr Dalton will produce a mathematical demonstration of his position, all doubts will be removed, and the mutual mixture of gases explained in a satisfactory manner.

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

[‡] *Manchester Memoires*, v. 572.

posing 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 hygrometical experiments of Saussure and De Luc.

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.

The second hypothesis, that vapours are in the elastic state, and that they are dissolved by gases precisely as one gas is by another, will account equally well for the phenomena as that of Dalton; and it furnishes us with a reason why vapour is not reduced to the liquid state by the incumbent pressure of the atmosphere. The combination of the gas enables it to sustain a pressure which it could not otherwise have supported.

Why air passes thro' hot vessels of clay containing steam.

8. Mr Dalton has applied his hypothesis to the explanation of a very curious set of experiments made by Dr Priestley; a short account of which has been given in the first volume of this Work *. He found that when moist earthenware retorts are heated, the vapour of water passes outwards through the pores of the ves-

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* P. 114.

sel, 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 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 they have an affinity for each other.

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

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* Priestley *On Air*, ii. 407. † American *Phil. Trans.* v. 14.

‡ *Phil. Mag.* xxiv. 14.

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.

Thus notwithstanding the ingenuity of Mr Dalton's hypothesis, and the elegant way in which it explains most of the facts, there are several circumstances which render it hazardous for us to adopt it. We must then conclude, that when gases and vapours are mixed together, they are retained together by a species of affinity not sufficiently strong to produce sensible condensation, or any of those other phenomena which commonly mark chemical combination; but sufficient to cause these elastic bodies to mix intimately and uniformly, and to keep them united. This weak species of affinity we may distinguish, with Mr Berthollet, by the name of *dissolution*. In the next Section, we shall con-

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* Berthollet, *Statique Chimique*, i. 498.

sider those gaseous bodies which *combine* in a much more marked manner with each other.

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, or in a state of *dissolution*. Now these gaseous bodies may be divided into two classes; some combine in all circumstances by mere mixture; others only unite in particular states.

1. Gases which combine by mixture.

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

	Products.
Oxygen with nitrous gas.......	Nitrous acid Nitric acid
Ammonia with vapour............	Liquid ammonia
muriatic acid......	Muriate of ammonia
fluoric acid........	Fluate of ammonia
carbonic acid......	Carbonate of ammonia
sulphurous acid .	Sulphite of ammonia
sulphuret. hyd.	Hydrosulph. of amm.

1. As far as we know at present, none of the compounds produced by the combination of the gases contained in the preceding table are entitled to the name of gases.

Products mostly solids.

The two first, nitric and nitrous acids, seem to be *vapours* ; the compound of ammonia and the vapour of water is a liquid ; all the rest are solid bodies. Indeed, scarcely any of the elastic fluids that combine whenever they come into contact, are entitled to the name of gases, in the strict sense of the word, except oxygen and nitrous gas ; the rest approach to the state of vapours.

Oxygen and nitrous gas unite in two proportions.

2. Oxygen and nitrous gas, when brought into contact, immediately unite and form a yellow-coloured vapour. From the experiments of Dalton, it appears that these gases are capable of uniting in two different proportions. One hundred measures of common air, when added to 36 measures of nitrous gas in a narrow tube over water, leave a residue of 79 inches ; and one hundred measures of common air, admitted to 72 measures of nitrous gas in a wide glass vessel over water, leave likewise a residue of 79 measures *. According to these experiments, 21 cubic inches of oxygen gas is capable of uniting with 36 and with 72 cubic inches of nitrous gas ; or 100 inches of oxygen unites with 171·4 and with 342·8 inches of nitrous gas. If we apply Mr Dalton's hypothesis, stated in a former Section, to these combinations, we shall have the first composed of one atom of oxygen united to one atom of nitrous gas ; the second, of one atom of oxygen united to two atoms of nitrous gas. The first appears to be the substance usually distinguished by the name of nitric acid ; the second is nitrous vapour, or nitric acid saturated with nitrous gas. The following will be the symbols denoting the composition of an atom of each, and the weight of that atom,

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* *Phil. Mag.* xxiii. 351.

obtained by adding together the numbers denoting the weight of each of the constituent atoms.

	Density.
○⦶○ Nitric acid...............	17
○⦶○⦶○ Nitrous vapour	28

The first is a triple compound, and can only be resolved into nitrous gas and oxygen, or into azote and oxygen; but the second is a quintuple compound, and may be resolved into nitrous oxide and oxygen, nitrous gas and oxygen, nitric acid and nitrous gas, oxygen and azote.

But though these are the extreme proportions in which these two gases unite, we know from daily experience, that they are capable likewise of uniting in all the intermediate proportions; constituting, no doubt, nitric acid, holding various doses of nitrous gas in solution. Thus, in Mr Davy's experiments on the composition of nitric acid, the acid which he formed for examination was composed of 100 measures of oxygen united to 218 measures of nitrous gas *.

3. As no set of experiments has been hitherto made on the combination of ammoniacal gas and vapour, we do not know in what proportion they combine; but merely, that whenever they come into contact, they are mutually condensed into a liquid.

Muriate of ammonia.

4. When muriatic acid gas and ammonia are brought into contact, they mutually condense each other into a solid, a white powder called muriate of ammonia. From my trials, it follows, that the two gases disappear when nearly the same bulk of each is present. Were we to suppose that the compound in that case is neutral and

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* *Researches*, p. 16.

free from water, and that the specific gravity of the two gases, as given in a preceding table, is correct, then sal ammoniac would be composed of rather more than three parts of muriatic acid by weight, united to one part of ammonia.

5. We are not in possession of an accurate set of experiments on the combination of ammonia with fluoric, carbonic, and sulphurous acids. We know only that these gases mutually condense each other and form solids.

Condensation occasioned by the combination.

6. The combination of these gases is obviously attended with a considerable condensation, though it is difficult to estimate it correctly in every instance, on account of the change of state which takes place. The specific gravity of nitric acid vapour ought, by calculation, to be 1·097, supposing no condensation to have taken place[*]. But its specific gravity, as ascertained by Davy, is 2·427 at least[†]. So that the density has more than doubled by the combination. But when the compound becomes solid, the condensation is of course enormously increased. Thus the specific gravity of sal ammoniac, supposing it to retain the gaseous state, ought, by calculation, to be 1·241, whereas it is in reality 1·4×816, or 1142, being reduced to rather less

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[*] Let P be the specific gravity of the nitrous gas, p its quantity; H the specific gravity of the oxygen, and b its quantity. The specific gravity of the compound, supposing no condensation, would be $\frac{PH(p+b)}{Pb \times Hp}$ Now, in the present case, we have $P = 1{\cdot}094$, $H = 1{\cdot}103$, $p = 58$, and $b = 34$; which gives us the specific gravity $= \frac{111{\cdot}06}{101{\cdot}17} = 1{\cdot}097$ nearly.

[†] I say at least, because Mr Davy's acid vapour obviously contained a superabundance of nitrous gas.

than $\frac{1}{900}$th part of its calculated bulk. A similar condensation no doubt takes place in the other compounds of ammonia and the acid gases, though the degree of it has not been ascertained by experiment.

7. The facility with which these last bodies combine, the enormous condensation which they undergo, the little heat which is evolved, and the difficulty of separating them again, are strong presumptions against their being gases in the same sense of the word as the other permanently elastic fluids. As to nitric acid, the condensation which it undergoes is much inferior; and we know from numerous experiments, that there is still retained by that acid an enormous quantity of heat, and that it is in reality a powerful supporter of combustion.

8. The rapidity with which the gaseous bodies which we have been considering combine, whenever they come into contact, seems to have been one of the strongest of Mr Dalton's reasons for supposing that gases are not mutually elastic: and it certainly does appear at first view as a very strong objection to the common doctrine. We must suppose that the affinity by which the particles are attracted is much more powerful than the repulsion. The imperfectly gaseous state of most of them seems also to facilitate the union; though this does not apply to the combination of nitrous gas and oxygen.

2. Gases which combine in particular circumstances,

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
Oxygen with muriatic acid	Oxymuriatic acid
oxymuriatic acid	Hyperoxymuriatic acid
sulphurous acid	Sulphuric acid
nitrous oxide ?	Nitric acid

Products chiefly elastic fluids and liquids.

1. 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.

Combination produced by heat and electricity.

2. 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 spontaneously, 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

Manner in which this is effected.

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 compression 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.

Though this explanation is certainly ingenious and very plausible, it is not beyond the reach of objection. How comes it that neither heat nor electricity cause any gases to combine, except one of the gases be oxygen or contains it?

Oxygen and muriatic acid.

3. I am not certain than any attempt has been made to unite oxygen gas and muriatic acid by means of electricity. It is extremely probable from analogy that the combination would take place, and that oxymuriatic acid would be the result. They combine readily when the oxygen is nascent and the muriatic acid in solution in water. Oxygen and oxymuriatic acid combine only in consequence of a pretty complicated action of affinities. From the greater difficulty which takes place in sepa-

rating the oxygen from hyperoxymuriatic acid than from oxymuriatic, it is probable that the former compound is more intimate than the latter. But the experiments hitherto made upon these bodies are not sufficiently numerous to enable chemists to consider them with precision.

Sulphurous acid and oxygen.

4. It is extremely 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, and 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 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.

These gases unite only in one proportion.

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 nitric acid. This is the more remarkable, because the

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* Priestley *On Air*, ii. 316.

bases in the last case are capable of uniting in various proportions. What fixes them down to this particular compound, nitric acid, when both are gaseous?

Condensation occasioned by the combination.

6. All 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 constituents which enter into combination; the second, the proportions of these by weight which combine; the third, the specific gravity of each of these constituents*; the fourth, the name of the compound formed; the fifth, its specific gravity, calculated from the second and third columns, on the supposition that no condensation took place; the sixth, the actual specific gravity of the compound; the seventh, the bulk of the compound, reckoning its bulk at 100, on the supposition that no condensation had taken place. The last column gives the condensation *per cent.* the numbers in it being the complements of those in the preceding column.

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[*] At the temperature of 60°, except in the first compound, when the specific gravity is taken at 212°.

Constituents.	Proportions.	Specific Gravity of each.	Compound formed.	Its Specific Grav. by calculation.	Its real Specific Gravity.	Bulk.	Condensation.
Oxygen Hydrogen	59·8 10·	0·675 0·065	Steam	0·287	0·700	41·	59·
Oxygen Carb. ox.	31· 69·	1·103 0·956	Carbonic acid	0·997	1·500	66·4	33·6
Oxygen Azote	70·23 29·77	1·103 0·978	Nitric acid	1·062	2·427	43·7	56·3
Oxygen Mur. acid	29· 100·	1·103 1·929	Oxym. acid	1·651	2·766	59·7	40·3
Oxygen Oxymur. acid	162· 129·	1·103 2·766	Hyperoxym. acid	1·503			
Oxygen Sulphurous acid	24·3 147·0	1·103 2·265	Sulphuric acid	1·970			
Oxygen Nitrons oxide	178· 158·	1·103 1·603	Nitric acid	1·292	2·427	53·	47·
Oxygen Nitrous oxide	78· 158·	1·103 1·603	Nitric acid	1·394	2·427	57·4	42·6

From this table it appears that oxygen and hydrogen undergo the greatest condensation of all the gases when they combine. The least of all appears to be sustained by oxygen and carbonic oxide, probably because one of these gases is already a compound. The condensation of nitrous oxide and oxygen, given in the two last horizontal columns of the table, is only hypothetical, as these two gases have not hitherto been combined artificially.

III. Besides the two sets 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.

3. Gases which decompose each other on mixture.

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

Oxygen with ....phosphureted hydrogen
Oxymuriatic acid with ..ammonia
phosphureted hydrogen
hydrogen
carbureted hydrogen
carbonic oxide
olefiant gas
sulphureted hydrogen
sulphurous acid
nitrous gas
Sulphureted hydrogen with nitrous gas
sulphurous acid

From this table it appears, that when the gases mutually decompose each other, both of them are generally compounds. Two instances only occur in the table in which one of the gases mixed is simple, namely, *oxygen* with phosphureted hydrogen, and *hydrogen* with oxymuriatic 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 oxymuriatic acid, as does ammonia when mixed with the same acid 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.

Decomposition sometimes accompanied by combustion.

Phosphureted hydrogen and oxygen.

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 phosphorus held in solution 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 deposite 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, phosphoric acid, and phosphorus, probably in the state of an oxide*.

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* See Berthollet, *Statique Chimique*, ii. 110.

Oxymuriatic acid and ammonia.

4. The spontaneous combustion of ammonia in oxymuriatic acid gas appears at first sight singular, as it does not burn in common air or oxygen gas, except when a heat is applied sufficiently high to decompose the ammonia. It doubtless depends, partly upon the weakness of the affinity with which the constituents of each are held together, the condensation, as appears from the preceding table, being less considerable than in most other instances; and partly on the diminution of elasticity which the oxygen experiences from its combination with the muriatic acid; a diminution by no means counterbalanced by the intimacy of the combination. In hyperoxymuriatic acid the oxygen and acid appear to be much more closely united. Hence, in all probability, it would neither decompose nor burn ammonia. The product of the combustion of ammonia by oxymuriatic acid seems only to be water. Fourcroy affirms, that during the combustion drops of water attach themselves to the sides of the vessel [*]. Whether the azote of the ammonia enters into any combination with oxygen, has not been ascertained. It does not seem likely. Fourcroy, indeed, affirms that the whole of the azote remains [†].

5. As phosphorus, even in the solid state, rapidly melts, and burns with a pale white flame in oxymuriatic acid gas, we need not be surprised that phosphuretted 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

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[*] *Ann. de Chim.* iv. 255.

[†] Fourcroy's *Connois. Chim.* ii. 338. Engl. Trans.

when the gas burns in common air. Although the experiment has not been made with much care, there is reason to believe that both the ingredients of the gas combine with oxygen, and that the products are water and phosphoric acid, while common muriatic acid is evolved.

Oxymuriatic acid and heavy inflammable airs.

6. Oxymuriatic acid acts in a different manner upon hydrogen, carbureted hydrogen, and carbonic oxide. With none of these does it occasion combustion, but they all decompose it slowly and imperceptibly; the respective constituents of each gas uniting to oxygen, and being converted into a product of combustion, provided the quantity of oxymuriatic acid be sufficient. This curious process can be considered in no other light than as a *combustion*, so extremely slow that neither the emission of heat nor light is perceptible; for otherwise the formation of *products* is altogether inconceivable. It is in reality, then, the same phenomenon as takes place in the preceding gases, differing only in rapidity.

It is to Mr Cruikshanks that we are indebted for the first accurate set of experiments on the action of these gases on each other. The oxymuriatic acid gas which he employed was obtained by heating a mixture of liquid muriatic acid and hyperoxymuriate of potash, and contained a much greater proportion of oxygen; but it is probable that the same phenomena would recur with common oxymuriatic acid gas, supposing that a sufficient dose of it were employed.

When one measure of pure hydrogen gas, and two measures of oxymuriatic acid gas, are mixed together in a phial previously filled with water, a slightly whitish cloud appears, but no perceptible diminution takes place. If the phial be stopped, and kept for 24 hours under water, upon taking out the stopper, water rushes in, and completely fills the phial *. If three measures of hydrogen gas, and 3½ measures of oxymuriatic acid, be mixed in a detonating tube over mercury, and an electric spark passed through them, a feeble explosion takes place; the mercury rises; and, on letting in a little water, completely fills the tube †. Here the very same effect is produced instantly by means of combustion, and slowly, without any perceptible inflammation. The hydrogen unites to the oxygen of the acid gas, and is converted into water; while the muriatic acid, set at liberty, is absorbed by the liquid.

The carbureted hydrogen gas used by Cruikshanks was obtained by passing camphor or ether through a hot tube. He remarked that its properties were altered by washing it with water. Dr Henry has pointed out the reason of this. In their recent state these bodies contain a mixture of olefiant gas, which the water removes ‡. When one measure of well-washed carbureted hydrogen gas is mixed in a phial with two measures of oxymuriatic acid, no immediate diminution of bulk takes place; but if the phial be left stopped for 24 hours, two-thirds of the mixture immediately disappear: the residue consists partly of carbonic acid, partly of carbonic oxide. But if the gases be mixed in the proportion of one measure of carbureted hydrogen, and 3·8 measures of oxymuriatic acid, then the whole of the residue is carbonic acid §.

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* Nicholson's *Quarto Jour.* v. 204. † Ibid. p. 286.

‡ Nicholson's *Jour.* xi. 70.

§ Cruikshanks, Nicholsons, *Quarto Jour.* v. 204.

When these gases are fired by means of electricity, a small portion of inflammable elastic fluid always remains, however great a proportion of oxymuriatic acid be employed. If the proportion of acid gas be too small, a quantity of charcoal is deposited at the time of the explosion; but if it be large, there is no deposite, the whole charcoal being converted into carbonic acid. One measure of carbureted hydrogen, and two of oxymuriatic acid, when fired, deposited charcoal; but one of the inflammable gas, and four of the acid gas, detonated feebly; no deposite took place, carbonic acid being left mixed with some inflammable air *.

These phenomena are very remarkable, and not easily explained. We see from them, that in all cases it is the hydrogen, as might be expected, which burns in preference to the carbon, in consequence of its stronger affinity for oxygen. Indeed the whole phenomena are precisely similar to what happens when phosphureted hydrogen is mixed with oxygen gas. If the gaseous supporter be present in too small a proportion, the hydrogen is burnt, while the phosphorus is partly burnt and partly oxidized; but if the oxygen be in sufficient quantity, the whole of the phosphorus is converted into an acid. In like manner, in this case the hydrogen is converted into water, and the carbon partly into carbonic acid, and partly into carbonic oxide, if the oxymuriatic acid gas be deficient, or wholly into carbonic acid if it be in sufficient quantity. The deposite of charcoal, when the mixture is fired, is obviously owing to the suddenness of the combustion of the hydrogen.

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* Cruikshanks, Nicholson's *Quarto Jour.* v. 204.

When equal bulks of carbonic oxide and oxymuriatic acid are mixed, no immediate change takes place; but if water be admitted after 24 hours, a rapid absorption is produced, and lime water absorbs the whole residue, except $\frac{1}{10}$th of the original bulk, which is still inflammable; but when one measure of the oxide is mixed with $1\frac{1}{3}$ measures of the acid gas, the whole is gradually changed into carbonic acid. These mixtures cannot be fired by means of electricity *. The reason is obviously because the inflammable gas contains no hydrogen; for it is the combustion of the hydrogen that occasions that of the carbon, as is obvious from the deposition of charcoal when there is a deficiency of oxygen.

Oxymuriatic acid and olefiant gas.

7. The action of oxymuriatic acid upon olefiant gas is a good deal different from its action on the preceding. When three measures of the acid gas are mixed with $2\frac{1}{2}$ of the olefiant gas over water, a rapid condensation takes place, accompanied by the evolution of heat; a watery vapour trickles down the sides of the vessel; and a white opaque fluid, having the appearance of oil, floats upon the surface of the water. If the two gases be pure they disappear completely †. The nature of this mutual action, first observed by the Dutch chemists, has not hitherto been accurately examined. It is obviously very different from combustion. The oily matter is very combustible. Whether this oily, or rather etherial fluid, be merely the whole olefiant gas combined with oxygen, or whether it be that gas con-

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* Nicholson's *Quarto Jour.* v. 204.

† Henry, Nicholson's *Jour.* xi. 70.

densed by the separation of a portion of its hydrogen, and the conversion of it into water, is unknown. The phenomena correspond pretty well with the latter supposition. When an electric spark is passed through this mixture before it has time to condense, a detonation takes place, water and carbonic acid are formed, and abundance of charcoal deposited, as was first observed by the Dutch chemists[*]. It is not improbable that the deposition of charcoal, observed by Cruikshanks, when a mixture of carbureted hydrogen and oxymuriatic acid was fired by electricity, was owing to the presence of some olefiant gas; for the quantity deposited was greatly diminished by washing the gas in water.

The following little Table exhibits the proportion of oxymuriatic acid gas necessary to be mixed with one measure of the four gases last examined, in order to obtain a complete decomposition:

Table of the bulk of gas necessary to produce decomposition.

One measure of	Measures of Acid Gas.
Hydrogen gas	1·16
Carbureted hydrogen	3·00
Carbonic oxide	1·33
Olefiant gas	1·20

8. The effect of oxymuriatic acid upon sulphureted hydrogen and sulphurous acid gas has not hitherto been examined with much precision. The latter is no doubt converted into sulphuric acid. In the former the hydrogen is converted into water, and the sulphur probably deposited in the state of an oxide. They would doubtless burn by means of electricity, and the pheno-

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[*] *Ann. de Chim.* xxi. 49.

mena, in all probability, would nearly coincide with the combustion of carbureted hydrogen in the same way.

Oxymuriatic acid and nitrous gas.

9. When nitrous gas and oxymuriatic acid are mixed together, Humboldt has shown that the former gas combines with oxygen, and is converted into nitric acid, while the latter is reduced to the state of common muriatic acid. Hence both are completely absorbed by water, supposing them pure, and mixed in the requisite proportions. He states these proportions at equal bulks of each [*]. This property, which nitrous gas has of absorbing oxygen from oxymuriatic acid, will appear at first view rather inconsistent with a fact well known to all practical chemists. When nitric and muriatic acids are mixed, oxymuriatic acid is formed, and may be expelled in considerable quantity by a moderate heat; but the decomposition of the nitric acid is a complicated case, and is the result of two forces acting conjointly; namely, the affinity of muriatic acid for oxygen, and that of nitric acid for nitrous gas. For a great part of the nitric acid remains undecomposed, and becomes in part saturated with that gas.

Nitrous gas and sulphureted hydrogen.

10. The spontaneous decomposition produced when nitrous gas and sulphureted hydrogen gas are mixed together, 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 has since been more minutely examined by Mr Davy [‡], who confirmed the fact previously asserted, that no sulphurous or sul-

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[*] *Ann. de Chim.* xxviii. 142.

[†] *Phil. Trans.* 1788, p. 384.

[‡] *Researches*, p. 203.

phuric acid is formed; and showed that the new compounds are nitrous oxide, 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 spontaneous decomposition appears at first sight altogether unaccountable; nor do I see how it can be rendered intelligible upon any principle, if we suppose that the ultimate products are the only ones formed: but it is highly probable that the first thing which happens is the mutual decomposition of an atom of nitrous gas by an atom of sulphureted hydrogen, and the formation of an atom of ammonia, and another of sulphurous acid; but sulphurous acid and sulphureted hydrogen gas mutually decompose each other, as has been shown by Berthollet. The next step, then, is the action of the new atom of sulphurous acid upon an atom of sulphureted hydrogen. This action is modified in such a manner by the superabundance of sulphureted hydrogen, that the products are an atom of oxide of sulphur and an atom of hydrogen; this atom of hydrogen acts in its turn upon two atoms of nitrous gas, combines with an atom of oxygen, and thus forms water, while the two atoms of nitrous gas, deprived of a portion of oxygen, remain in the state of nitrous oxide.

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 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
arsenical 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

Nitrous oxide with 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
muriatic acid

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 combustible 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.

Sulphureted hydrogen and oxygen.

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 precisely the same as 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 distin-

guishes 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 combustion of arsenical hydrogen is precisely similar to that of the preceding. It is the hydrogen which burns while the arsenic is deposited, if the supply of oxygen be small. When two parts of the combustible gas are exploded with three of oxygen, the metal is oxidized. Probably, were the proportion of oxygen sufficient, the arsenic would be acidified *.

Oxygen and heavy inflammable air.

4. The phenomena of the combustion of carbureted hydrogen and olefiant gas with oxygen have been examined by Cruickshanks, Berthollet, and Henry. They are extremely curious, and not easily shown to be analogous to what happens in other cases. The decompositions to which they bear the greatest resemblance, are those of the same gases when fired with oxymuriatic acid. When this acid gas is deficient in quantity, there is always formed a portion of inflammable gas, which possessed the properties of carbonic oxide, while a quantity of charcoal is deposited. In the same manner, when olefiant gas or carbureted hydrogen is mixed with an under proportion of oxygen, charcoal is deposited, and the residue is inflammable. Berthollet mixed four measures of olefiant gas with three of oxygen, and fired them by means of electricity. After the explosion the bulk was no less than 11 measures: or the gases had ex-

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* See Trommsdorf, Nicholson's *Journal*, vi. 206.

panded rather more than one-half their original bulk. Of course the specific gravity must have diminished in the same proportion. The residue was inflammable gas, containing a little carbonic acid. Some water, too, appears to have been formed. The residual gas, when mixed with a sufficient dose of oxygen, exploded again, and the residue was completely absorbed by lime-water *. This experiment cannot be explained without supposing the gas formed by the first explosion different from any at present known. Berthollet endeavours to show that it is carbonic oxide; but the specific gravity of this gas is greater than that of olefiant gas, and its formation ought to have been accompanied by a condensation instead of expansion. The fact, too, that a great portion of the oxygen must combine with the ingredients of the olefiant gas without combustion, while another portion actually mixed with it is undergoing combustion, is sufficiently puzzling. Clement and Desormes have got rid of the difficulty by supposing that hydrogen gas is evolved; but the evolution of pure hydrogen gas by combustion, while oxygen gas is present, and the combination of this oxygen in preference with carbon, are absolutely inconceivable, and cannot therefore be admitted. Mr Cruickshanks mixed six measures of what he considered as pure carbureted hydrogen with 4½ of oxygen †. After the explosion the residual gas amounted to about 17·75 measures. Of these 2¼ were carbonic acid gas; the remaining 10½

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* Berthollet, *Statique Chimique*, ii. 71.

† This is in the same proportion as in Berthollet's experiments; viz. four measures carbureted hydrogen and three oxygen: the residue would have been 8·5, had he used these measures.

were inflammable, and required for complete combustion $5\frac{1}{4}$ measures of oxygen gas *. In this experiment the first explosion obviously produced the combustion of a portion of the gas. The rest undoubtedly united with oxygen. The inflammable residue agrees with carbonic oxide in the quantity of oxygen necessary to burn it completely; but it differs essentially from that gas, both in specific gravity, as is obvious from the expansion, and in the quantity of carbonic acid formed. For carbonic oxide yields nearly its bulk of carbonic acid, whereas this gas yields only half its bulk. These facts, as well as the preceding, are incompatible with the supposition that this gas agrees with any of those at present known. They demonstrate, I think, the truth of Berthollet's notion, that there really exists a gas entitled to the name of oxycarbureted hydrogen; for it is not possible to doubt the existence of hydrogen in this residual gas. But this illustrious chemist has not perceived that it differs essentially in its properties from carbonic oxide. We may presume, therefore, with Berthollet, that when carbureted hydrogen or olefiant gas is exploded with an under proportion of oxygen gas, there are formed water and carbonic acid by the combustion, and, besides, a notable proportion of oxycarbureted hydrogen. It is not unlikely, from the experiments of Dr William Henry, that oxycarbureted hydrogen is formed during the distillation of peat and wood †.

Oxycarbureted hydrogen produced.

On the supposition that the residual gas is oxycarbureted hydrogen, the mutual decompositions and combi-

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* Nicholson's *Quarto Jour.* v. 7.

† Nicholson's *Jour.* xi. 66. When peat is distilled a gas is obtained, which also possesses the characters of oxycarbureted hydrogen.

nations may be represented by symbols according to Dalton's hypothesis. Let ⊗ be the symbol of carbon, and let us suppose with Dalton, that olefiant gas is composed of an atom of hydrogen and an atom of carbon, then its symbol will be ⊙⊕; the symbol for oxycarbureted hydrogen will be ⊙○⊕. To burn olefiant gas completely, three atoms of oxygen would be necessary for every atom of the combustible gas; for the products would be

⊙○ Water
○⊕○ Carbonic acid.

Now let us suppose that instead of three atoms of oxygen for every atom of olefiant gas, there are present only five atoms for every three of the combustible gas, in that case only one-third of the atoms of olefiant gas would be completely burnt by combining with three atoms of oxygen each; the remaining two thirds of the atoms would combine each with one atom of oxygen, and thus be converted into oxycarbureted hydrogen. In the case of carbureted hydrogen, the results would be explicable on a similar hypothesis.

When the quantity of oxygen is sufficient, both carbureted hydrogen and olefiant gas burn completely, the products being water and carbonic acid. From the experiments of Cruikshanks, Henry, and Dalton, we learn that pure carbureted hydrogen, in order to undergo complete combustion, requires twice its bulk of oxygen gas, and olefiant gas three times its bulk. The carbonic acid yielded by the first is just equivalent to its own bulk; that yielded by the second is twice its bulk *.

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* Cruikshank's, Nicholson's *Quarto Jour.* v. 6. Henry, Ibid. xi. 66.

Ether and oxygen.

5. 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. Now if the specific gravity of the vapour of ether be 2·25, a cubic inch of it should weigh

0·7 grains. The 6·8 inches of oxygen weigh 2·3 grains, which makes a total of 3 grains. The products were 4·6 inches of carbonic acid and water: 4·6 inches of carbonic acid contain 4·6 inches of the oxygen gas, weighing 1·6 grains, and combined with about ·6 grains of carbon. The remaining 2·2 inches of oxygen must have combined with hydrogen; and we know that they must have combined with what is nearly equivalent to 4·4 inches, or about 0·1 grain of hydrogen. Hence ether is composed of

Constituents of ether.

0·1 hydrogen
0·6 carbon
———
0·7

which corresponds with the weight of the vapour of ether [*]. When the vapour of alcohol is fired in the same way, a much greater proportion of carbonic acid is produced. Cruikshanks, from his experiments on this vapour, concludes that it is a compound of eight parts carbon and one hydrogen, and that it contains no oxygen; but Mr Dalton, who repeated the same experiments, and who considers the gas produced when alcohol is passed through a red hot tube as a mixture of olefiant gas and carbonic oxide, considers an atom of alcohol as composed of three atoms of carbon, two of hydrogen, and one of oxygen.

Such are the phenomena of the decomposition of the compound combustible gases when fired with oxygen

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[*] In this reasoning no correction has been introduced for the temperature. When it is attended to, the proportion of carbon will be somewhat greater than that stated in the text.

either deficient in quantity or sufficient to saturate them completely. The following little Table exhibits the bulk of oxygen necessary to decompose completely, and saturate with oxygen, 100 inches of each of these bodies.

Bulk of oxygen which saturates these gases.

100 Measures of	Measures of Oxygen.
Sulphureted hydrogen	75
Arsenical hydrogen	150+
Carbureted hydrogen	200
Olefiant gas	300
Vapour of ether	680
——— alcohol	—

Nitrous oxide,

6. 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 Mr Davy that we are indebted for the most exact set of experiments on these decompositions.

And hydrogen.

It appears from the experiments of Davy, that when nitrous oxide and hydrogen are mixed together in the proportion of 100 measures of the latter gas to 97·5 measures of the former, an electric spark occasions the complete combustion of the hydrogen and decomposition of the nitrous oxide. The products are water and azote, amounting to 102·5 measures. In this case nothing else happens than a complete combustion of the hydrogen: the phenomenon is exactly the same as when oxygen and hydrogen are exploded by electricity. It shows us the superior affinity of hydrogen over azote. When the proportion of nitrous oxide greatly exceeds what is requisite for burning the whole of the hydrogen, in that case the surplus is decomposed and converted into nitric acid, and a gas which possesses the properties of common air. The same decomposition happens when the nitrous oxide is passed through a red hot tube. We must ascribe it therefore solely to the heat evolved by the combustion of the hydrogen *. Thus it does not appear that the nature of the decomposition is altered, in the case of hydrogen and nitrous oxide, by varying the proportion of the ingredients.

Nitrous oxide and phosphureted hydrogen.

7. When one measure of phosphureted hydrogen is mixed with $2\frac{1}{2}$ measures of nitrous oxide, electricity produces an explosion, accompanied by a complete decomposition. The new products are water and phosphoric acid, and the residual gas, amounting to $2\frac{1}{2}$ measures, is pure azote. This combustion is precisely similar to that of the same gas in pure oxygen; so that the azote in nitrous oxide acts merely by retarding the combination of the oxygen a little, and thus renders a greater degree of heat necessary. When there is an excess of nitrous oxide, as five measures of it to one of the combustible gas, the same complete decomposition of the gas takes place, and the residue of nitrous oxide is decomposed by the heat of the combustion into nitric acid and common air, precisely as when passed through a red hot tube. The phenomena are not so easily ex-

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* Davy's *Researches*, p. 286.

plained when the phosphureted hydrogen is in excess. Thus, one measure of that gas with half a measure of nitrous gas do not explode at all. In that case, we must suppose that the atoms of nitrous oxide are at too great a distance from each other to be affected by the condensation. Probably the combustion takes place, however, at the place where the spark passes; and by the long continued action of electricity, the two gases would probably decompose each other, as far as their proportions would admit. When one measure of phosphureted hydrogen is mixed with 1$\frac{1}{4}$ measure of nitrous oxide, detonation is produced. Dense white fumes fill the vessel; and the residual gas, just equal in bulk to the original mixture, was found by Mr Davy to consist of a mixture of azote and hydrogen. This result is truly anomalous; for in all other cases we have found that hydrogen burns in preference to phosphorus. The heat produced must have been sufficient to set fire to hydrogen; for we know, from Davy's experiments, that phosphorus will not burn in nitrous oxide except when exposed to a white heat*.

Nitrous oxide and sulphureted hydrogen.

8. Sulphureted hydrogen gas, like phosphureted hydrogen, will not detonate with nitrous oxide, unless the proportion of the latter gas be sufficient to unite with both of its constituents. Thus one measure of the combustible gas, with 1$\frac{1}{4}$ or 1·4 measures, do not act upon each other; but when one measure of it is mixed with 1$\frac{3}{4}$, or with 3$\frac{1}{2}$ measures of nitrous oxide, both gases are completely decomposed. In the first case, the products are water, sulphurous acid, and azote; in

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* Davy's *Researches*, p.300.

the second, water, sulphuric acid, and azote. In both cases the azote is simply separated; so that the combustion is the same as that of sulphureted hydrogen in oxygen gas. The combination of the sulphur depends upon the proportion of oxygen present. When the quantity is sufficient, the whole is converted into sulphuric acid; but when it is deficient, sulphurous acid is the product. In this respect the combustion of sulphureted hydrogen in nitrous oxide resembles that of carbureted hydrogen in oxymuriatic acid [*].

Nitrous oxide and olefiant gas.

9. Olefiant gas detonates with various proportions of nitrous oxide. When the quantity of the latter gas is sufficient, the constituents of the inflammable gas are both saturated with oxygen; the products being water, carbonic acid, and azote, mixed apparently with a little oxygen: but when the proportion of nitrous oxide is small, an inflammable gas remains, just as when it is detonated with oxygen. In all cases the residual gas is more bulky than the original mixture. Thus one measure of olefiant gas with 1·2 of nitrous oxide leave a residue of 2·25 measures; of which 0·7 measure is carbonic acid, the rest a mixture of azote and an inflammable gas, which detonates with nitrous oxide. One measure of olefiant gas with 2$\frac{1}{3}$ measures of nitrous oxide leave a residue of four measures, of which 1$\frac{2}{3}$ are carbonic acid, the rest azote with a little oxygen. In these cases, besides water and carbonic acid, it is not unlikely that some ammonia may be formed when the proportion of nitrous oxide is small, and some nitric

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[*] Davy's, *Researches*, p. 306.

acid when it is large. On no other hypothesis can the small residue of azóte be accounted for *.

The effect of nitrous oxide upon carbureted hydrogen and carbonic oxide has not yet been examined with care; but analogy would lead us to suppose it pretty much the same as that of oxygen, only that a higher temperature is requisite to begin the mutual action. The vapour of ether and of alcohol may be exploded in it precisely as in oxygen, and doubtless with a similar result †.

Thus the phenomena of the combustion of gases in nitrous oxide are very analogous to their combustion in oxygen. The azote seems to be nearly passive, or to act only by diminishing the activity of the oxygen. The changes which happen in the residue of nitrous oxide when it is used in excess, are rather to be ascribed to the heat evolved, than to the action of the rest of the mixture. The following Table exhibits the bulk of nitrous oxide requisite to produce complete combustion and saturation with oxygen in 100 measures of the various gases hitherto tried.

Bulk of nitrous oxide which saturates these gases.

100 Measures	Measures of Nitrous Oxide.
Hydrogen	97·5
Olefiant gas	233·3
Phosphureted hydrogen	250
Sulphureted hydrogen	350

Nitric acid.

10. Nitric acid sets fire to all these combustible gases when passed along with them through a red-hot tube. No accurate set of experiments has hitherto been made

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* Davy's *Researches*, p. 313.

† Ibid.

upon the subject; but it is extremely probable that the products are analogous to those produced by nitrous oxide, and that, like it, the whole may be referred to the combustion of the gases in oxygen. Indeed, as nitric acid is decomposed by a red heat, and oxygen evolved, this must of necessity be the case.

Nitrous gas.

11. It is not a little singular, that though the constituents of nitrous gas be the same as those of nitrous oxide, it neither detonates with, nor decomposes, any of the combustible gases whose action upon the supporters we have been just considering; at least Mr Davy could not succeed in firing mixtures of nitrous gas with hydrogen and phosphureted hydrogen, the two which are most combustible *. This can only be accounted for by the very great intimacy of the combination of the constituents of this gas. However, as this gas has been shown to be a supporter of combustion, as both charcoal and phosphorus burn in it at a high temperature, it is by no means improbable that it would set fire to most of them if mixed in some proportion or other.

Nitrous gas and nascent hydrogen.

There is a decomposition of nitrous gas by nascent hydrogen extremely difficult to explain. It was first observed by Priestley and Austin, and afterwards examined by Davy †. It takes place when moist iron is placed in contact with nitrous gas. The iron is oxidized at the expence of the water, hydrogen is evolved, the nitrous gas is converted into nitrous oxide, and some ammonia is formed. 100 Measures of nitrous gas, by

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* *Researches*, p. 136.

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

this process, are reduced to about $41\frac{2}{3}$ measures of nitrous oxide, indicating a loss of $58\frac{1}{3}$ *per cent.*

Now 100 inches of nitrous gas weigh...33·92 grains
$41\frac{2}{3}$ inches of nitrous oxide.......20·60

There is therefore a loss of.....................13·32
which is more than $\frac{1}{3}$d of the whole.

	Azote.		Oxygen.
The nitrous gas is composed of	14·37 gr.	and	19·55
The nitrous oxide of...............	13·		7·60
Hence there is a deficit of........	1·37,	and	11·95

The 1·37 grains azote, to be converted into ammonia, require ·27 hydrogen, and the 11·95 grains of oxygen require 1·31 of hydrogen to convert them into water. According to this statement, no less than 19 grains of water must have been decomposed, and nearly 40 inches of hydrogen evolved. It is extremely difficult to account for the formation of ammonia in this case, unless we suppose a small portion of nitric acid to be formed, and afterwards to be decomposed by the iron.

12. 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 carbonic 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 spontaneously. This change can be ascribed only to the superior affinity of hydrogen for oxygen. It is curious that the 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.

Vapour and carbureted hydrogen.

When electric sparks are taken in carbureted hydrogen containing the vapour of water, the bulk is increased, and 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 the 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 the hydrogen.

Vapour and muriatic acid.

The same doctrine is equally necessary to explain the decomposition of vapour when electric sparks are passed through muriatic acid gas, likewise ascertained by the same chemist. Hydrogen gas is evolved as in the former case, and the muriatic acid combines with oxy-

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

gen. The affinity of muriatic acid for oxygen is still weaker than that of carbon, yet we see that, assisted by a great mass, it is capable, in certain circumstances, of decomposing it.

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

Action of water on gases.

Though the number of liquid bodies is pretty considerable, 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 portion 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 nifferent 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 William Henry and of Mr Dalton, 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 absorption 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 all the gases which are but little absorbable by water, placing them in the order of their absorption, and beginning with the least absorbable:

Table of the gases little absorbable by water.

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

The gas separates in a vacuum.

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 diminishes 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.

Its quantity regulated by the temperature

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.

And purity of the water.

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

Experiments of Henry and Dalton.

chemists, especially by those of Dr William Henry and Mr Dalton. 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 two 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 Dal-

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* See *Phil. Trans.* 1803, and Nicholson's *Jour.* vi. 229. The only

ton 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:

Table of the bulk of gases absorbed by water.

GASES.	Absorption according to	
	HENRY.	DALTON
Carbonic acid	108	100
Sulphureted hydrogen..	106	100
Nitrous oxide	86	100
Olefiant gas..........	—	12·5
Nitrous gas...........	5·	3·7
Oxygen gas............	3·7	3·7
Phosphureted hydrogen	2·14	—
Carbureted hydrogen ..	1·	3·7
Azotic gas............	1·53	1·56
Hydrogen..............	1·61	1·56
Carbonic oxide........	2·01	1·56

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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.

The difference between these two 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, except in a few cases, 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 $1\frac{1}{5}$ times 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 Mr Davy stated it at 54 ‡. It has been since ascertained, that this deficiency was owing to the impurity of the gases examined. We may consider Mr Dalton'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

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* *Phil. Mag.* xxiv. 15.

† Nicholson's *Journal*, vi. 231.

‡ *Researches*, p. 140.

portion 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.

These gases divisible into four sets.

3. But if we consider Dalton's statement as correct, then it follows 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 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.

Effect of pressure.

4. From the experiments of Dr William Henry upon gases subjected 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 22½ 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.

Absorbed gases retain their elasticity.

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.

Gases supposed only mechanically mixed with water.

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 from $\frac{1}{2}$ 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, that 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. 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.

Reasons for supposing them dissolved in it.

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

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* Nicholson's *Jour.* v. 225.

† *Opusc.* i. 9.

the gases by water to the simple principles of chemical affinity. It is, in reality, only a peculiar case of chemical *dissolution*, 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 none-elastic, and limits the quantity of gas which can combine; for when the attraction between the liquid and gas is just balanced by that 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.

Chap. II.

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 William 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 density; 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 former 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.

Thus there is nothing in the absorption of gases by water that does not agree well with the notion of their combining with that liquid in consequence of an affinity for it. We learn from the experiments of Dalton, that the cube root of the bulk absorbed is proportional to that affinity. Hence the affinities of the four sets of gases for water are in the following proportions:

Affinity.

1. Carbonic acid, sulphureted hydrogen, nitrous oxide.. = 4
2. Olefiant gas.. = 3

Affinity.

3. Oxygen, nitrous gas, carbureted hydrogen, phosphureted hydrogen........................ = 2
4. Azote, hydrogen, carbonic oxide.............. = 1

In considering the absorption of gases by water, the external pressure ought to be kept out of view, as it does not at all affect the bulk of the elastic fluid absorbed. We ought to consider the gases in such a state of expansion that their atoms exercise no sensible repulsion on each other, but cannot approach any nearer without occasioning sensible repulsion. Let us suppose, that in that state the affinity between water and azote, and the other gases in the fourth class, is so weak that it is balanced by the smallest elasticity. In that case water would absorb exactly its bulk of these gases. The affinity between water and oxygen, and the other gases constituting the third series, being double, water will absorb eight times its bulk of them, because the atoms must approach to half their former distance before the elasticity balances the affinity. For the same reason, water will absorb 27 times its bulk of olefiant gas, and 64 times its bulk of carbonic acid and all the gases constituting the first series.

Proportion of gas absorbed depends upon the residue.

6. From the experiments of Dr William 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.

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

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 jar full of oxygen or any other gas, the sulphureted hydrogen, or nitrous oxid, makes its escape in a great measure, and mingles with the oxygen. To preserve the impregnation 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 William Henry, who announced it as a demonstration of the truth of Mr Dalton's peculiar theory of the non-

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

elasticity of gases to each other*. For if gas can be retained in water by the pressure 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.

It must be obvious, that the effect of a residue of a foreign gas upon the quantity absorbed, and a foreign atmosphere in separating the gas from water, both depend upon the very same cause. They admit of a very satisfactory explanation upon Mr Dalton's hypothesis; but they may be explained equally well without having recourse to it. They afford, therefore, no reason for adopting that hypothesis, unless its truth can be otherwise established by satisfactory experiments.

Reason of this.

All gases we have seen have a species of affinity for each other, and are capable of dissolving each other. This dissolving power is unlimited, because the gases are all in the same state. Liquids also are capable of dissolving gases; but their solvent power is limited by the elasticity of the elastic fluids dissolved. As gases act without restraint, and as the action of liquids is restrained by the opposing force of elasticity, the action of the gases will be more powerful than that of liquids, unless the force of affinity in the latter be so considerable as to produce a combination too intimate to be merely entitled to the name of *dissolution;* but no such degree of affinity exists between the water and the gases which we are considering. Hence every gas will exert a certain dissolving power upon every other gas; this power will oppose the absorption of the gas by water, and of course diminish that absorption; but the

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[*] Nicholson's *Jour.* viii. 298.

power will be proportional to the relative bulk of the opposing gas. Hence the quantity of any gas absorbed by water *ought* to diminish as the bulk of any foreign gas in the residue increases, as Dr Henry found to be the case. For the very same reason, when water impregnated with any gas is brought into contact with a different gas, a portion of the dissolved gas ought to leave the water, and combine with the elastic fluid; and this proportion ought to be such, that the force exerted by the water upon the portion of gas retained just balances the force exerted by the elastic fluid on the quantity absorbed.

Thus, the separation of almost the whole, or of a part of the gas from the water, is not the consequence of an increase of elasticity from diminished pressure, but of an increase of elasticity from the attraction of the superincumbent gas.

Let us suppose that two gases, equally absorbable by water, are mixed in equal proportions, and that water is impregnated with them. As their solubility is equal, so of consequence is their affinity. Hence the same proportion of each will be absorbed; for we have no reason to suppose that the solvent power of water for one gas is altered by its having dissolved another gas. It will therefore absorb its own bulk of each of them; but as each of them, in consequence of the mutual mixture, is reduced to half the usual density, this is precisely the same thing as if water absorbed half its bulk of each of them separately. If water impregnated with its own bulk of one gas be brought into contact with its own bulk of another equally absorbable, half the impregnating gas will escape, and half the superincumbent gas will be absorbed, because the action of such gases on water and on each other, supposing the bulks equal, is the same.

If we suppose equal bulks of two gases not equally absorbable to be brought into contact with water, the liquid will absorb the same bulk of each as it would do separately. Thus, if the gases be carbonic acid and olefiant gas, it will absorb its own bulk of the first, and $\frac{1}{8}$th of its bulk of the second; but as the density of each of these gases is reduced to one-half, this is the same thing as if the liquid were to absorb nearly half its bulk of carbonic acid of the usual density, and $\frac{1}{16}$th of its bulk of olefiant gas. If water impregnated with its own bulk of carbonic acid be brought into contact with its own bulk of olefiant gas, then half the carbonic acid will escape, while only $\frac{1}{16}$th part of the olefiant gas will be absorbed: because the olefiant gas exerts the same power upon the carbonic acid as the water, while the water exerts but half of the power upon olefiant gas that the escaped portion of carbonic acid does.

This reasoning might easily be applied to mixtures of all the gases in any proportion whatever. To find how much of each gas will be absorbed by water when two gases are mixed together, we have only to conceive that water absorbs its usual bulk of each, and then to consider what is the relative density of each gas in water, to know correctly the quantity of each really taken up. Thus, suppose a mixture of 80 parts azote and 20 oxygen, water will absorb $\frac{1}{64}$th of its bulk of the first and $\frac{1}{27}$th of its bulk of the second; but the density of azote in this case is only $\frac{80}{100}$th parts, or $\frac{8}{10}$ths of its usual density, and that of oxygen $\frac{20}{100}$th parts, or $\frac{1}{5}$th. Therefore, to find the bulk of each really absorbed, supposing it taken at the usual density, we must reduce $\frac{1}{64}$th to $\frac{8}{10}$ths, and $\frac{1}{27}$th to $\frac{1}{5}$th of its bulk. The result would be nearly $\frac{1}{80}$th of azote and $\frac{1}{135}$th of oxygen.

But if we know the proportion of each gas absorbed, we have only to subtract that portion in order to find the nature of the residue.

Proportion of gas absorbed depends upon temperature.

7. The proportion of gases absorbed by water is considerably influenced by the temperature. Dr William Henry found, that 100 inches of water at 55° absorbed 108 inches of carbonic acid; but the same quantity of water at 85° absorbed 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 attend 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 temperature between 32° and 212° without any change in the proportion of the gas contained in

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* Nicholson's *Jour.* p. 235.

the water[*]. In this case the superincumbent gas suffers the same change of its elasticity as the portion contained in the water, and consequently 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 any pure gas whatever, the whole of that gas will be absorbed 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.

Water supposed by some to convert gases into azote.

A great number of experiments have been made on this subject by different chemists, especially by Dr Priestley[†] and Mr Berger[‡]; but as they neglected to notice the nature and quantity of gas with which the water used was impregnated, 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 $\frac{1}{7}$th of its bulk, the residuum consisted 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 reduced to 0·7 or to ·75. This change is obviously connected with some particular change which takes place in stagnant water; probably a species of putrefaction. Some substances contained in the wa-

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[*] *Phil. Mag.* xxiv. 16.

[†] Amer. Trans. v. 21.

[‡] *Jour. de Phys.* lvii. 5.

ter, and taken up from the vessel, seem to acquire the property of uniting with oxygen, 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 $\frac{3}{4}$ths 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 supposition 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.

List of the more absorbable gases.

II. All the very absorbable gases belong to the class of acids and alkalies. The following is a list of such of them as have been hitherto examined, placed in the inverse order of their absorbability :

1. Oxymuriatic acid gas
2. Sulphurous acid
3. Fluoric acid
4. Muriatic acid
5. Ammoniacal

Probably both the hyperoxymuriatic acid and the prussic acid ought to be classed with the preceding elastic fluids ; but no exact experiments relative to their absorbability have been hitherto made.

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* *Phil. Mag.* xxiv. 17.

Chap. II.

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.

Oxymuriatic acid	1·5+
Sulphurous acid	33
Fluoric acid	175+
Muriatic acid	516
Ammoniacal	780

The absorption of oxymuriatic acid, as stated in this table, is certainly greatly under the truth; at least if we can judge from the rapidity with which the absorption of this gas takes place. It is stated from an experiment of Berthollet, made long ago, that a cubic inch of water absorbs about $1\frac{1}{3}$d grain troy of this gas. The remaining numbers contained in the table are the result of my own experiments. I did not succeed in ascertaining the quantity of fluoric acid absorbed by water. A cubic inch of water, after it had absorbed 175 inches of that gas, was become a solid jelly, and could not be made to absorb any more. The gas was extricated in glass vessels, and of course contained silica, to which the jelly was owing.

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.
Oxymuriatic acid	1·002+
Sulphurous acid	1·040
Fluoric 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 inches it is obvious that only $\frac{2}{3}$ds 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 muriatic acid gas in the mixture is just $\frac{2}{3}$ds 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 saturated with them be ascertained. The following Table exhibits these densities:

Quantity contained in a given bulk of the water.

Oxymuriatic acid	1·5	
Sulphurous	31·7	= 3^3 nearly
Muriatic	344·0	= 7^3
Ammonia	468·0	= 8^3

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 consider-

Combine chemically with the water.

ed in the preceding part of this Section. Not only the rapidity of absorption, 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 barometer 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 condensation 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 hem in general terms.

Alcohol seems to bear a strong resemblance to water in the power of absorbing gases. Oils also absorb several gases precisely as water; but upon others they act with more energy. Dr Priestley found that both oil of turpentine and olive oil absorb nitrous gas in considerable quantity, and decompose it. They have also the property of absorbing and condensing the oxygen of common air. 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 COMBINATON 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

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* Priestley *On Air*, i. 372; ii. 229. Davy's *Researches*, p. 160.

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 five; but two of them, muriatic acid and fluoric acid, have scarcely been observed to combine with any solids except alkalies, earths, and metallic oxides. With these they form combinations of a complicated nature called *salts*, the examination of which belongs to a subsequent chapter. *Oxygen*, *hydrogen*, and *azote* are the only simple gases which at present claim our attention.

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

Oxygen with carbon.

With carbon it unites only in three proportions, as far at least as we know at present, and forms the three compounds called *carbonic acid*, *carbonic oxide*, and *carbonous oxide*. The two first are well known; they are gaseous fluids. The third has not been examined; but it is presumed to exist, from the phenomena which appear during the combustion of the diamond. It is a solid substance. Of these compounds the carbonic acid has been analysed with the greatest care. If we conclude, from the experiments of Lavoisier and Tennant, as confirmed by Allen and Pepys, that it is composed of 28 carbon and 72 oxygen, and suppose with Dalton that a particle of it is composed of one atom of carbon and two of oxygen, we can easily find the relative weight of an atom of carbon: for one atom of carbon must be to two atoms of oxygen as 28 : 72; or to one atom of oxygen as 28 : 36, or as 7 to 9. But we found before, that an atom of oxygen was 6; we must therefore diminish the numbers 7 and 9, each by $\frac{1}{3}$d, in order to convert 9 into 6, and preserve the same proportion between them. This gives us 4$\frac{2}{3}$ds instead of 7. According to this hypothesis, 4$\frac{2}{3}$ds is the weight of an atom of carbon, provided that of oxygen be 6.

Let us now compare the weight thus found with the analysis of the other two compounds of oxygen and carbon. As carbonic oxide contains less oxygen than carbonic acid, we must, according to Mr Dalton's hypothesis, consider it as composed of one atom of oxygen and one atom of carbon: and for a similar reason, carbonous oxide must consist of two atoms of carbon united to one of oxygen.

From the experiments of Cruikshanks, we learn that carbonic oxide is composed of 41 parts, by weight, of oxygen, and 28 of carbon. Therefore we have an atom of oxygen to an atom of carbon as 41 : 28, or as 6 : 4·1 nearly. This does not differ very much from the preceding. A very small error in the two experiments on which the composition of these bodies is founded would reconcile them. The mean of both is nearly 4$\frac{1}{2}$, which we may consider as indicating nearly the weight of an atom of carbon. The following will be the symbols for the composition of an atom of each of the compounds of carbon and oxygen, together with their weight according to the numbers thus adopted.

Constituents.

		Density.
○⊕	Carbonic oxide	10·5
⊕○⊕	Carbonous oxide	15·0
○⊕○	Carbonic acid	16·5

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. There is still an ambiguity about this compound; the circumstance of its being lighter than oxygen, although it consists of oxygen holding carbon in solution, is an anomaly pointed out by Berthollet, which has not yet been accounted for in a satisfactory manner. If carbon were an elastic fluid, its specific gravity, according to the above statement, might be supposed to be ·809, that of air being 1·00. In that case the specific gravity of carbonic oxide, supposing that no condensation took place, ought to be exactly 0·956, which it is in reality. But these suppositions appear to me inadmissible, unless we take into view another circumstance, which Berthollet has overlooked: I mean the difference between the states of carbonic oxide and carbonic acid. The first is a combustible, the second a product; hence the oxygen in the first must contain a portion of caloric of which the second is destitute. This dose probably prevents the condensation, and preserves to the compound all the elasticity that it would have had, supposing the carbon gaseous.

In cases of combustion, the first change of the carbon seems to be into carbonous oxide; a combination probably as little intimate as carbonic oxide, but not gaseous, on account of the great proportion of carbon. The ultimate compound is carbonic acid, the most intimate of all, as is obvious from its great density and difficult decomposition.

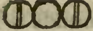
Oxygen with phosphorus.

2. Oxygen is capable of uniting likewise with at least three proportions of phosphorus, forming the compounds called phosphoric oxide, 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 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 converted 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 phosphorus, and upon the comparatively small quantity of oxygen with which they unite.

As phosphoric acid has been analysed with accuracy, it will enable us, by the application of Dalton's hypothesis, to ascertain the comparative weight of an atom of phosphorus, and thence to deduce the composition of the other compounds. This acid is composed of 115 parts by weight of oxygen and 100 of phosphorus. If we suppose with Dalton that it is formed by the union of one atom of phosphorus with two of oxygen, then we have an atom of phosphorus to two atoms of oxygen, as 100 : 115, and to one atom of oxygen as 100 : 57·5. Hence, if the weight of an atom of oxygen be 6, that of an atom of phosphorus must be 10·4. Let the symbol for phosphorus be , then the symbols for the three compounds of oxygen and phosphorus, and the weight of an atom of each, will be as follows:

Constituents.

		Density.
	Phosphorous acid	16·4

		Density.
	Oxide of phosphorus	26·8
	Phosphoric acid	22·4

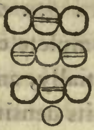
As phosphoric acid is the result of a complete combustion, while phosphorous acid is still partially, and oxide of phosphorus completely combustible, its density ought to be greater than that of the rest, which is the case. The specific gravity of melted phosphoric acid is 2·85, while that of phosphorus is not more than 1·8. Thus phosphorus, when united to oxygen, undergoes a condensation. The density of the oxygen is increased more than 1000 times. This very great augmentation of density accounts for the permanency of this compound, and the extreme difficulty of decomposing it.

Oxygen with sulphur.

3. Oxygen unites also to sulphur in three proportions, and forms compounds with it different from those which it forms with carbon and phosphorus; for one of them is a gas, another is a liquid, and the third is a solid. These compounds are oxide of sulphur, sulphurous acid, and sulphuric acid. The last has been analysed with care. The analysis will enable us, by means of Dalton's hypothesis, to estimate the relative weight of an atom of sulphur. This acid is composed of 136·5 parts by weight of oxygen and 100 of sulphur. If we suppose with Dalton that it is formed by the union of an atom of sulphur to three atoms of oxygen, then we have three atoms of oxygen to one atom of sulphur as 136·5 : 100; and one atom of oxygen to one atom of sulphur as 45.5 : 100, or as 6 to 13. Hence the weight of an atom of sulphur would be 13. If we compare this with my analysis of sulphurous acid, and suppose it composed of two atoms of oxygen and one atom of sulphur, we obtain nearly the same weight of an atom

of sulphur. The following are the symbols and density of the atoms of these different compounds:

Constituents.



Sulphurous acid 25
Oxide of sulphur 32
Sulphuric acid.............31

There is a very striking resemblance between the combinations of oxygen with phosphorus and sulphur. A certain elevation of temperature is necessary to begin the combination. This heat probably acts by diminishing the cohesion of the atoms of the solid bodies. The first compound in both is solid and combustible. This combination is far from intimate, but it disposes the solid bodies to a closer union. Thus, to a certain extent, the oxygen loses its elastic form, and is condensed into the solids. When the combustion is complete, both of them form products of combustion. The intermediate compound seems to be the result of an imperfect combustion, and to be less intimate than the ultimate compound: for when sulphurous acid and phosphorous acid are exposed to a sufficiently strong heat, they are decomposed; sulphur and sulphuric acid being separated in the one case, and phosphorus and phosphoric acid in the other. Water, however, seems to be a necessary agent in these decompositions.

Constituents.

But notwithstanding the great similarity between phosphorus and sulphur, and between the compounds which they form with oxygen, the differences between these compounds are considerable. The union between phosphorus and oxygen is much more intimate than that between oxygen and sulphur. Hence the oxygen in the former is in a much more condensed state, and the decomposition is much more difficult than in the latter.

There is much less difference between phosphoric and phosphorous acids than between sulphurous and sulphuric. These differences are probably owing to the greater affinity of phosphorus for oxygen. The constituents of sulphurous acid are much more loosely united than of sulphuric. Hence the reason of the comparative ease with which it may be decomposed by many substances which do not act upon sulphuric acid. Hence perhaps the reason why it retains an elastic form. It deserves attention, that many substances, as phosphorus, mercury, &c. have the property of converting sulphuric acid into sulphurous, and that the compounds formed are of the very same nature as if they had been formed by a supporter of combustion; but much heat is required to produce the action.

Oxygen with metals.

4. 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. The atoms of the metals are probably incomparably more dense than those of other bodies.

The investigation of the composition of the metallic oxides is not far enough advanced to enable us to apply to them the hypothesis of Dalton with much advantage. It would be easy indeed, by taking the atoms of oxygen capable of uniting with an atom of metal at pleasure, to find numbers which would correspond with our table of the composition of these oxides given in a preceding part of this Work *; for in all those metallic oxides which have been analysed with care, the proportion of oxygen increases pretty regularly. This will appear from the following Table, in which the proportion of oxygen which unites with a given weight of metal is stated numerically:

Proportion of oxygen.

	Proportion of Oxygen.
PLATINUM.	
Protoxide	1
Peroxide	2
MERCURY.	
Protoxide	1
Peroxide	2
COPPER.	
Protoxide	1
Peroxide	2
IRON.	
Protoxide	1
Black oxide	2
Peroxide	5
TIN.	
Grey oxide	2
Peroxide	3
LEAD.	
Yellow oxide	2
Red oxide	3
Peroxide	6

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* Vol. I. p. 391.

	Proportion of Oxygen.
ZINC.	
Protoxide	1
Peroxide	2
ANTIMONY.	
White oxide	3
Peroxide	4
ARSENIC.	
White oxide	3
Arsenic acid	5
MANGANESE.	
White oxide	2
Red oxide	3
Peroxide	5
TITANIUM.	
Protoxide	1
Red oxide	2
White	3

Of all the metallic oxides those are by far the most intimate compounds, and the most difficult to decompose, which are formed by combustion. They are perfect products of combustion, and resemble the products of the simple combustibles in many respects. Were we to suppose these oxides compounds of one atom of the metal with two atoms of oxygen, as is the case with the products of the simple combustibles, we might in that case ascertain the weight of an atom of each of the metals. All those oxides in the preceding Table which have the number 2 after them are formed by combustion. Were that supposition to be admitted, the numbers which follow the other oxides would indicate

Book III.

the number of atoms of oxygen in them united to an atom of the metal. The following would be the weight of an atom of each metal, according to this hypothesis, supposing that of oxygen 6.

Weight of the metals.

Metals.	Density.	Metals.	Density.
Lead	150	Tin	48
Mercury	120	Zinc	48
Antimony	80	Manganese	48
Platinum	80	Arsenic	54·5
Copper	48	Iron	32·4

The metals differ from the simple combustibles in the property which they have of uniting with additional doses of oxygen, after they have formed with it their most intimate combination. These new compounds retain the oxygen with much less energy than those which we have been considering. In this respect they agree with azote, which combines with more oxygen than is contained in nitrous gas, the compound which is of most difficult decomposition. All these new metallic combinations contain the oxygen in a state capable of supporting combustion. It is from them that we usually obtain oxygen gas. Whether all the metals possess this property, has not been ascertained. Iron, manganese, and tin, possess it in the most remarkable degree. They absorb oxygen even from the atmosphere. Lead also possesses it to a considerable extent, and so likewise does arsenic, and probably also antimony.

Many of the metals are capable also of uniting with smaller doses of oxygen than that which they absorb during combustion. These combinations are less intimate, their character is not so well marked, they have a much weaker tendency to unite with other bodies, and are of a less permanent nature, than the compounds from combustion. In what state the oxide which they contain is, has not been ascertained; but it is not unlikely that they bear a certain resemblance to the combustible oxides.

Hydrogen with simple solids.

5. Though there exists a considerable affinity between hydrogen and the three simple combustibles, 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 and sulphur, and probably likewise with two of phosphorus. At least no other satisfactory account can be given of the great difference between the properties of phosphureted hydrogen at different times. If we apply the hypothesis of Dalton to these compounds, we may consider them as composed of one and two atoms of the hydrogen united to one atom of the solid. The following will be the symbols for these compounds, and the weight of an atom of each according to this hypothesis:

Constituents.

⊙⊕	Olefiant gas	5·5
⊙⊕⊙	Carbureted hydrogen	6·5
⊙⦶	Superphosphureted hydrogen	11·4
⊙⦶⊙	Phosphureted hydrogen	12.4
⊙⊜	Supersulphureted hydrogen	14
⊙⊜⊙	Sulphureted hydrogen	15

Let us compare this hypothesis with the analysis of such of these compounds as we are acquainted with.

By the analyses of Messrs Henry and Cruikshanks, carbureted hydrogen contains at most 13·4 by weight of carbon and 5·2 of hydrogen. According to this statement, we have the weight of two atoms of hydrogen to that of an atom of carbon as 51 : 134, or as 1 to 2·5; and that of one atom of hydrogen to one of carbon as 1 to 5;—a result which does not differ much from the weight of carbon found from the analysis of carbonic acid.

According to the experiments of the Dutch chemists and Henry, olefiant gas contains at most 23·3 of carbon by weight and 5·48 of hydrogen. According to this statement, we have an atom of hydrogen to an atom of carbon as 548 : 2330, or as 1 to 4¼, which is still nearer the weight of carbon from carbonic acid than the preceding. The mean of the whole would be 4·6, which is probably very near the truth.

Our knowledge of the combinations of sulphur and phosphorus with hydrogen, is still too imperfect to admit of comparison with the results obtained from the analysis of sulphuric and phosphoric acids. Thenard's analysis of sulphureted hydrogen by no means corresponds with the notion, that this gas contains two atoms of hydrogen and one of sulphur, provided the weight of sulphur be estimated from the constitution of sulphuric acid; but many circumstances render this analysis suspicious. It is difficult to see how sulphureted hydrogen could be completely decomposed by an acid, and its sulphur acidified without some loss; and all this loss being ascribed to hydrogen would greatly increase the proportion of it obtained from such an analysis. Besides, from an experiment of Davy, it appears that the proportion of hydrogen in sulphureted hydrogen is insignificant when compared with the sulphur; for he found that just double the quantity of nitrous gas was necessary to convert the constituents of sulphureted hydrogen into sulphuric acid and water, that were required to convert them into sulphurous acid and water *.

Composition of ether.

Ether, from the analysis of Cruikshanks, we found to be a compound of hydrogen and carbon, as well as the gases which we have just been considering. As it contains more carbon than olefiant gas, we must consider it according to Dalton's hypothesis, as composed of two atoms of carbon and one of hydrogen. Its symbol will be ⊕⊙⊕. The analysis of it, as stated in a

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* See Section III· of this Chapter, p. 499.

preceding page of this Chapter *, does not agree with this statement; but in that statement no correction was introduced for the temperature, because Cruikshanks did not specify the temperature in which his experiments were made. Mr Dalton has since repeated the experiments, and according to his account, when the proper corrections are introduced, the analysis agrees very nearly with the supposition of its being composed of two atoms of carbon and one of hydrogen. We must therefore consider it as composed of more than eight parts by weight of carbon to one of hydrogen. The weight of an atom of it will be 10. But the analysis of Saussure does not agree with this conclusion.

Thus hydrogen and carbon unite in three proportions, constituting one binary compound, namely *olefiant gas*, and two ternary compounds, namely, *carbureted hydrogen*, composed of two atoms of hydrogen and one of carbon; and *ether*, composed of two atoms of carbon and one of hydrogen. We see in them the gradual effect of the carbon; as its quantity increases, the specific gravity of the compound increases, and its elasticity diminishes, till in the last of them we find that the compound is no longer a gas but a vapour. Olefiant gas seems to be the most intimate compound of the three. A red heat decomposes ether, and converts it into olefiant gas, carbureted hydrogen, and charcoal; but upon the two others it has no effect whatever.

Sulphureted hydrogen is the most intimate of the combinations of sulphur and hydrogen. A red heat does not decompose it. Supersulphureted hydrogen is formed directly by the combination of sulphureted hy-

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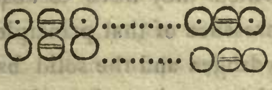
* Page 495.

drogen on sulphur. The last, however, must be deprived of the cohesion which usually joins its particles together, otherwise the combination cannot take place. When sulphur and sulphureted hydrogen are united with an alkali, and suddenly disengaged by an acid, they unite at the instant of their evolution. This is the method which succeeds best in obtaining it.

Formation of sulphureted hydrogen;

It is during the decomposition of water by the compound agency of an acid and a metal united to sulphur, that sulphureted 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 cohesion 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 sulphuric acid. Thus, when nitric acid is poured upon the sulphureted oxide of manganese, sulphureted hydrogen gas exhales, and sulphuric acid is formed, as has been shown by Klaproth and Vauquelin. The nitric acid in this case seems merely to dissolve the metallic oxide and disengage the sulphur. Two particles of sulphur must act at once upon two atoms of water, one of them combining with all the hydrogen, and the other with all the oxygen. Thus,



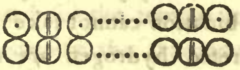
Sulphureted hydrogen
Sulphurous acid

Of phosphureted hydrogen.

The formation of phosphureted hydrogen is quite analogous. We obtain it when phosphorus is boiled with a liquid alkali. Water is decomposed, and phosphoric acid and phosphureted hydrogen formed at once. The alkali seems only to act by retaining the phosphorus

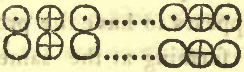
Constituents.

in a heat sufficiently high to enable it to decompose water. The symbols of this decomposition will be



Phosphureted hydrogen
Phosphoric acid

Carbureted hydrogen is disengaged spontaneously from stagnated water, and is obviously produced by the putrefaction 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 together. The following will be the symbols representing this decomposition:



Carbureted hydrogen
Carbonic acid

Oils.

Oils have a very strong resemblance to olefiant gas; indeed they may be said to differ only in the state. By the analysis of Lavoisier they ought to consist, like that gas, of an atom of hydrogen joined to an atom of carbon. Like olefiant gas, they deposite charcoal when burned with an under proportion of oxygen. But notwithstanding that analysis, it is extremely probable that they are of a more complex nature. Their little volatility would indicate a much greater proportion of carbon; while the tendency which they have to absorb oxygen would indicate the presence of that principle.

All the compounds of hydrogen and the solid bases are combustible. Those which contain carbon give the greatest proportion of light during combustion, and in these the quantity of light increases with the carbon. Carbureted hydrogen gives the least, olefiant gas still more, and ether the most of all. This deserves attention, because in some other vapours and gases which contain carbon, the combustion is but feeble; as in carbonic oxide and alcohol, both of which only burn with a blue flame. In these there is also oxygen present. It is not unlikely that there is an union between the oxygen and carbon, and that this is the cause of the comparatively little light emitted; the carbon having undergone a kind of semi-combustion before. These remarks are not contrary to a position given in a former part of this Work, that the light emitted is proportional to the quantity of oxygen consumed; for this will be found to hold accurately in these gases and vapours.

6. Azote has the property of combining with carbon, phosphorus, and sulphur, and of forming gaseous compounds not yet sufficiently known to admit of examination. Neither can any remarks be offered on the combinations of hydrogen with the metallic bodies.

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 and nitrous oxide 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, oxymuriatic acid, and hyperoxymuriatic 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 instance of the direct combination of a compound gas with a solid base; these are the following:

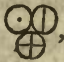
Carbonic acid and charcoal.

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 two atoms of oxygen with one atom of carbon, and carbonic oxide of one of oxygen with one 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 explanation. 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 combustion, were not the diminished specific gravity inexplicable upon any other supposition than the union of a new dose of heat.

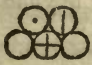
Ammonia and charcoal.

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; and Berthollet showed that this acid is a compound of azote, hydrogen, and carbon. It must therefore be formed by the direct union of ammonia with carbon. A red heat indeed decomposes ammonia; but it seems the presence of carbon prevents the decomposition, and enables it to enter into a combination of a

Prussic acid.

more intimate nature. It has been supposed by some, that prussic acid contains oxygen as a constituent; but the very high temperature in which the union takes place renders this unlikely. For in such a temperature oxygen always unites with carbon or hydrogen separately by combustion; unless we are to suppose that the oxygen, before its union, was in that state of combination which constitutes a product. But in the present case there is no product. Water cannot be suspected, because the experiments of Richter and Bucholz have shown that water prevents the formation of prussic acid, and even occasions its decomposition. Prussic acid, then, seems to be a triple compound of one atom of hydrogen, one of azote, and one of carbon. Its symbol will be , and the density of an atom of it 10·5.

Oxyprussic acid.

Berthollet has shown, that when prussic acid is treated with oxymuriatic acid, it combines with oxygen, and is formed into a new compound, which he has called oxyprussic acid. The least heat resolves this new acid into ammonia and carbonic acid. Hence its composition is obvious: Two atoms of oxygen must have combined with every atom of prussic acid, and rendered it a quintenary compound. Its symbol will be . These elements seem to be loosely combined; but heat makes them combine intimately into ammonia and carbonic acid, which mutually unite. The most singular circumstance attending this combination is the change from a combustible oxide to carbonic acid without any combustion.

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

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

Alcohol.

Alcohol is a liquid which is known to be composed of oxygen, hydrogen, and carbon. The combustion of its vapour proves that the proportion of carbon is very considerable. It is usually formed by the mutual action of gluten, and what is called saccharine matter, upon each other. By heat it may be resolved into various compound elastic fluids, though it has never yet been formed artificially by uniting them together. Various opinions have been entertained respecting the composition of this fluid. Mr Dalton considers it as composed of three atoms of carbon, two of hydrogen, and one of oxygen, and represents its composition thus . His reason is, that by passing it through a red hot tube, it may be converted into carbonic oxide and olefiant gas. With me this has never been the case; there has always been a deposite of a fetid oil.

No conjectures in the present state of the science can be offered on the composition of the combustible acids, and far less of the animal and vegetable substances in general. Many of these, however, are not now beyond the reach of chemical analysis.

CHAP. III.

OF LIQUIDS.

It has been sufficiently ascertained that the state of most bodies depends upon temperature; that solids may be converted 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 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 bodies 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 liquids, consider how far the state of liquidity affects the union of these bodies with each other, and with solids. The subject 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 resistance to an impressing force, or have a certain degree of *viscidity*.

Cause of fluidity.

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

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

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.

Liquids cohere.

3. The particles of liquids cohere together, as well as those of solids, and there is a considerable difference between 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.

Compressible.

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

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

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.

List of liquids.

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.

1. Mercury.

II. COMPOUND.

a. Simple gases combined.

2. Water.
3. Nitric acid.

b. Gases with a solid base.

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

c. Solids combined.

12. Phosphuret of sulphur.

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.

Their specific gravity.

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	— —
Nitric acid	1·583
Sulphuric acid	1·885
Phosphuret of Sulphur	—
Oxymuriate 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.

Density of their atoms.

By the application of Dalton's hypothesis respecting the combination of atoms, we deduced, in the preceding Chapter, the weight of the atoms of several of these liquids. The following are the symbols of their composition, and the numbers representing the weight of each, according to that hypothesis;

Constituents.		Density.
⊙○	Water	7
⊕⊙⊕	Ether (sulphuric)	10
⊙⊕⊙ ⊕○⊕	Alcohol	21·5
⊙⊜	Supersulphureted hydrogen	14
○⦶○	Nitric acid	17
○⊜○ ○	Sulphuric acid	31

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 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.

OF 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.

Form a homogeneous compound.

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 ge-

neral 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 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 great-

est 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.

Condensation of sulphuric acid and water.

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:

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 $\frac{1}{11}$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.

Liquids dissolve each other

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.

Like gases.

This dissolution of liquids by each other is exactly similar to the mutual dissolution of the gases. It may seem at first sight remarkable that it is not as general among liquids as among gases: but there is this great difference between the state of gases and liquids, that the particles of the latter cohere, and therefore oppose the admission of foreign bodies among them; whereas this is not the case with the gases. It seems to be this cohesion chiefly that occasions the difference. Hence, probably the reason why those liquids that approach nearest to each other in their properties dissolve each other most readily.

Liquids which dissolve fixed quantities of others.

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

Water with ether
    volatile oils
    sulphuret of carbon
    oxymuriate of tin
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.

Water and oxymuriate of tin.

It may appear perhaps, at first sight, needless to have included oxymuriate of tin in the table, as the liquid state of this salt may be ascribed to water. But there is reason to believe that the fuming liquor of Libavius contains very little water, and that, like phosphuret of sulphur, it owes its liquid state to the nature of the combination of its constituents with each other. There is no other salt which exactly resembles it in this respect; but several other oxymuriates approach it, as the *butter of antimony*, &c. Oxymuriate of tin is capable of uniting with any portion whatever of water; but water unites only with a determinate portion of the salt. Adet ascertained, that when 22 parts by weight of the fuming oxymuriate are mixed with 7 of water, the two liquids combine and form a solid mass. These we may consider as the proportions which constitute the most intimate combination of these bodies. We have here an instance of water diminishing the solubility of bodies in consequence of the increase of condensation which it produces; for the liquid oxymuriate is not nearly so volatile as the fuming liquor. There are many instances of the same kind: Thus very strong nitric acid is more volatile than what is moderately strong.

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 *.

Liquids decomposing each other.

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.

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.

Action of solids liquified.

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 so-

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* *Statique Chimique*, i. 41.

lid 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.

The proportion of the ingredients which enter into combination 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.

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 action, and the want of correct experiments respecting them. These are *supersulphureted hydrogen*, *phosphuret of sulphur*, and *oxymuriate of tin*. Upon these liquids I have no remarks 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	Ether
Alcohol	Petroleum

Volatile oils	Mercury
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 bodies, and its presence in general greatly facilitates the action of substances on one another. Hence it is almost always indispensable when artificial combinations or decompositions 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 different kinds of combinations with solid bodies. In the one species the compound continues solid, in the other it becomes 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.

1. Hydrate.

To the first species of combinations 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.

Table of hydrates.

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.

Chap. III.

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. I do not know that any exception exists: every salt, as far as known, is capable of uniting with water in a solid state. 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 de-

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[*] *Statique Chimique*, i. 35.

stroying 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 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 evaporation 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 con-

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

Hydrate of lime.

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

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* *Phil. Trans.* 1770, and *Chemical Essays*, v. 43.

† *Ann. de Chim.* xxvii. 116; xxviii. 3, and 282; xxxi. 284.

lime, and ascertained the specific gravity after each addition. The following Table exhibits the result of these curious experiments 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 Calculation.	Difference.
1st.	0	1·5949	—	—
	183	1·6137	1·5841	+296
	1620	1·4877	1·5123	—246
	3355	0·7852	1·4449	—6597
2d.	0	1·4558	—	—
	629	1·4819	1·4292	+527
	1562	1·4737	1·3941	+796
	2500	1·4000	1·3648	+354
	5000	0·8983	1·3038	—4055
3d.	0	1·3715	—	—
	312	1·4506	1·3602	+904
	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 diminution. Thus it appears that the hydrate of lime is specifically 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;

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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.

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 gravity of water saturated with each of them at the temperature 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.

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

Table of densities.

Salts.	Specific Gravity.	Sp. Grav. of saturated Solution.	Salt in 1000 parts of the Solution.	Sp. Grav. 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	2·009	+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 *.

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* *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	1·0479	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	1·0869	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.	Hyper-oxymuriate 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	1·0461	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	–	—	1·598[illegible]	—

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

Chap. III.

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	—	—	—	1·1482	1·2172	—
46	—	—	—	1·1567	1·2287	—
48	—	—	—	1·1656	1·2403	—
50	—	—	—	1·1755	1·2520	—

Book III.

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· 438
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	—	·3351	—	—	—	—
54	—	1·3527	—	—	—	—
56	—	1·3707	—	—	—	—
58	—	1·3902	—	—	—	—
60	—	1·4120	—	—	—	—

This Table is so simple as scarcely to require any explanation. 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.

Explanation of the table.

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 :

$$32-30 : 1{\cdot}1989-1{\cdot}1840 : : x : 1900-1840 ;$$

Or, which is the same thing,

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

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 $S=24\cdot88$. Let it be required to reduce it so that it shall contain only 10 *per cent.* of salt. Here $S'=10$. We have therefore $x=\frac{2488-1000}{10}=148\cdot8$. 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

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

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 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
52·25	Nitrate of magnesia	1·307	Almost all	A little	55	+2·75

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

Temperature before Mixture.	Saline Solution used.	Specific Gravity of Ditto.	Portion of Salt dissolved.	ortion of Salt precipitated from the Solution.	New Temperature produced	Change of Temperature.
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.

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

These curious phenomena obviously depend upon the mutual action which certain salts exert upon each other, which by diminishing 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 described 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 *.

Action of alcohol on solids.

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:

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. Tannin, and many vegetable substances.

Water and alcohol together appear to act upon several solids 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

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

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

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,
Copper,
Tellurium,
Arsenic,
Antimony.

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,
Cobalt,
Rhodium,
Manganese
Molybdenum.

Its action upon the other metals has not been tried.

When several of the metals are dipt into mercury, they come out moistened with it just as a piece of wood

Adhesion of metals to mercury.

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

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

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.

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. Sick-

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

II. Alloys.

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

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* 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.

III. WOODS.

Locust tree	20,100
Jujeb	18,500
Beech, oak	17,300
Orange	15,500
Alder	13,900
Elm	13,200
Mulberry	12,500
Willow	12,500
Ash	12,000
Plum	11,800
Elder	10,000
Pomegranate	9,750
Lemon	9,250
Tamarind	8,750
Fir	8,330
Walnut	8,130
Pitch pine	7,656
Quince	6,750
Cypress	6,000
Poplar	5,500
Cedar	4,880

IV. BONES.

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

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 AH (fig. 14.) represent the insensible distance between two particles ; and let the ordinates of the curve IQ q q' q'' represent the attracting and repelling forces of the two particles, as the second moves along the line AB while the first remains in the point A. The ordinate of the curves situated above the line AH represent repulsive forces, and 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 AB 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 BC it is attracted; and the attraction is a maximum at P, because there the ordinate PQ is a maximum. At the point C it is neither attracted nor repelled. In every part of CD it is repelled; in D it is neither attracted nor repelled; in DE 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 cohesive force of undecompounded solid bodies is very considerable. 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 crystallized silica, are always very hard. In the metals the cohesion is very often increased considerably by alloying them together. Thus the cohesion of copper is doubled by alloying it with one-sixth of its weight of tin, though the cohesion 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* (κρυσταλλος) originally signified *ice*; but it was afterwards applied by the ancients to crystallized silica, or *rock crystal*; because, as Pliny informs

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

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 kingdom, 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 substance always affects when it crystallizes: this indeed is considered as one of the best marks for distinguishing one substance from another. Thus common salt is observed to assume 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.

Crystals formed by

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 rendering bodies fluid, namely, solution in a liquid, and fusion by heat. These of course are the only methods of forming crystals in our power.

Solution,

Solution is the common method of crystallizing salts. They are dissolved in the water: the water is slowly evaporated, 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 proportions 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 gradually 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; 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

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* *Jour. de Phys.* lv. 300.

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 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 at its upper extremity. Mr Leblanc even affirms that saline solutions almost always increase in density according to their depth from the surface.

Nature of crystallization.

5. 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 geometrical 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?

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

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* *Treatise on the Origin of Forms and Qualities.*

the combination of a determinate number of similar bodies must produce similar figures. Hauy 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.

All crystals have a primitive form.

6. 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 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 Hauy has called it, very often lies concealed in those very crystals which appear to deviate farthest from it. And Hauy 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. 15.) 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 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 h 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 OX (fig. 16.), terminated by twelve pentagons, parallel two and two : of which those at the extremities, that is to say, ASRIO, IGEDO, BAODC at one end, and FKNPQ, MNPXU, ZQPXY 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 RSUXY, ZYRIG, &c. were the remains of the six sides of the original prism.

By 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 YIZ, UXY, &c. (fig. 17.) By continuing the same sections, these triangles at last disappeared, and the prism was converted into the rhomboid *a e* (fig. 18.)

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.

Integrant particles of three figures.

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 of the crystal must be the figure of the integrant particles of which it is composed. The mechanical division, indeed, cannot be continued so far, but it may be continued till it 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.

Hauy 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 Hauy 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 seldon affect that form; and all of them have a certain latitude and a certain number of forms which they assume occasionally 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 Hauy *secondary forms.* Now what is the reason of this latitude in crystallizing? why do bodies assume so often these secondary forms?

Secondary crystals owing to

7. 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.

In the solvents; and

2*d*, 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 †.

3*d*, 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 Hauy; 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.

To the different decrements of the crystalline laminæ.

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.

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* Leblanc, *Ann. de Chim.* xiv. 149.

† Fourcroy and Vauquelin, Ibid. xiv. 149.

Let us suppose that ABFG (fig. 19.) 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 together constitute the cube. Upon ABCD, 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. 20.) will fall exactly on the square marked with the same letters in fig. 19.

Above this lamina let us apply a second *l m p u* (fig. 21.), composed of 25 cubes; it will be situated exactly above the square marked with the same letters (fig. 19.). Upon this second let us apply a third lamina *v x y z* (fig. 22.), consisting only of 9 cubes; so that its base shall rest upon the letters *v x y z* (fig. 19.) Lastly, on the middle square *r* let us place the small cube *r* (fig. 23.), which will represent the last lamina.

It is evident that by this process a quadrangular pyramid has been formed upon the face ABCD (fig. 19.) the base of which is this face, and the vertex the cube *r* (fig. 23.) 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 gradual 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 exceedingly 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 DCBE (fig. 24.) being the pyramid resting upon the face ABCD (fig. 19.), and CBOG (fig. 24.) the pyramid applied to the next face BCGH (fig. 19.), if we consider that every thing is uniform from E to O (fig. 24.), in the manner in which the edges of the *laminæ of superposition* (as the Abbé Hauy calls the laminæ which compose the pyramids) mutually project beyond each other, it will readily be conceived that the face CEB of the first pyramid ought to be exactly in the same plane with the face COB of the adjacent pyramid; and that therefore the two faces together will form one rhomb ECOB. But all the sides of the six pyramids amount to 24 triangles similar to CEB; 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 Hauy 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 crystals are of four kinds.

These 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. Hauy 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.

1. Decrements on the edges.

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.

2. Decrements on the angles.

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 ABGF (fig. 25.), considered as a nucleus, a secondary solid, in which the laminæ of superposition shall decrease on all sides by single rows of cubes, but in a direction parallel to the diagonals. Let ABCD (fig. 26.), the superior base of the nucleus, be divided into 81 squares, representing the faces of the small cubes of which it is composed. Fig. 27. represents the superior surface of the first lamina of superposition, which must be placed above ABCD (fig. 26.) in such a manner, that the points *a*′, *b*′, *c*′, *d*′, (fig. 27.) answer to the points *a*, *b*, *c*, *d* (fig. 26.) By this disposition the squares A*a*, B*b*, C*c*, D*d* (fig. 26.) which compose the four outermost rows of squares parallel to the diagonals AC, BD, remain uncovered. It is evident also, that the borders QV, ON, IL, GF, (fig. 27.) project by one range beyond the borders AB, AD, CD, BC (fig. 26.), 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 AB, BC, CD, DA 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. 28.). It must be placed so that the points a'' b'' c'', d'' correspond to the points a', b', c', d', (fig. 27.), which will leave uncovered a second row of cubes at each angle, parallel to the diagonals AC and BD. The solid still increases towards the sides. The large faces of the laminæ of superposition, which in fig. 27. were octagons, in fig. 28. 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 $B'M'L'S'$ (fig. 29.), less by one range in every direction than the preceding lamina (fig. 28.). This square must be placed so that the points e', f', g', h' (fig. 29.) correspond to the points e, f, g, h (fig. 28.) Figures 30, 31, 32, and 33, 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 laminæ z' (fig. 34.) is a single cube, which ought to be placed upon the square z (fig. 33.).

The laminæ of superposition, thus applied upon the side ABCD (fig. 26.), 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. 35; in which the inferior angle C is the same point with the angle C of the nucleus (fig. 25. and 26.); and the diagonal LQ represents $L'G'$ of the lamina $A'G'L'K'$ (fig. 28.). And as the number of laminæ composing the triangle LQC (fig. 35.) is much smaller than that of the laminæ forming the triangle ZLQ, 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 decrement by one range, the three quadrilaterals which belong to each solid angle, as C (fig. 25.), will be in the same plane, and will form an equilateral triangle ZIN (fig. 36.). 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.

Third and fourth decrements.

The third law is occasioned by the abstraction of double, triple, &c. particles. Fig. 37. exhibits an instance of the subtractions in question; and it is seen that the moleculæ which compose the range represented 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.

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

These different laws of decrement account for all the different 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.

Modifications to which these decrements are subject.

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 successively 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 Hauy 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.

" If amidst this diversity of laws (observes Mr Hauy), sometimes insulated, sometimes united by combinations more or less complex, the number of the ranges subtracted were itself extremely variable ; for example, were these decrements by 12, 20, 30, or 40 ranges, or more, as might absolutely be possible, the multitude of the forms which might exist in each kind of mineral would be immense, and exceed what could be imagined. But the power which affects the subtractions seems to have a very limited action. These subtractions, for the most part, take place by one or two ranges of molecules. I have found none which exceeded four ranges, except in a variety of calcareous spar, forming part of the collection of Gillet Laumont, the structure of which depends on a decrement by six ranges ; so that if there exist laws which exceed the decrements by four ranges, there is reason to believe that they rarely take place in nature. Yet, notwithstanding these narrow limits by which the laws of crystallization are circumscribed, I have found, by confining myself to two of the simplest laws, that is to say, those which produce subtractions by one or two ranges, that calcareous spar is susceptible of 2044 different forms : a number which exceeds more than 50 times that of the forms already known ; and if we admit into the combination decrements by three and four ranges, calculation will give 8,388,604 possible forms in regard to the same substance. This number may be still very much augmented, in consequence of decrements either mixed or intermediary.

"The striæ remarked on the surface of a multitude of crystals afford a new proof in favour of theory, as they always have directions parallel to the projecting edges of the laminæ of superposition, which mutually go beyond each other, unless they arise from some particular want of regularity. Not that the inequalities resulting from the decrements must be always sensible, supposing the form of the crystals had always that degree of finishing of which it is susceptible; for, on account of the extreme minuteness of the molecules, the surface would appear of a beautiful polish, and the striæ would elude our senses. There are therefore secondary crystals where they are not at all observed, while they are very visible in other crystals of the same nature and form. In the latter case, the action of the causes which produce crystallization not having fully enjoyed all the conditions necessary for perfecting that so delicate operation of nature, there have been starts and interruptions in their progress; so that, the law of continuity not having been exactly observed, there have remained on the surface of the crystal vacancies apparent to our eyes. These small deviations are attended with this advantage, that they point out the direction according to which the striæ are arranged in lines on the perfect forms where they escape our organs, and thus contribute to unfold to us the real mechanism of the structure.

"The small vacuities which the edges of the laminæ of superposition leave on the surface of even the most perfect secondary crystals, by their re-entering and salient angles, thus afford a satisfactory solution of the difficulty a little before mentioned; which is, that the fragments obtained by division, the external sides of which form part of the faces of the secondary crystal, are not like those drawn from the anterior part. For this diversity, which is only apparent, arises from the sides in question being composed of a multitude of small planes really inclined to one another, but which, on account of their smallness, present the appearance of one plane; so that if the division could reach its utmost bounds, all these fragments would be resolved into molecules similar to each other, and to those situated towards the centre.

"The fecundity of the laws on which the variations of crystalline forms depend, is not confined to the producing of a multitude of very different forms with the same molecules. It often happens also, that molecules of different figures arrange themselves in such a manner as gives rise to like polyhedra in different kinds of minerals. Thus the dodecahedron with rhombuses for its planes, which we obtained by combining cubic molecules, exists in the garnet with a structure composed of small tetrahedra, having isosceles triangular faces; and I have found it in sparry fluor *(fluate of lime)*, where there is also an assemblage of tetrahedra, but regular: that is to say, the faces of which are equilateral triangles. Nay more, it is possible that similar molecules may produce the same crystalline form by different laws of decrement. In short, calculation has conducted me to another result, which appeared to me still more remarkable, which is, that in consequence of a simple law of decrement, there may exist a crystal which externally has a perfect resemblance to the nucleus, that is to say, to a solid that does not arise from any law of decrement *."

Such is a general view of Hauy'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.

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* *Ann. de Chim.* xvii. 225. For a more complete account of this theory, the reader is referred to Hauy's *Mineralogy*, vols. 1st and 2d. A larger detail would have been inconsistent with the plan of this Work.

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
Phosphorus
Carbon
Metals
Earths

II. Compounds.

1. Oxide of sulphur
    phosphorus
  Charcoal
  Metallic oxides
2. Sulphurets of metals
    fixed alkalies
    earths
3. Phosphurets of carbon
    metals
    earths
4. Carburets of iron
5. Alloys
6. Solid acids
7. Earths with earths
    metallic oxides
    fixed alkalies

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.

Specific Gravity.

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.
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	1·987 to 7·840
Sulphur	1·990 —
Earths with alkalies	2·732 to 3·329
Carbon	3·518 to 3·531
Metallic sulphurets	3·225 to 10·000
Metals and alloys	0·600 to 23·000

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. Fixed alkalies with solid oils.
9. 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.

2. 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 hereafter to belong to that class of solids which combine only in certain proportions.

3. 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.

Solids that unite only in certain proportions.

II. The following Table exhibits the principal solids which have hitherto been observed to unite only in determinate proportions.

- 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.

One of the bodies must be fluid.

1. As far as is known at present, none of these bodies act upon each other while both continue in the so-

Chap. IV.

lid 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 exceptions, 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 cohesion 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 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. If we apply the hypothesis of Dalton, and compare the analysis of the artificial metallic sulphurets with the weight of an atom of sulphur, and of each individual metal, it would appear that the most intimate combination consists of one atom of the metal united with one atom of sulphur; that very frequently (probably indeed in all cases) two atoms of sulphur unite with one of metal; and that the different sulphurets are capable of dissolving each other, and forming a kind of alloy. It is to this combination that the variety in the composition of native sulphurets is chiefly to be ascribed.

The following Table will enable the reader to compare the results of analysis with the calculation founded on the supposition that the metals and sulphur unite atom to atom; that the weight of an atom of sulphur is 13; and that the weight of an atom of the respective metals is as represented in the first column of the table. The second column gives the weight of sulphur united to an hundred parts of the metal by calculation; the third by analysis.

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* *Jour. de Phys.* lx. 349.

Metals.	Weight of a Metallic Atom.	Weight of Sulphur combined.	
		By Calculation.	By experiment.
Silver	93·7	14	17·6
Bismuth	93·7	14	17·5
Arsenic	54·5	24	25
Copper	48·0	27	14 to 30
Mercury	120·0	10·8	17·6
Tin	48·0	27	17·6
Lead	150·0	8·7	12 to 25
Antimony	80·0	16·2	33·3
Iron	32·4	40	60 to 112
Molybdenum	37·5	34·6	66

The first three sulphurets agree sufficiently well with the calculation, but all the rest differ from it very much. No doubt, it would be possible to reconcile the whole by supposing the sulphurets, which differ most from the calculation, to be combined with the metal, with each other, &c. But such suppositions would be attended with no advantage. We shall therefore leave the subject at present as hopeless, till it be farther elucidated by subsequent experiments.

Sulphurets rarer than the mean.

4. 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
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.

Neutralization explained.

7. If we take a given quantity of sulphuric acid diluted with water, and add it slowly to 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 the 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 other preponderate according to the proportions 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 neutralization 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. We may therefore suppose, that in it the acid and base unite atom to atom. If we apply Dalton's hypothesis, we may find the relative weight of the constituents of those neutral salts which have been analysed. This will afford a test of considerable importance of the degree of confidence to be put in the hypothesis; the subject of course deserves to be investigated with some attention.

When describing the salts in the preceding Book, I exhibited the various analyses of each that have been published, and then selecting that particular analysis which appeared most to be depended on, placed it at the end of each genus under the form of a table. From these tables we shall choose our examples. It will be proper to pitch upon the sulphates, nitrates, muriates, carbonates, and sulphites, as the genera which have been analysed with the greatest care. The following Table shows the weight of each base united to 100 parts of acid in the most remarkable neutral salts belonging to these genera.

Bases.	Sulphates.	Nitrates.	Muriates.	Carbonates.	Sulphites
Barytes . . .	203	178·12	314·5	354·5	151
Strontian . .	138	116·86	216·2	231	—
Potash. . . .	130	117·7	185·7	95·3	125
Soda	78·32	73·43	114	97·4	58
Lime.	76·7	55·70	118·3	122	97·9
Magnesia. .	57·92	47·64	89·8	50	41
Ammonia. .	26·05	40·38	33	33·9	48·3

These numbers in each column ought (supposing the analysis rigidly correct) to give the weight of the respective bases, provided the weight of an atom of acid be reckoned 100, and the acid and base always unite atom to atom. But the weight of an atom of all the acids belonging to these genera, as determined in a preceding Chapter, was found to be as follows:

Weight of acids,

	Density.
Sulphuric acid...	31
Nitric.............	17
Muriatic...........	18
Carbonic..........	16·5
Sulphurous.......	25

If instead of 100, which in the preceding table of the composition of the salts is used as the constant weight of acid, we substitute the supposed weight of an atom of each acid, and then calculate the weight of base with which it is combined, we obtain the following Table.

Bases.	Sulphates.	Nitrates.	Muriates.	Carbonates.	Sulphites.
Barytes.....	63	30	56·6	60·5	37·7
Strontian ...	43	19·8	30	38	
Potash	40	20	33	16·2	31·2
Soda	24	12·5	20·4	16·5	14·5
Lime.........	23·7	9·5	21·3	20·7	24·5
Magnesia...	18	8·1	16	8·5	10·2
Ammonia ..	8	6·8	6	5·7	12·0

These numbers ought to represent the weight of the respective bases, and they ought to be the same in every column, provided the acid and base unite atom to atom. On inspecting the table there appears a striking coincidence between the numbers under the titles *sulphates*, *muriates*, and several of the *carbonates:* But neither the nitrates nor sulphites agree with the rest. The numbers under the nitrates approach to one-half of the numbers under the sulphates and muriates, indicating that in them two atoms of acid unite with one of base. The sulphites are more irregular, but show an approach to the numbers under the nitrates. If we take the mean of all the columns, multiplying columns 2d and 5th by 2, and leaving out the carbonates of the fixed alkalies, which do not accord with the others, we obtain the following Table, which may be considered as representing the relative weight of each base, on the supposition that the weight of an atom of the acids is as represented in a preceding table, and that the weight of an atom of hydrogen is equal to 1.

Of bases.

	Weight.
Barytes	63
Strontian	37·6
Potash	38
Soda	23·3
Lime	21·8
Magnesia	17·6
Ammonia	9

Of all the genera of salts, we may consider the sulphates as the one which has been analysed with most precision. Now the preceding table differs very little from that afforded by the direct analyſis of the sulphates. The muriates may be placed next in order of precision; as

Chap. IV.

the proportion of their acid may be ascertained with almost as much exactness as that of the sulphuric. It is satisfactory to observe how nearly the analysis of the muriates corresponds with the weight here given. The analysis of the earthy carbonates is likewise capable of much exactness; but this is not the case with the alkaline carbonates, if we except that of ammonia, which may be calculated from the proportion of combining gases. Now in the genus of carbonates, it is only those with a fixed alkaline base that deviate much from the mean. The nitrates, from the nature of the acid, cannot be analysed with the same precision as the rest. However, it is only the fixed alkaline nitrates that deviate (and only inconsiderably) from the mean, provided we suppose that two atoms of acid unite to one of base. As to the sulphites, they have been hitherto analysed only by Fourcroy and Vauquelin. They deviate farthest from the mean.

Upon the whole, if we consider that the numbers representing the weight of the acids were furnished by Dalton's hypothesis, from data altogether unconnected with the composition of the salts, the very near coincidence between the preceding table of weights, and the result of analysis, must appear something more than accidental, and affords a very strong presumption in favour of the truth of Dalton's hypothesis.

If these considerations have any weight, the following Table ought to represent the proportion of the constituents in all the neutral salts formed by the combination of the acids and bases contained in it:

Constituents of neutral salts.

Acids.	Proportion.	Bases.	Proportion.
Sulphurous -	25×2=50	Barytes - - -	63
Nitric - -	17×2=34	Strontian - - -	37

Acids.	Proportion.	Bases.	Proportion.
Sulphuric	31	Potash	38
Phosphoric	22	Soda	23·3
Muriatic	18	Lime	21·8
Carbonic	16·5	Magnesia	17·6
Phosphorous	16	Ammonia	9

These numbers represent either the weight of an atom of each, or twice that weight. The meaning of the table, we presume, will be obvious at once. The number attached to each acid represents the weight of acid capable of saturating the weight of each base respectively marked in the table. Thus 50 parts by weight of sulphurous acid saturate 63 parts of barytes, and sulphite of barytes is composed, by weight, of 50 acid and 63 base. Phosphate of lime is composed of 22 acid and 21·8 base; a proportion which nearly coincides with the analysis of Ekeberg, and therefore serves to confirm it.

9. When the solutions of two neutral salts are mixed with each other, a decomposition either partial or complete often takes place. Thus, if muriate of barytes and sulphate of soda be mixed together, the sulphuric acid unites to the barytes, forming sulphate of barytes, while the muriatic acid unites to the soda. Now, in all these cases of mutual decomposition, the state of neutralization is not altered. If the original salts were neutral, so will the new. No excess of acid or base is to be found in the solution. This important fact seems to have been first stated distinctly by Richter. It was afterwards noticed by Guyton Morveau *, and still

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* See *Ann. de Chim.* xxv. 296.; *Statique Chimique*, i. 134.

more lately by Berthollet, who has pointed out its great importance, and confirmed it by numerous experiments of his own *.

From this general law it follows as a consequence, that all the acids and alkalies follow the same ratio in neutralizing each other. Thus, suppose that the quantity of barytes and of lime necessary to saturate a given weight of sulphuric acid be represented by a and b, the weights of the same bases necessary to saturate any other acid will be to each other as a to b; and if the weights of any two acids, as the sulphuric and muriatic, necessary to saturate a given weight of barytes, be represented by m and n, then the weights of the same acids necessary to saturate any other base will be to each other as m to n. Now it is impossible that this can hold true unless the acids and bases unite to each other, either atom to atom, or at least a determinate number of atoms of the one to one atom of the other. Here, then, we have a decisive proof that the theory of Dalton, which has been repeatedly illustrated in this Book, is something more than a hypothesis; that it deserves particular attention; and that it may be of considerable service in assisting us to ascertain the constitution of solid bodies.

10. If the acids and bases usually form neutral salts by uniting together, atom to atom, we have only to ascertain the weight of an atom of every acid and base, in order to have the composition of all the neutral salts with accuracy. The preceding table contains the weight of seven bases; but besides these we have four

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* *Statique Chimique*, i. 117.

more, namely, *alumina, glucina, yttria,* and *zirconia.* Two circumstances render it difficult to detect the weight of these bases from the analysis of the salts into which they enter: The first is the small number of neutral salts which these bases are capable of forming, and the second the few analyses hitherto made of the salts into which they enter.

Weight of alumina.

There are two analyses of salts containing alumina which it seems reasonable to place some confidence in; namely, of alum by Vauquelin, and of muriate of alumina by Bucholz. Now both are supersalts, and must therefore consist of two atoms of acid united to one atom of base. Alum is a triple salt. Half the acid which it contains must be united to potash. If we calculate, taking all these circumstances into consideration, we obtain 9·05 for the weight of an atom of alumina from the muriate, and 9·25 from alum. The mean is 9·15, which we may consider as an approximation to the weight of an atom of alumina. There is no analysis of any salt containing the other three bases from which it would be safe to calculate their weight.

11. Besides the acids whose weight has been stated in this Section, there are many others capable of uniting with bases and forming neutral salts. It would be easy to obtain the weight of each of these, if we were in possession of an analysis of any one species in each genus of these salts that could be depended on. The following numbers accord best with the analyses hitherto published. I shall first state them under the form of a table, and then mention the reason for pitching upon them.

Of other acids.

	Weight.		Weight.
1. Fluoric	11·5	3. Boracic	24.5
2. Oxalic	39.5	4. Succinic	32.5

	Weight.		Weight.
5. Citric	35·1	7. Tartaric	45·7
6. Acetic	36	8. Tungstic	47·6

The first, fourth, and seventh of these numbers have been taken from Richter's table of the relative proportion of acids and bases, by weight, which combine. We are not in possession of correct analyses of any species belonging to the fluates, succinates, or tartrates.

The weight of the oxalic acid is the result of my own experiments: It differs very much from the result given by previous trials of Bergman and Vauquelin.

The weight of boracic acid is given from the analysis of borax by Bergman. As that salt contains an excess of base, we must suppose it a compound of one atom of acid with two of base.

The weight of citric acid is the mean of Vauquelin's analysis of the citrates of potash, soda, lime, and magnesia. It differs essentially from the number given by Richter, which, when reduced to our proportions, becomes 45·4.

The weight of the acetic acid is obtained from Bucholz's analysis of the acetate of barytes, and that of tungstic acid from Klaproth's analysis of tungstate of lime; both of which are entitled to confidence.

We may now, then, collect together in a single table the relative weights of an atom of all acids and bases which we have been able to ascertain. They claim particular attention, because, independent of the hypothesis of Dalton, they must be considered as approaching, as nearly as the present state of the science will admit, to the real weight of acids and bases, which saturate each other respectively, and form neutral salts *.

Weight of the acids and bases.

I. BASES.

Barytes	63	Lime	21·8
Strontian	37·6	Magnesia	17·6
Potash	38	Alumina	9·3
Soda	23·3	Ammonia	9

II. ACIDS.

Tungstic	47·6	Sulphuric	31
Tartaric	45·7	Boracic	24·5
Sulphurous	50	Phosphoric	22
Oxalic	39·5	Muriatic	18
Acetic	36	Carbonic	16·5
Citric	35·1	Phosphorous	16
Nitric	34	Fluoric	11·5
Succinic	32·5		

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* I shall insert here the table of Richter, as drawn up by Fischer, of the relative weights of acids and bases which saturate each other, that the reader may compare it with that in the text, obtained solely from analysis.

BASES.

Alumina	525	Soda	859
Magnesia	615	Strontian	1329
Ammonia	672	Potash	1605
Lime	793	Barytes	2222

ACIDS.

Fluoric	427	Sulphuric	1000
Carbonic	577	Succinic	1209
Sebacic	706	Nitric	1405
Muriatic	712	Acetic	1480
Oxalic	755	Citric	1683
Phosphoric	979	Tartaric	1694
Formic	988		

Statique Chimique, i. 13.

The weight of an atom of the neutral salts formed by the combination of these bodies, is obtained by adding together the numbers representing the weight of an atom of the acid and of the base. Thus the weight of an atom of sulphate of barytes is 63+31, or 94; that of an atom of nitrate of potash is 72, and so on.

Supersalts and subsalts.

12. But the acids and bases are capable, not only of forming neutral salts, but frequently also of uniting with each other in various proportions. In some the proportion of acid, in others that of the base predominates. The former set have received the name of *supersalts*, the latter that of *subsalts*. The simplest way of considering these bodies is, to conceive the supersalts to be compounds of two atoms of acid with one of the base, and the subsalts of two atoms of base with one of acid. Thus supersulphate of potash is composed of one atom of potash united to two of sulphuric acid, or by weight of 38 parts of base and 62 of acid. Borax, on the other hand, is composed of two atoms of soda united to one of boracic acid, or by weight of 24·5 parts of acid and 46·6 of base.

All the salts are not capable of being exhibited in these various states; probably because the tendency to crystallize, or to assume a solid form, depends upon certain proportions only. It is probable, that in many cases in which they do crystallize in all these states, the different varieties are capable of uniting with each other; and this may account for the variable results obtained by analysis.

Triple salts.

13. Sometimes an acid is capable of uniting with two bases at once, and of forming a triple salt, as it is called. Thus sulphuric acid unites at once with magnesia and ammonia. It is probable that such combinations

are the result of an atom of one salt combining with an atom of another. In the example stated, we may suppose that an atom of sulphate of magnesia has combined with an atom of sulphate of ammonia. In like manner, alum may be considered as a compound of an atom of sulphate of potash with an atom of supersulphate of alumina. To discover the weight of each salt thus combined, we have only to get the weight of an atom of each salt. Thus the weight of an atom of sulphate of potash is 69, and that of an atom of supersulphate of alumina 71·3. Therefore alum is a compound of 69 parts, by weight, of sulphate of potash, and 71·3 of supersulphate of alumina.

Salts having both different acids and bases are also capable of combining in the same way, and of forming quadruple salts. Very few examples have hitherto occurred of more complicated saline combinations, though it is very possible that they may exist.

Proportion of water combined.

14. But the solid salts are not mere combinations of an acid and a base; they are almost all hydrates, or contain water as a constituent. The proportion of this water seems to be susceptible of considerable variation, and very frequently the quantity is enormous. We may conceive an atom of the salt to form a hydrate, by combining with one or more atoms of water. The proportion of water seems almost always to exceed one atom. But the experiments hitherto made to settle the portion of water contained in the salts, are not sufficiently precise to enable us to attempt to ascertain the number of atoms of water which enter into these combinations. Sulphate of potash seems to contain one atom of water, while the quantity in sulphate of soda cannot be less than 11 atoms.

15. The metalline salts seem of a more complicated nature than the alkaline. They are seldom neutral, containing almost always an excess either of acid or base. They have a great tendency to unite with each other: The number of metalline salts belonging to any genus hitherto analysed with precision, is too small to enable us to form correct notions respecting the number of atoms which combine. As soon as the analysis is far enough advanced, it will furnish us with a method of determining the weight of the metallic oxides.

CHAP. V.

OF COMBINATION AND DECOMPOSITION.

Importance of a knowledge 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 *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.

Compounds of two kinds.

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 be 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,

Book III.

that some persons have denied the combination altogether, and have supposed the bodies to be only mechanically mixed.

Dissolutions.

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 gases*, 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

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* See page 454. of Volume III.

† See page 556. Ibid.

‡ See page 625. Ibid.

§ See page 505. Ibid.

‖ See p. 563. Ibid.

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.

And chemical combinations.

2. Those bodies which form compounds differing very much from the 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.

They combine in certain proportions only.

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 muriatic acid unite in two proportions; but we can unite them directly in no more than one. Oxygen and azote unite in three proportions; but we can unite them directly in only one. The other

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* See a list of them in page 561. of Volume III.

combinations are obtained by decomposing the compound formed directly.

In like manner, the combination of a gaseous and solid body is limited to certain proportions. Oxygen unites with carbon, 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 three 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; and probably the rule, with a few exceptions, extends to the sulphurets also.

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.

Mr Berthollet's doctrine seems, then, to require a small modification, as far as the proportions of chemical compounds are concerned. Bodies indeed seem capable of uniting in various proportions; but surely the phenomena are far from indica tingthat the proportions are unlimited. It is true, indeed, that the illustrious chemist, whose opinion I am considering, allows, that in most compounds the proportion of the ingredients is determinate, and assigns reasons, equally ingenious and plausible, by which he is enabled to explain it, without being under the necessity of giving up his opinion. The circumstances which he points out are doubtless of great importance, and contribute in a considerable degree to the production of the permanent compounds which we have been considering. Yet they do not seem, in all cases at least, sufficient to account for the determinate proportions in which substances combine, unless we suppose in the atoms themselves a tendency to unite in determinate quantities.

SECT. II.

OF DECOMPOSITION.

Examples 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.

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.

Ascribed to affinity.

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 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

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

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.

Bergman's theory of decomposition may be stated in a few words. According to him, all substances which combine have an *affinity* for each other. Now the affinity of two bodies for each other is a constant force, which may be represented by numbers. It varies in intensity in different bodies; so that the affinity of a body *a* for *c* is not the same as that of *b*, but always either greater or less. Affinity is *elective;* that is to say, if *a* has a stronger affinity for *m* than *b* has, and if *m* be combined with *b*, forming a compound, which we may represent by *mb ; a*, upon being mixed with this compound, has the property of separating *b* completely from *m*, and taking its place, so as to form a new compound *ma*, while *b* is entirely disengaged *.

Of elective attraction.

According to this explanation, *decomposition* measures the intensity of the affinity which exists between bodies. If *a*, upon being added to the compound *mb*, separates

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* Bergman, iii. 294.

b and forms the compound *am*, then *a* has a greater affinity for *m* than *b* has. Hence the tables of decompositions published by Bergman were called tables of *elective attractions*, or of *affinity*. They were considered as indicating the order of affinity; and attempts were even made to express the intensity of the affinity of each particular body by numbers. This opinion, however, did not originate with Bergman. It prevailed long before his time; being hinted at by Mayow, expressed in rather a clearer manner by Geoffroy, and stated at great length by Limbourg and Sage *. Hence the tables were constructed not merely from the order in which the decompositions take place, but substances were placed in them even when they produced no sensible decompositions, when other circumstances seemed to indicate the order of their affinity. This is the case to a very considerable degree in the tables of affinity given by Geoffroy, Limbourg, Rouelle, and even of Bergman. Gellert's table is constructed upon a different plan. It exhibits the order in which bodies unite most readily, and only gives the order of decomposition incidentally. This table, though imperfect, deserves considerable attention. It appears to have been constructed almost entirely from actual experiment, and obviously furnished Bergman with the greatest part of the columns in his tables, which profess to give the affinities of bodies in the *dry way*, or when subjected to heat †.

Opposed by Berthollet.

Such were the opinions entertained by chemists when Berthollet published his dissertation on affinity in the

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* *Dissertation de* Jean Phillipe Limbourg, M. D. *sur les Affinites Chimiques*, 1761.

† See Gellert's *Metallurgic Chemistry*, p. 185.

third volume of the Memoirs of the Institute, and called in question the fundamental propositions of the theory of Bergman. He allowed, indeed, that bodies differ in the degree of their affinity for each other; but showed that it cannot be considered as a constant force, since it varies with the quantity of the acting bodies, quantity being capable of supplying the place of affinity. He proved likewise, by a variety of well chosen and convincing examples, that *decomposition* cannot be considered as the measure of the intensity of affinity; that the immediate effect of affinity is in all cases a combination; and that it never occasions decomposition except indirectly, and in consequence of circumstances altogether unconnected with the intensity of affinity.

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 dropt 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.

Berthollet appears to me to have established the fundamental part of his doctrine; namely, that quantity alters the force of affinity, and that decomposition is not occasioned by elective attraction; by experiments equally decisive and convincing. We must therefore conclude, that the tables published by Bergman and other chemists do not represent correctly the order of affinities, but merely of *decomposition*. Indeed Berthollet has shown, that in many cases they do not even represent the order of decompositions correctly; those decompositions which the tables represent as complete being only partial, and sometimes depending in a great measure upon the proportions of the ingredients employed.

His standard of affinity

Berthollet considers, as the only standard of the intensity of affinity, the quantity of a given body necessary to neutralize a given weight of another. He supposes the affinity inversely as this quantity. Thus, if it be required to find the proportional affinity of the three bodies *b*, *c*, and *d* for A. If to neutralize a given weight of A = 1, there be required of

b a weight = 1
c............ = 2
d............ = 3

Then the affinities of *b*, *c*, and *d* for A are respectively as the inverse of the numbers 1, 2, and 3.

Affinity of $b = 1$ or 6
$c = \frac{1}{2}$ or 3
$d = \frac{1}{3}$ or 2

This opinion seems to have first occurred to Kirwan, but was modified by that philosopher to suit the prevalent theory of elective attractions. As new-modelled by Berthollet, it appears extremely plausible, and corresponds well with many chemical phenomena: but it depends for its plausibility upon the particular view of neutralization which Berthollet has given. He con-

Depends on his definition of neutralization.

ceives *acidity* and *alkalinity* (for all the examples are drawn from the salts) as two opposite forces, increasing with the quantity of each body; and *neutralization* as indicating that they just balance each other, and of course are equal in intensity. The smaller the quantity of any acid capable of neutralizing a given weight of base, the more powerful is its *acidity*. But it does not follow as a consequence, that the force with which an acid combines with its base is proportional to its power of destroying the *alkalinity* of that base. How do we determine that the alkalinity of a base is neutralized? By its ceasing to act upon other substances as an alkali does. Thus, when an alkali no longer changes vegetable blues, we say that it is *neutralized*. Now, may we not conceive, that in such a case the alkali acts upon the vegetable blue precisely as at first; that the acid acts upon it likewise in a different way; and that in cases of neutralization, the proportion of acid is just sufficient to counteract the effect of the alkali, and thus to prevent any change from taking place? In cases of neutralization, the action of the acid upon vegetable blues is the same in strength with that of the alkali. It follows therefore as a consequence, that the energy of an acid on vegetable blues is inversely proportional to the quantity of it necessary to produce neutralization; but surely it does not follow from this, that the force with which an acid attacks an alkali is proportional to the energy with which it acts upon vegetable blues. Except in the case of acids and alkalies, we have no means of determining when neutralization is produced. Who can say, for instance, what proportion of sulphur is necessary to neutralize a metal, or of oxygen to neutralize carbon? Can we even affirm, without altering the meaning of language, that in water, one of the most insipid of all compounds, the oxygen and hydrogen neutralize each other?

Not supported by proof.

An opinion, nearly similar to that of Berthollet, seems to have been entertained by Sir Isaac Newton, and I am far from pretending to call it in question. It may very possibly be true; but so may the opposite opinion, which, indeed, might be supported by plausible arguments. The truth is, and it is now full time to declare it, that we are profoundly ignorant of every thing regarding the strength of affinity. Berthollet has succeeded in overturning all our preconceived 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 decomposition.

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

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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.

constructed, partly 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.

Oxygen, and simple combustibles and incombustibles.

I. OXYGEN.

Hydrogen
Carbon
Phosphorus
Sulphur
Azote
Muriatic acid

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 muriatic acid be placed last in order, it is known to be capable of separating a certain portion of oxygen from nitric acid; but nitrous gas deprives oxymuriatic acid of the whole of its oxygen, and converts it 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.

Metals from acid solutions.

Zinc
Iron
Tin
Antimony
Arsenic
Lead
Bismuth
Copper
Platinum
Mercury
Palladium, Rhodium }
Iridium, Osmium }
Silver
Gold

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 platina. 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 lately 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

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* Nicholson's *Jour.* xiv. 94.

the experiments of Priesley, we know that hydrogen is capable of reducing oxide of iron to the metallic state. Charcoal 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 muriatic acid 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.

Oxides from acids.

Protoxide of iron
Peroxide of silver
Red oxide of mercury
Peroxide of zinc
Oxide of manganese
Oxide of lead?
Peroxide of copper
Peroxide of iron

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 *.

Bases from acids.

IV. Acid Solutions.

Fixed alkalies
Barytes
Strontian
Lime
Ammonia
Magnesia
Yttria
Glucina
Zirconia
Alumina
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 precipitation 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 neutralize 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 dropt into potash so pure that it occasions no muddiness in barytes or lime water, a fla-

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* *Ann. de Chim.* xlix. 21.

ky 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 propriety, 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, as it forms with acids a salt approaching more nearly to neutralization. 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.

Acids do not precipitate each other.

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.

Precipitants of alkalies,

1. ALKALIES.	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 dropt 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 as 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.

Alkaline earths.

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 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, prussiate 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	Sulphate of iron Nitrate of mercury
Platinum	Sal ammoniac
Silver	Muriate of soda
Mercury	Muriate of soda
Palladium	Prussiate of Mercury
Rhodium	O Zinc
Iridium	O
Osmium	O, Mercury
Copper	O, Iron
Iron	Succinate of soda
Nickel	O, Sulphate of potash
Tin	Oxymuriate of mercury
Lead	Sulphate of soda
Zinc	O, Alkaline carbonates
Bismuth	Water, muriate of soda
Antimony	Water, hydrosulphuret of potash
Tellurium	Water
Arsenic	Nitrate of lead

Metallic Oxides.	Precipitants.
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 muriate 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 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 of soda or ammonia has lately 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 oxymuriate of mercury. 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 muriate 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.

Acids.

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
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.

Table of the solubility of salts.

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.*

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

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

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

Effect of insolubility.

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.

Precipitation of metals,

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 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 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.

Chap. V.

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

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 of 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.

Chap. V.

Salts Mixed.	Proportions.	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 dropt 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 dropt 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 decomposition. 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 produced 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 sufficient heat is applied, and many of the metals separate sulphur from mercury.

To these general laws, however, there are several exceptions. 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 *.

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* *Statique Chimique*, i. 308.

TABLE

OF CHEMICAL DECOMPOSITIONS.

I.
ALKALIES.

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

II.
BARYTES AND STRONTIAN.

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

III.
LIME.

- Oxalic
- Sulphuric
- Tartaric
- Succinic
- Phosphoric
- Saclactic
- Nitric
- Muriatic
- Suberic
- Fluoric
- Arsenic
- Citric
- Malic
- Benzoic
- Acetic
- Boracic
- Sulphurous
- Nitrous
- Carbonic
- Prussic

IV.
MAGNESIA.

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

V.
ALUMINA.

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

VI.
OXIDE OF GOLD.

- Muriatic acid
- Nitric
- Sulphuric
- Arsenic
- Fluoric
- Tartaric
- Phoshoric
- 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
Saclectic
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
Zirconia

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

END OF VOLUME THIRD.

CHEMISTRY

Plate III. *End of Vol. III.*

Fig. 19.

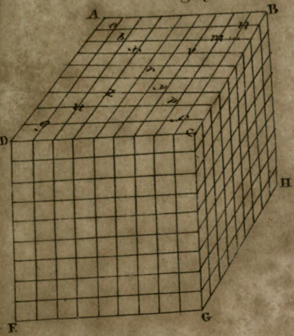


Fig. 20.

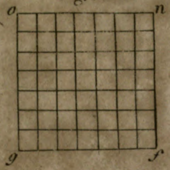
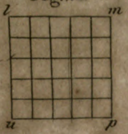


Fig. 21.



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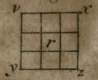
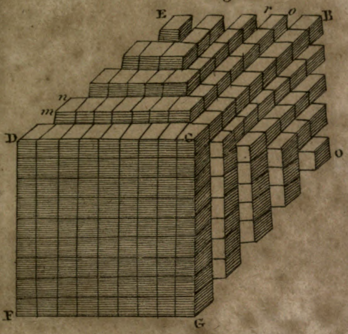


Fig. 23.

Fig. 24.



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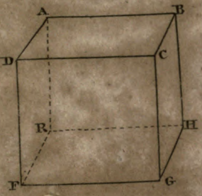

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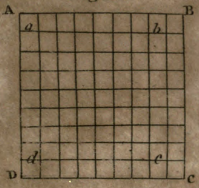

Fig. 27.

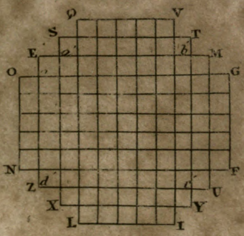

Fig. 28.